THE DISTRIBUTION OF ELECTRONS BETWEEN THE PLATE AND GRID OF A THREE ELECTRODE TUBE AS DETERMINED BY POSITIVE CAESIUM IONS

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Abstract

Number of electrons emitted from a Cs covered surface per positive Cs ion. The source of the ions was a tungsten filament maintained at about 1200°K in the bulb of a radiotron UX201A containing caesium vapor. The plate current and positive ion current emitted from the filament were observed for each of several negative grid potentials as the plate potential was varied from +45 to −600 volts. From these observations the number of electrons that was emitted from the caesium-covered grid per positive ion was calculated. The number increased uniformly from zero at about 95 volts to 0.24 at 600 volts.

Calibration of tube. After corrections for the emission of secondary electrons from grid and plate were made, the ratio of the positive ion current to the plate to the positive ion emission from the filament was found to increase to 0.86 as the ratio of the plate potential to the grid potential reached 0.75. Beyond this point the relative distribution of positive ions remained constant for all ratios of plate to grid potential. This fraction 0.86, is the same as the ratio between the total area of a surface in the plane of the grid and the actual area of the grid as seen from the filament. Assuming the same distribution of electrons as positive ions, the fraction of the electrons reaching grid and plate in this type of tube may be calculated from the grid dimensions provided the plate potential is greater than 0.75 of that of the grid.

Introduction

In a previous report[1] the writer described experiments which led to the determination of the relative distrubution of positive caesium ions between the cylindrical plate and grid of a three-electrode tube. It was also shown that the fraction of positive ions caught by the grid and plate respectively was proportional to the area of the solid and the open portions of the grid. 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 was assumed that with positive voltages of grid and plate the fraction of electrons caught by the plate would be measured by the ratio of the projected area on the plate of the open portion of the grid to the total plate-area.

The material presented in this paper describes similar experiments with a plane-anode type of tube.

Apparatus

The tube was a standard radiotron UX201A with a pure tungsten filament, which was the source of positive caesium ions when maintained at a

[1] Hyatt, Phys. Rev. **32**, 922 (1928).

temperature of about 1200°K.[2] A diagram of the tube and electrical connections is shown in Fig. 1. 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 often resulted in leakage currents across the stem after the caesium had been distilled into the tube. The plate was heated by induction until all evidence of emitted gases had disappeared.

Caesium was generated by heating by induction a metal capsule containing a mixture of caesium chloride and calcium. The experimental tube was then sealed off from the pumping system and tested.

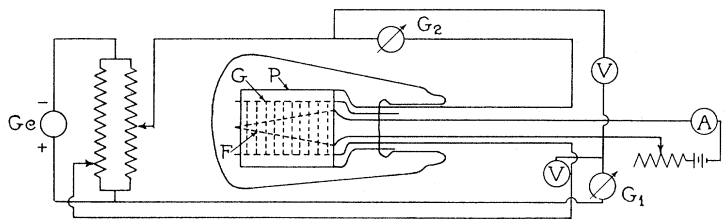

Fig. 1. Diagram of tube and electrical connections.

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, G_1. A galvanometer, G_2, in the filament-plate circuit indicated the total plate current.

Experimental Procedure

The experiments were carried on while the tube was immersed in a water bath maintained at about 30°C in order to hold the pressure of the caesium vapor constant. The grid and plate were 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 +45 to −600 volts with respect to the positive end of the filament, while the grid potential was maintained constant at each of the values, −125, −250, −360 and −500 volts.

Results

While the plate potential was varied from +45 to 0, the plate current was nearly constant and consisted of electrons which were emitted from the caesium covered grid by the bombardment of positive ions. This is shown by the part of the curve below the axis of abscissas in Fig. 2. At these plate potentials it was assumed that all the positive ions were collected by the grid. The electron current to the plate divided by the positive ion current

[2] Langmuir and Kingdon, Science **57,** 58 (1923).

from the filament gives the number of secondary electrons per positive ion on the grid. This ratio for various accelerating grid potentials with the plate

