Secondary Electron Emission from a Hot Nickel Target Due to Bombardment by Hydrogen Ions

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A hot nickel target was bombarded by hydrogen molecular ions to determine the number of secondary electrons emitted per positive ion at various voltages. The method used was that of Oliphant. The ions were drawn from a discharge, collimated by a narrow canal, bent by an electric field and allowed to impinge on the hot target. The latter was surrounded by a platinized bulb which served as a collector for the electrons. After the target had been kept hot for six weeks, values consistent among themselves could be obtained. The number of electrons elicited from the target per positive ion varied from 0.046 at 303 electron volts to 0.223 at 1539 electron volts ion energy. The number of reflected positive ions is a measurable fraction of the total positive ion beam.

IN the ordinary vacuum discharge the emission of electrons from the cathode has been attributed to various agencies, such as photons, positive ions, and metastable atoms. Many attempts have been made to determine the part played by positive ions in this emission. Much of the work done has been vitiated by failure to isolate this effect from the others or by lack of proper degassing. The work of Jackson[1] on the alkali ions and that of Oliphant[2] on helium ions striking molybdenum is not open to these objections, but these ions are not so important in a discharge as the ions of hydrogen. Oliphant's method was used in the present investigation to determine the secondary electron emission from a nickel target under bombardment by hydrogen ions.

APPARATUS

The device for producing a sufficiently large beam of positive ions is essentially that of Oliphant. A tube was built as illustrated in Fig. 1. It was made of Pyrex glass and the metal parts were all of nickel except the platinum film on the collector and the tungsten filaments. A discharge was maintained between the hot filament, F, and the coiled anode, A, in the bulb D. From the discharge plasma, which filled D, positive ions were drawn to C by a suitable potential between C and F. Some of these passed down the canal back of C which served to collimate the ions. They then passed through E to the plane parallel deflecting plates, P. The beam was bent through two further diaphragms to the target, T, from which secondary electrons were emitted. These electrons were collected by the platinum film on the bulb surrounding T.

Differential pumping allowed a pressure in D sufficient to support the discharge and a pressure in the other end so low that the beam of ions remained well defined. This was made possible by the canal back of C which was five cm long and two mm in diameter. The openings in E were also two millimeters in diameter. The deflecting plates, P, were 1.5 cm in length and about 13 mm apart. They were placed in the tube in a position to produce a deflection of the positive ion beam

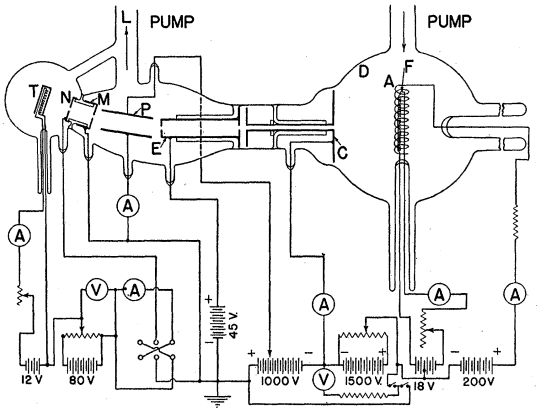

FIG. 1. Diagram of apparatus.

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[1] W. J. Jackson, Phys. Rev. **28**, 524 (1926); **30**, 473 (1927).
[2] M. L. E. Oliphant and P. B. Moon, Proc. Roy. Soc. **A127**, 373 (1930).

of about twenty degrees. This arrangement eliminates extraneous effects at the target due to impingement upon it of metastable atoms or of photons from the discharge. The diaphragm, M, also had an opening 2 mm in diameter, but N had one of 5 mm to prevent the beam from striking it. This was necessary since this diaphragm formed part of the collector.

The target consisted of a nickel cylinder 3 mm in thickness, 1 cm in diameter. Inside it was a heating coil of 12 cm of 10-mil tungsten wire coiled on a 0.03-cm mandril. This coil was enclosed in a quartz ring for support.

