SECONDARY ELECTRON EMISSION PRODUCED BY POSITIVE CAESIUM IONS

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Abstract

Number of electrons emitted from a Cs covered grid and plate per positive Cs ion striking them.—The source of the positive caesium ions, a short tungsten filament maintained at about 1200°K in the presence of caesium vapor, was mounted on the axis of a long cylindrical grid and plate. The plate current and total positive ion emission current were observed for each of several negative grid potentials as the plate potential was varied from +50 to −650 volts. From these observations the number of electrons that were emitted from the caesium covered grid and plate per positive ion was calculated. This number increased uniformly from 0.01 at approximately 100 volts to 0.15 at 600 volts.

Calibration of tube.—After corrections for the emission of secondary electrons were made, the ratio of the positive ion current to the plate to the total emission current was found to be independent of the plate and grid potentials for plate potentials greater than 0.2 of the grid potential. This ratio, 0.72, is the same as the ratio between the total area of the plate less the projected area of the grid, and the total plate area. Assuming the same distribution of electrons as positive ions, we can calculate the ratio of the plate current to the grid current in this type of tube.

Introduction

THE subject of secondary electron emission from various surfaces due to the bombardment of positive ions has been investigated by several people.[1–4] Similar studies have recently been made by Klein[5] and Jackson.[6]

The material presented in this paper describes experiments with a three-electrode tube to determine the number of electrons emitted from a caesium covered molybdenum surface per caesium positive ion as a function of the accelerating potential.

Apparatus

A diagram of the tube and electrical connections is shown in Fig. 1. The source of the positive ions was a tungsten filament, F, 2.5 cm long maintained at about 1200°K in the presence of caesium vapor.[7] This filament was mounted along the axis of a cylindrical grid, G, 4.5 cm long made of 0.0127 cm (5 mil) molybdenum wire wound on a 0.75 cm mandrel. There were forty turns of grid wire per 2.5 cm length of grid. A cylindrical molybdenum plate, P, 1.3 cm in diameter and 4.5 cm long, was mounted outside the grid and

[1] Cheney, Phys, Rev. **10,** 335 (1917).
[2] Baerwald, Ann. d. Physik **41,** 643 (1913); **60,** 1 (1919); **65,** 167 (1921).
[3] Hahn, Zeits. f. Physik **14,** 355 (1923).
[4] Baderau, Phys. Zeits. **25,** 137 (1924).
[5] Klein, Phys. Rev. **26,** 800 (1925).
[6] Jackson, Phys. Rev. **28,** 524 (1927); **30,** 473 (1927).
[7] Langmuir and Kingdon, Science **57,** 58 (1923).

coaxial with it. These electrodes were mounted in a lime glass tube with a side tube from which the caesium was to be distilled. The tube was evacuated by a mercury vapor pump backed by an oil pump. A trap was immersed in liquid air during the exhaust. The tube was baked out at about 200°C while the pumps were running. A higher temperature bakeout resulted in leakage currents across the stem after the caesium had been distilled into the tube.

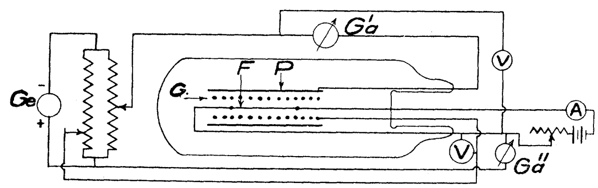

Fig. 1. Diagram of tube and electrical connections.

The filament was held at a high temperature for several seconds to free it of absorbed gases. The plate and grid were heated by induction until all evidence of emitted gases had disappeared.

Caesium was formed in the side tube by heating a mixture of caesium chloride and calcium. The caesium was then distilled into the tube and the side tube drawn off. The experimental tube was then sealed off from the pumping system and tested.

The filament was heated by the current from a storage battery and the grid and plate potentials were maintained by a motor generator set, *Ge*. The positive ion emission from the filament which was approximately two microamperes at the existing caesium vapor pressure was measured by a galvanometer, *Ga''*. A galvanometer, *Ga'*, in the filament-plate circuit indicated the net current to the plate.