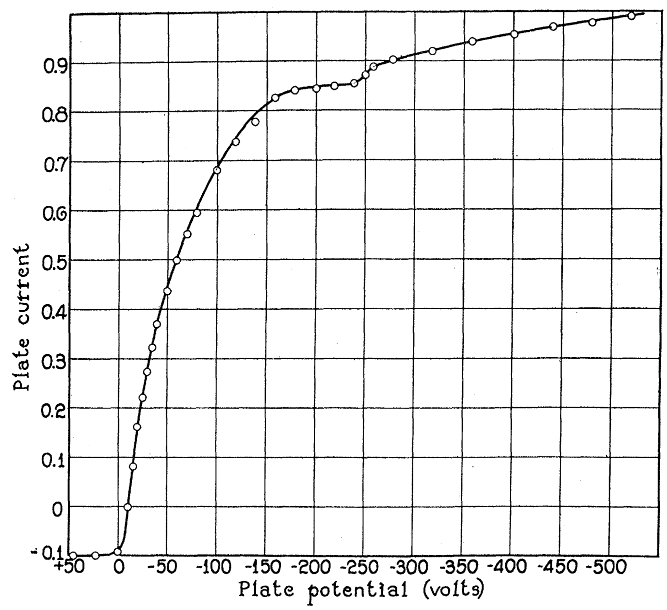

Fig. 2. Total plate current as a function of plate potential with grid at −250 volts. Positive ordinates indicate an excess of positive ions to the plate, negative ordinates indicate an electron current from grid to plate.

maintained at +45 is shown by Curve I in Fig. 3. The curve indicates that the emission of secondary electrons starts at about 95 volts and that the

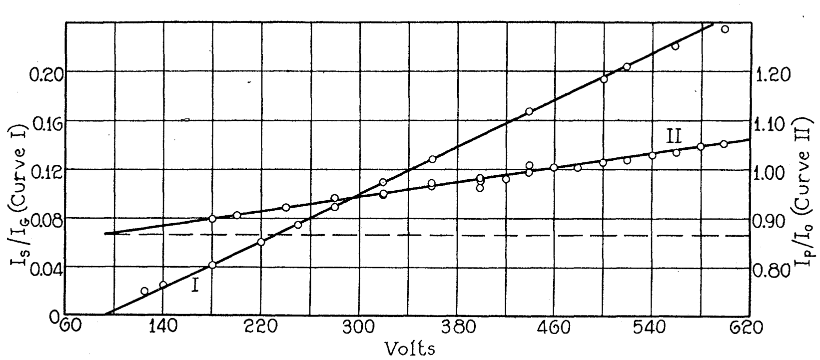

Fig. 3. Curve I. Number of secondary electrons from the grid per positive ion at the grid as a function of the grid potential. Curve II. Total plate current in terms of unit positive ion emission from the filament as a function of the plate potential for values of E_p/E_g greater than unity.

number of secondary electrons per positive ion increases uniformly with the accelerating potential.

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 is shown by the curve in Fig. 2. The ordinates represent the plate current, I_p, and the abscissas represent the plate potential, E_p. The grid potential, E_g, was held at -250 volts. I_p increases rather rapidly up to -150 volts and then changes but little until a potential a little less than -250 is reached. At this point there is a sudden increase in I_p which is followed by a uniform change as E_p increases. The plate current for values of E_p less than E_g is made up of positive ions from the filament and secondary electrons from the grid. As the ratio of the plate to grid potential passes unity, the plate ceases to collect secondary electrons from the grid and begins to lose them to the grid and filament. 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.

The ratio of the plate current, I_p, to the total emission current from the filament, 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. 4 for each of several grid potentials. The values of I_p/I_0, for each grid potential, increase until E_p/E_g reaches about 0.75 and then remain nearly constant until E_p/E_g becomes unity. For values of E_p/E_g greater than unity there is a nearly uniform increase in I_p/I_0.

Fraction of Positive Ions Striking Grid and Plate

The actual positive ion current to the plate may be calculated from the data in Figs. 3 and 4 as follows: Consider the curve in Fig. 4 for E_g -250 volts. The difference between the ordinate 1 and the values of I_p/I_0 represents the fraction of the total current that reaches the grid. Below values of E_p/E_g equal to unity, the grid current is made up of positive ions from the filament and secondary electrons from the grid itself. If the grid current for values of E_p/E_g less than unity be multiplied by the value of the number of secondary electrons per positive ion at the grid obtained from the data of Curve I of Fig. 3, the result approximately represents the secondary electron current from grid to plate. This value is somewhat too large, since the grid current already included the secondary electrons emitted to the plate. If this 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 grid current with which we started was too large. If the calculation is repeated, using the new value of the plate current we obtain the true value of the positive ion plate current for values of E_p/E_g less than unity.