The pumping was done by a Gaede four-stage steel diffusion pump backed by a Cenco Hyvac pump. One mercury cut-off made it possible to pump out the whole system to the highest possible vacuum, another allowed continuous circulatory pumping into D and out at L with the system cut off from the fore pump and any stopcocks. The gas flowed over a boat of P_2O_5 before entering D, and solid CO_2 in acetone was kept continuously on two traps of low resistance, one between the cut-offs and the tube, the other between the diffusion pump and the tube. Hydrogen entered on the high pressure side of the system through a heated palladium tube which was connected to a gas main.

The electrical connections were as shown. All voltages were supplied by storage batteries to keep the current as steady as possible. About 200 volts were used for the discharge. The desired accelerating voltage was applied to C. For low voltages it was necessary to apply a larger negative voltage to C in order to obtain a beam, and then to apply a decelerating voltage to E. Oliphant found for helium that it was necessary to apply 1500 volts accelerating voltage in order to get a beam, but it was not necessary with hydrogen in the present tube. A decelerating voltage of about 45 volts on E at all times seemed to facilitate the passage of the beam. A deflecting voltage was applied to bend the beam to the target in the observing chamber. Other batteries served to heat the target filament and to apply a potential between the target and the collector. The galvanometer, G, with the reversing switch in one direction measured the current to the target and collector, i.e., the main positive ion beam; with the switch in the other direction it registered the current to the collector only. The galvanometer used had a sensitivity of 10,064 megohms, CDRX 22,000 ohms, period 13.2 sec., and a resistance of 575 ohms.

Experimental Procedure

The vacuum system was too large to be thoroughly baked, but the tube itself was heated in an electric furnace, and the rest of the system flashed with a blow-torch at the same time that the system was being pumped out. The vacuum was then maintained continuously for nearly a year except for a few hours when the filament was being changed. The pumps were kept in operation for days at a time. Solid carbon dioxide in acetone was kept on the mercury traps continuously for two months. During the preliminary experiments preceding this so little gas escaped from the walls and metal parts that on two occasions when hydrogen was left in the system overnight no change in the discharge characteristics could be observed.

The first step was to get a beam through to the deflecting plates. The current to the lower deflecting plate was not a measure of the size of the positive ion beam reaching it. Ions were reflected from the lower plate, secondary electrons were emitted, and photoelectrons were extracted by light coming from the discharge. A rough measure of the size of the beam to the middle portion of the tube was the total current to the three electrodes there. For this current to be as much as 15 microamperes it was necessary for the tube voltages, filament current, and the gas pressure to have quite critical values. With a discharge voltage of 200 volts the current through the 10-mil tungsten filament wire was about 5 amperes. The magnitude of the positive ion beam was sensitive to changes in the current in the filament but was even more sensitive to changes in pressure. When the pressure exceeded only slightly a critical value there would be a large discharge current and many positive ions to C, but there would be no beam since the ions were scattered out of their path by gas molecules. Maintaining the proper pressure, once found, was also a problem since hydrogen disappears in a discharge. As the pressure decreased, larger and larger numbers of positive ions were obtained

until suddenly there was too little gas to maintain a discharge. However, the disappearance of hydrogen in the discharge decreased with continued use of the tube. At first the proper pressure was found by getting as large a current as possible through a microammeter which measured the total current to the deflecting plates and the diaphragm. Then the deflecting voltage was put on the plates and the potential varied until a beam to the target could be detected.

At this point the discharge variables again had to be regulated to find the most favorable values. In addition the positive ion current to the target was very sensitive to the deflecting voltage, falling off sharply on each side of a maximum, as shown in Fig. 2. This was interpreted to mean that the beam reaching P was quite homogeneous.

Currents to the target and to the collector were then studied by means of a variable potential between target and collector.