Experimental Procedure

The experiments were carried on while the tube was immersed in a water bath maintained at 20°C in order to hold the pressure of the caesium vapor constant. The grid and plate were, of course, covered with at least a monatomic layer of caesium throughout the experiments.

The positive ion emission from the filament and the plate current were observed as the plate potential was varied from +50 to −650 volts with respect to the positive end of the filament, while the grid potential was maintained constant at each of several values between −100 and −600 volts.

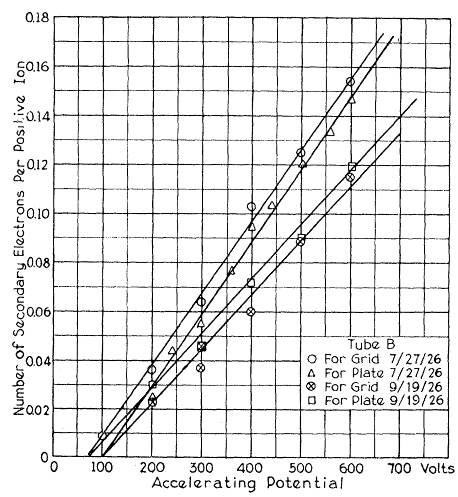

Fig. 2. Secondary electron emission produced at the grid and plate by caesium positive ions. Tube B.

Results

The number of secondary electrons produced by the impact of positive ions on the grid may be found as follows: While the plate potential was being varied from +50 to 0, the plate current was constant and consisted of electrons which were emitted from the caesium covered grid by the bombardment of positive ions. This is shown by the points below the abscissa axis in Fig. 4. At these plate potentials all positive ions were collected by the grid. The electron current to the plate divided by the positive ion current from the filament gives the number of secondary electrons per positive ion on the grid. This ratio for various accelerating grid potentials is shown by the curves for the grid in Fig. 2.

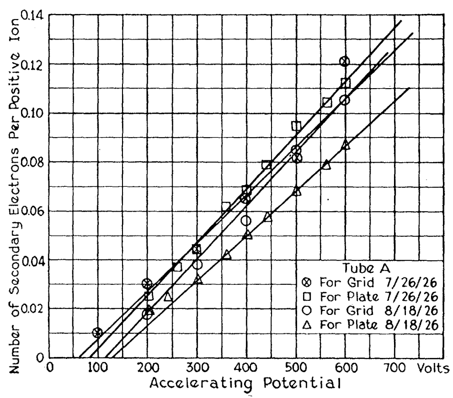

Fig. 3. Secondary electron emission produced at the grid and plate by caesium positive ions. Tube A.

The number of secondary electrons per positive ion increases uniformly from 0.01 at 100 volts to about 0.15 at 600 volts. The second curve for the gird was plotted from data taken at a later date and it shows that the ratio of secondary electrons to positive ions is less than indicated by the first curve. This difference is due to a change in the surface condition of the caesium. The curves for the grid that are shown in Fig. 3, were plotted from the data taken, with a second tube. A comparison of the two sets of curves shows that the secondary emission starts at about 100 volts in both cases but that the increase with accelerating potential is less for the second tube.

As the plate potential was made negative for a fixed negative grid potential, the plate current reversed because the plate began to collect positive ions in addition to the electrons from the grid. This condition is shown by the curve in Fig. 4. The ordinates represent the plate current, I_p, and the abscissas represent the plate potential, E_p. The potential of the grid was maintained at -500 volts. I_p rapidly attains a value which is quite constant between the values of E_p, -50 and -500. Immediately below the value of E_p equal to 500 volts, there is a rapid increase in I_p. This is followed by a nearly uniform increase in I_p as E_p increases.

The nearly horizontal portion of the curve in Fig. 4 indicates that for a given grid potential the plate current, which is made up of positive ions from the filament and secondary electrons from the grid, is constant until the plate becomes as negative as the grid. As the ratio of plate to grid voltage passes through unity, the plate ceases to collect secondary electrons from the grid and begins to lose them to the grid. The increase in I_p as the plate is made more negative than the grid indicates that the number of secondary electrons from the plate increases as the positive ion speed increases.