It is probable that the number of secondary electrons from the plate per positive ion at the plate for a given plate potential is very nearly the same as that for the grid at the same potential. If this is assumed, it becomes possible to determine the fraction of the positive ions that reaches the plate for values of E_p/E_g greater than unity.

It was observed during the experiments that the emission current, I_0, suddenly increased as E_p/E_g passed through unity and then increased but little for larger values of E_p/E_g. This increase in I_0 was probably due to a few secondary electrons from the plate that were not caught by the grid, and to the secondary electrons from the grid that no longer go to the plate on account of the adverse field. The true positive ion emission from the filament for values of E_p/E_g greater than unity was then calculated by taking into account the above mentioned increase in the observed emission. If the observed plate current is now divided by this corrected value of the emission current larger ratios of I_p/I_0 are obtained.

The fraction of the total positive ion current reaching the plate for ratios of E_p/E_g above unity may be calculated as follows. The corrected values of

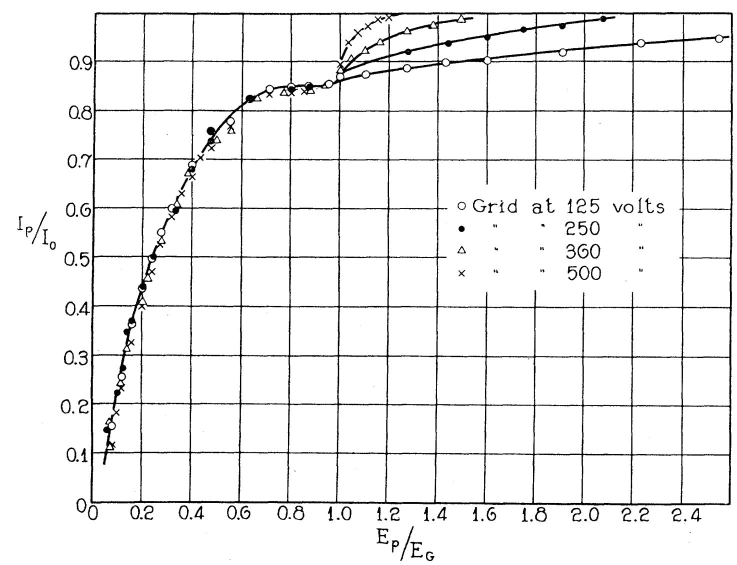

Fig. 4. Ratio of plate current, I_p, to the emission current, I_0, as a function of the ratio of the plate potential, E_p, to the grid potential, E_g.

I_p/I_0 are multiplied by the number of secondary electrons per positive ion at the grid according to Curve I in Fig. 3. This product is subtracted from the value of I_p/I_0 and is approximately the true fraction of positive ions that reach the plate. However, this value is a little too small for I_p/I_0 is larger than the actual fraction of positive ions to the plate. If the calculation is again made using the new value of I_p/I_0, we obtain a value which represents the fraction of the positive ions reaching the plate.

The same calculations have been applied to the curves in Fig. 4 for each grid potential and the resulting values of the fraction of the positive ions reaching the plate are in close agreement.

The plot shown in Fig. 5 represents the results obtained by making the calculations that have been described. The fraction F of the total positive ion emission that reaches the plate is plotted as ordinates and the ratio E_p/E_g is plotted as abscissas for each of four grid potentials.

The fraction F increases to a value of 0.86 at a plate potential equal to 0.75 of the grid potential and then falls off by a little more than one percent as the plate reaches a potential twice that of the grid. The degree to which the results for values of E_p/E_g greater than unity conform to those for values less than unity justifies the assumptions that were made in the calculations.

However, the small decrease in F for the higher ratios of E_p/E_g suggests that the number of secondary electrons per positive ion at the plate is somewhat less than for the grid. This difference may be accounted for if a few of the positive ions from the filament go around the end of the plate and strike the back from which the secondary electrons would not be collected. The