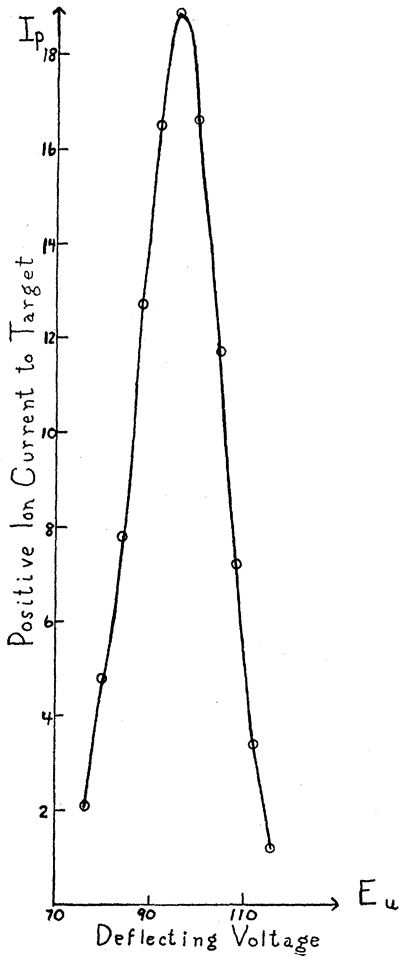

FIG. 2. Curve showing how the positive ion current to the target varies with the deflecting voltage for 855-volt ions.

RESULTS

Cold target

Data were first obtained for a cold target which had not been degassed. To find the number of electrons emitted by the target per positive ion of given energy, current-voltage curves for the collector were plotted. One such curve is that of Fig. 3, for 625-volt ions. In all of these curves

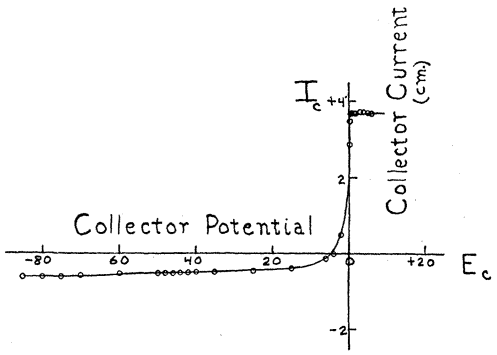

FIG. 3. Current-voltage curve for the collector for 625-volt ions. (Cold target.)

saturation was obtained when the collector was a few volts positive with respect to the target. It was therefore assumed that this saturation current was a measure of the difference of secondary electrons and reflected positives from the target to the collector. As the collector voltage was decreased toward zero this current decreased and finally reversed its direction. This means that fewer and fewer electrons were collected until only the reflected positives arrived from the target. A saturation current for negative voltages would have given the number of positives reflected, but the curve never became parallel to the voltage axis in the case of the cold target. The current, however, did become linear with respect to the voltage beyond about fifty volts; and it was assumed that no electrons were collected beyond fifty volts, and that if the line beyond fifty volts were extended back to the

current axis the intercept there was a measure of the positive ions reflected. A serious error was not introduced since the values of the electron emission at various voltages are not reproducible in the case of a cold target. Hence the number of secondary electrons was deduced from each graph and the ratio of this current to that of the positive ion beam calculated. A set of values is shown in Fig. 4. Only the general trend of the curve can be seen from the single points, but it is obvious that the number of secondary electrons per positive ion increases with positive ion voltage and that within the range of voltages studied it is always less than one.

The measurements of the number of reflected positives showed too much variation to indicate any relation to the positive ion voltage for the cold target.

Heated target

Similar results were obtained for a target which had been heated for a long time and was used hot. The difficulty was in getting the target clean, and keeping its surface in a condition to give reproducible results.

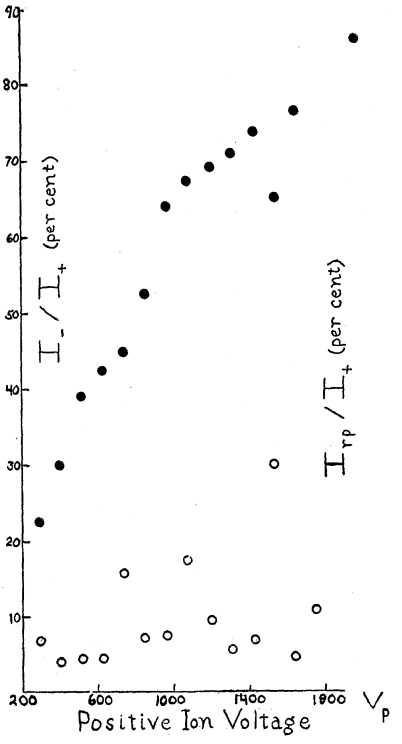

FIG. 4. Variation of the number of secondary electrons (●) and of reflected positives (o) per positive ion with positive ion voltage for a cold target.