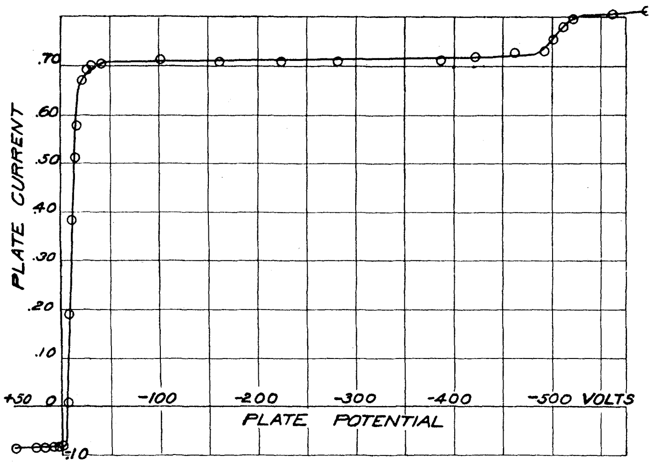

Fig. 4. Total plate current as a function of plate voltage with the grid at −500 volts. Positive ordinates indicate an excess of positive ions to the plate, negative ordinates indicate an electron current from grid to the plate.

In order to analyze the type of data shown in Fig. 4, the ratio of the plate current, I_p, to the total emission current I_0, is plotted as ordinates, and the ratio of the plate potential, E_p, to the grid potential, E_g, is plotted as abscissas in Fig. 5 for each of several grid potentials. The values of I_p/I_0, for each grid potential, rapidly attains a value which is constant between the

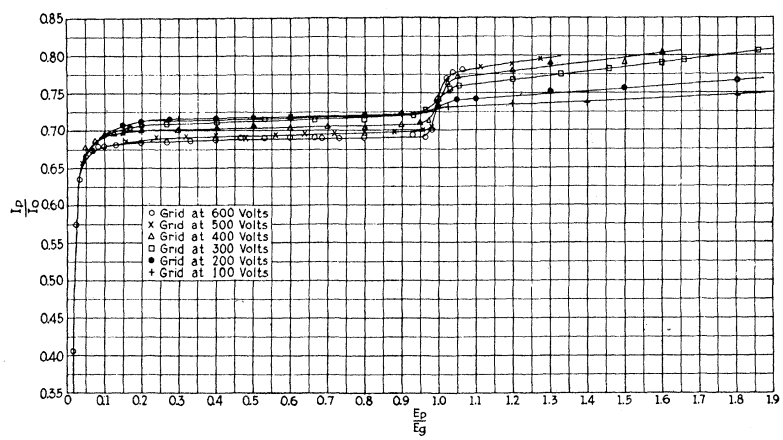

Fig. 5. Curves showing the ratio of the plate current, I_p to the emission current, I_o, as a function of the ratio of the plate potential, E_p, to the grid potential, E_g.

values of E_p/E_g 0.2 and 1. For values of E_p/E_g greater than 1 there is a nearly uniform increase in I_p/I_0.

Fraction of Positive Ions Striking Grid and Plate

In order to calculate the number of secondary electrons that are emitted from the plate per positive ion, it is necessary to know the actual primary positive ion current to the plate. This current may be calculated from the data in Figs. 2 and 5 as follows. Consider, in Fig. 5, the portion of the 600 volt curve between E_p/E_g equal to 0.2 and 0.95. The difference between the ordinate 1 and the average value of I_p/I_0 for that part of the curve represents the fraction of the total current that reaches the grid. This grid current is made up of positive ions from the filament and secondary electrons from the grid itself. If the value of the grid current be multiplied by the value of the number of secondary electrons per positive ion at the grid obtained in Fig. 2, the result approximately represents the secondary electron current from grid to plate. This value is a little too large, since the grid current included the secondary electrons emitted to the plate. However, if the calculated value of the secondary electron current from the grid be added to the observed plate current, we obtain an approximate value of the actual positive ion current to the plate. This current is a little too large because the value of the grid current with which we have started is a little too large. If the calculation is again made, using the new value of the plate current, calculated as described above, we obtain a value of the positive ion current to the plate which is probably very near the true current. This current, which is in terms of unit emission from the filament, represents the fraction of the positive ions striking the plate for the given value of the grid potential.