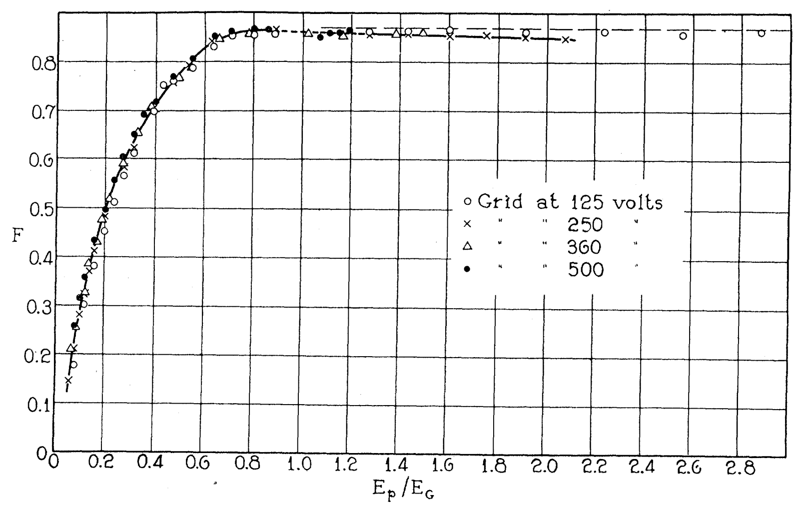

Fig. 5. Curves showing the fraction F of the total positive ion emission reaching the plate as a function of the ratio E_p/E_g while the grid of a tube was maintained at each of four potentials.

ends of the filaments in the tubes used did extend to the ends of the plate so it is probable that some of the ions did go around the ends to the back of the plate.

A second and probably less certain method of determining F for values of E_p/E_g greater than unity may be described as follows:

The values of I_p/I_0 shown by the curves in Fig. 4 were corrected for the increase in I_0 as E_p/E_g passed through unity as described above. These corrected values of I_p/I_0 are shown by Curve II in Fig. 3, where they are plotted as a function of the plate potential. The values of I_p/I_0 for the same plate potential but for different grid potentials fit together to give a good straight line. If the fraction of positive ions that strike the plate remains constant then the slope of this curve indicates the rate of increase of the number of secondary electrons per positive ion at the plate as the accelerating potential increases. Curve I, Fig. 3 shows that secondary electron emission from the grid starts at about 95 volts. If it is assumed that secondary emission from the plate starts at the same accelerating potential, then the value of I_p/I_0, for Curve II, Fig. 3, corresponding to a plate potential of 95 volts, would represent the actual positive ion current to the plate in terms of unit emission from the filament. The ordinate on Curve II corresponding to 95 volts is 0.87. This is but little larger than the value of F obtained by the first method. The dashed line drawn at 0.87 for values of E_p/E_g greater than unity, in Fig. 5 indicates this value of F.

The plot shown in Fig. 6 shows the results obtained from four tubes of the UX201A type. The grid was maintained at -250 volts in each of the four cases.

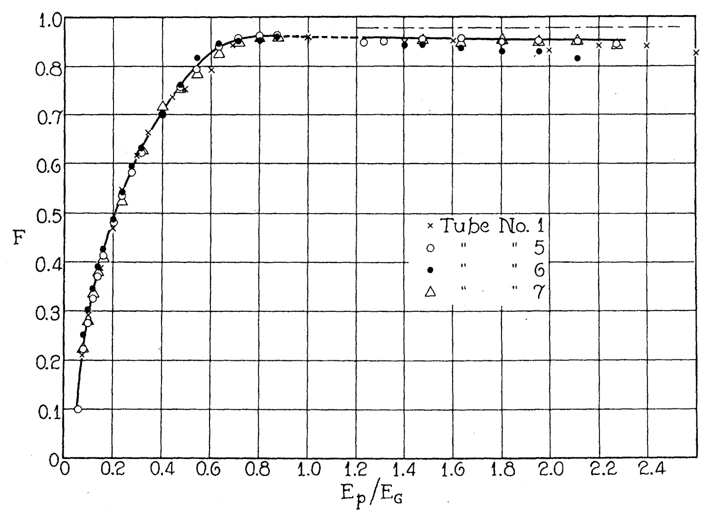

Fig. 6. The fraction F of the total positive ion emission reaching the plate as a function of the ratio E_p/E_g. Data from four tubes with the grid maintained at -250 volts.

It was anticipated, as in the experiment with the cylindrical anode tube previously reported, that the fraction of positive ions caught by the grid and plate respectively, would be the same as the ratio of solid to open parts of the grid. The area of the closed portion of the grid as seen from the filament and the total area of a surface in the plane of the grid were calculated for one of the tubes. The ratio of the closed area of the grid to the total area turns out to be 0.14 and the ratio of the open area to the total area is 0.86. This is nearly the same as the values of F shown in Figs. 5 and 6, for values of E_p/E_g greater than 0.75. Since it may be shown theoretically that electron paths are the same as the positive ion paths at the same potentials, it may be concluded that the shadowing or screening effect of the grid as regards the electron current to the plate may be calculated from the grid dimensions.