At first when the target was heated and then allowed to cool the secondary emission decreased. Later it was apparent that the value of the emission depended not only on how long the target had been kept hot and at what temperature but how long it had been cold after the heat treatment and how much hydrogen had been let into the system just previous to taking the readings. If too much gas was let in and pumped out the emission increased enormously; and, if the discharge was sufficiently unsteady so that readings were postponed as much as twenty minutes after the target was cooled, the emission again increased. Values of the secondary emission were obtained in the same way as for the cold target.

It was then decided to try to use the target hot while taking readings. However, although the target had been heated as hot as possible for a good many hours there was still so much thermionic positive ion current from the target leads that no readings were possible. This effect was gradually reduced by heating. After a few days of continued heating a series of values obtained at a temperature of about 900 degrees centigrade was 8.1, 8.6, 7.4, 7.7, 10.0, 9.5, 10.0, 9.2, 8.2, 8.3, 7.4 percent, the variations apparently having no relation to one another. The target was then kept hot continuously for six weeks at about 900°C except that night and morning it was cooled down in a high vacuum long enough to change the heating source from a storage battery to a transformer and *vice versa*. In addition, between readings it was heated a good deal hotter than this, so that it was at a hotter temperature for two or three hours each day. It was finally found that fairly reproducible results could be obtained if the whole system were pumped out for ten minutes between runs, if at the same time the temperature of the target were raised as close as one dared to the melting point, and if the new supply of gas was let in and allowed to come to equilibrium while the target was still at the hottest temperature. Furthermore after this long heat treatment the collector current became saturated at about fifty volts negative so that the uncertainty in the number of reflected positive ions disappeared.

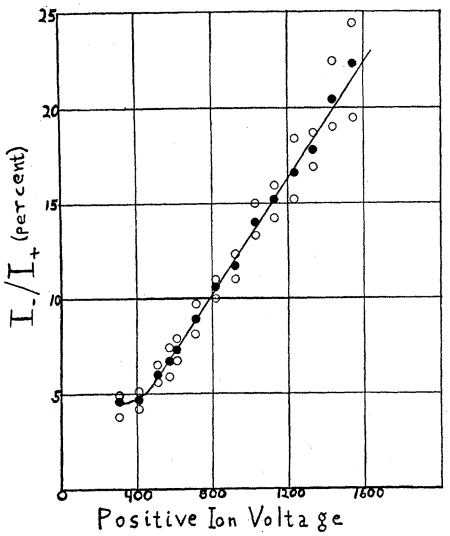

FIG. 5. Variation of the secondary electron emission from the hot target with the positive ion voltage. Average values (●), extreme values (o).

Final readings were taken with the target at approximately 900°C. The ratios of the number of secondary electrons from the target to the number of positive ions striking the target over the range of positive ion voltages are shown in Table I and these are plotted in Fig. 5. The extreme as well as the average values for each voltage are shown on the curve. The curve indicates a linear relationship between the secondary emission produced by an ion and its kinetic energy except at low voltages where there is an apparent tendency toward a constant value. The values of the emission range from 4.6 percent at 303 volts to 22.3 percent at 1539 volts. The variations in the measurements at one voltage were probably due to the continued adsorption of hydrogen even on the hot target face so that a really clean surface was not obtained. However, it is believed that the surface was as thoroughly degassed as it could be under hydrogen ion bombardment.

TABLE I. *Ratio of secondary electron current to positive ion current striking target at various positive ion voltages.*

V_P	I_-/I_+ (percent)	No. of Observations	Percent Deviation
303	4.6	7	3.0
406	4.7	7	1.1
509	6.0	5	2.3
571	6.7	7	2.1
612	7.3	10	1.4
715	8.9	10	1.8
818	10.6	5	1.2
921	11.7	6	1.4
1024	14.0	9	1.1
1127	15.2	8	2.1
1230	16.6	10	1.9
1333	17.8	7	0.93
1436	20.4	6	2.4
1539	22.3	9	2.1

The number of reflected positive ions shows a tendency to increase with positive ion voltage as shown in Fig. 6.