If the same calculation is applied to the curves in Fig. 5, for each grid potential, the resulting values of the ratio I_p/I_0 do not differ by more than one percent from their mean, which is 0.724. This indicates, at least for grid potentials between 100 and 600 volts, that the relative distribution of positive ions between grid and plate is constant as long as the potential of the plate is greater than 0.2 and less than 0.95 of the grid potential.

It is probable that this same distribution of positive ions holds for ratios of E_p/E_g greater than unity. If this distribution is assumed, then, in Fig. 5, the difference between the values of I_p/I_0 and 0.724, above E_p/E_g equal to 1, is represented by the secondary electron current emitted from the caesium covered plate. This difference for a given E_p divided by 0.724 gives the number of secondary electrons per positive ion incident on the plate.

It was found that these ratios of secondary electrons to positive ions for a given plate potential but for the different grid potentials were in agreement, and were also in agreement with the number of secondary electrons per positive ion for the grid. This justifies the assumption made above that the fraction of positive ions which goes to grid and plate respectively, is constant for all values of E_p/E_g; the plate collecting 72 percent and the grid 28 percent of the ions emitted from the filament.

The curves for the plate that are shown in Fig. 2, were plotted from the results calculated in this way. The number of secondary electrons per positive ion increases uniformly from 0.01 at 100 volts to 0.15 at 600 volts. The two curves for the plate were plotted from data taken with an interval of six weeks. The difference between them indicates a change in surface conditions.

The curves in Fig. 3 show the relation between the number of secondary electrons per positive ion and the accelerating potential for the caesium covered plate in a second tube.

Calibration of Tube

The plot shown in Fig. 6, represents the fraction, F, of the total ion emission that reaches the plate as a function of E_p/E_g after the secondary electron emission from the grid and plate has been taken into account for each of the curves in Fig. 5. The actual positive ion current to the plate per unit ion emission from the filament for each of the grid potentials lie within the shaded region of the plot, and the average 0.725 is represented by the horizontal line.

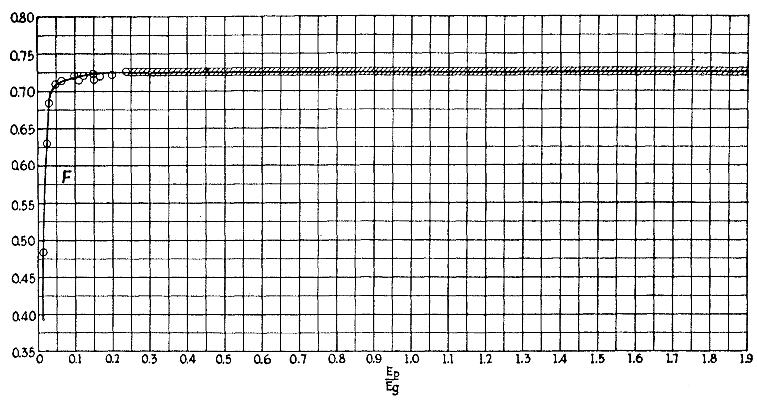

Fig. 6. Curve showing the fraction, F, of the total positive ion emission that reaches the plate as a function of the ratio E_p/E_g.

Upon referring to Fig. 2 again, it may be observed, according to the intercept on the abscissa axis, that the secondary emission from the grid at accelerating potentials less than 100 volts is zero. Observations that were made when both the plate and grid were maintained at -50 volts showed that the ratio, I_p/I_0, was 0.723, a value close to the corresponding one found above.

It was anticipated that the fraction of positive ions caught by the grid and plate respectively, would be the same as the ratio of solid to open portions of the grid. Accordingly, the area of the inner surface of the plate and the projected area of the grid on the plate per centimeter length of the plate were calculated from their dimensions. The ratio of the projected grid area to the total plate area turns out to be 0.27 and the ratio of the plate area less the projected grid area to the total plate area is 0.73. This last ratio is very close to the ratio 0.725, shown in Fig. 6. It can be shown theoretically that the paths of positive ions in a tube of this type are the same as those of electrons at the same accelerating voltage. Hence it may be assumed that with positive voltages of grid and plate the fraction of electrons caught by the grid will be measured by the projected area of the grid. This result is of considerable importance for work on secondary electron emission. It obviously applies, so far as the present evidence goes, only to cylindrical tubes of the type used in these tests.

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