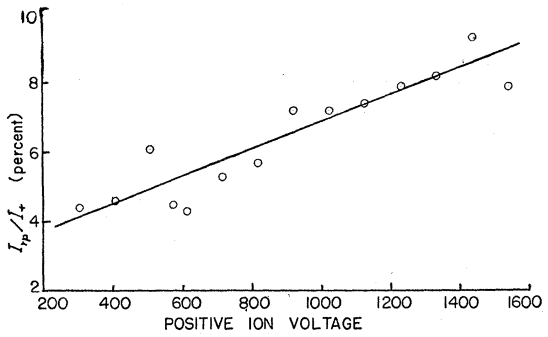

FIG. 6. Positive ion reflection at the hot target.

DISCUSSION

These results may be compared with those of Jackson and Oliphant, referred to above. Jackson's values of secondary emission, due to positive alkali ions striking various metals, were low compared with the values obtained here for hydrogen on nickel. Moreover, no emission was detected by Jackson unless the ion had an energy of a few hundred electron volts. The work of Oliphant using helium on molybdenum is more like the present case, since the difference between the work function of the metal and the ionization potential of the ion is high. As in the present case the emission is large for the cold non-degassed target, and very much smaller for the clean hot target. However, in the present case the emission of electrons due to positive ions with an energy of 1000 electron volts is about one-fifth as large as Oliphant's value for helium ions striking a hot molybdenum target.

An attempt was made to study the velocity distribution of the secondary electrons, but conditions of unsteadiness did not permit many points to be obtained and the curves were not reproducible. The lack of reproducibility is probably due to differences in the surface condition of the target for different amounts of

hydrogen adsorbed. If the contact potential between the target and the collector changed with the amount of hydrogen adsorbed the whole curve would shift to the right or left by the amount of this change in successive runs. It is thought, therefore, that a prolonged study of the velocity distributions of the electrons produced by hydrogen could not give definite results.

Studies of the number of positive ions reflected from a metal surface are not very numerous. Gurney[3] reported that for K, Cs, or Li ions on a Pt target the reflection was small or even zero at normal incidence. Jackson[1] reported less than two percent in his experiments on secondary emission from alkali ions. Oliphant gives no values for the number of helium ions reflected from hot molybdenum but the results of these experiments on hydrogen ions striking hot nickel show reflection of a magnitude that cannot be neglected in comparison with the secondary emission. The increase in the reflection with positive ion voltage is not regular and it is believed that the surface condition of the target had a greater effect upon the positive ion reflection than upon the secondary electron emission. In a few cases in which more hydrogen than usual had been let into the system before taking a run the number of reflected ions increased enormously while the number of secondary electrons remained the same, as if positives were more easily reflected by a layer of adsorbed hydrogen than by a clean nickel surface. Hence there is some indication that hydrogen ion reflection might be a sensitive detector of the amount of hydrogen adsorbed on a surface.

[3] R. W. Gurney, Phys. Rev. **32**, 467 (1928).

It is not clear why the line representing the reflected positives (Fig. 6), when extrapolated to zero voltage, indicates a finite percentage of reflected positives. Possibly a few ions, on their way to the target, struck a diaphragm and were reflected to the platinum film, thus increasing the apparent number of positives reflected from the target. It is also not certain why the collector current reached saturation when the collector voltage was increased to 80 volts negative with respect to the target, since the energy of the primary ions was increased by this voltage and the number of reflected positives should therefore increase. However, this change as shown by the slope of the line in Fig. 6, must have been small.

It is believed that the high vacuum in the collector precluded the possibility of much ionization of gas molecules by the ion beam in that portion of the tube. If such ionization existed it would increase the apparent number of both secondary electrons and reflected positives and the values deduced from the data taken in these experiments would be too large by a very small amount.

These experiments show that if hydrogen ions bombard a hot nickel target, kept as clean as is possible under hydrogen ion bombardment, the number of secondary electrons per positive ion increased from 0.046 to 0.223 when the positive ion energy increases from 303 volts to 1539 volts. This increase is nearly linear except for low voltages at which the secondary emission tends towards a constant value. Therefore it would seem that, if the conditions in the ordinary discharge are comparable with those existing in a high vacuum with a hot target, the part played in maintaining the discharge by hydrogen ions striking the cathode is relatively small.