THE MODIFICATION OF THE THERMIONIC CURRENT IN VACUUM TUBES WHEN POTASSIUM DEPOSITED ON THE INSIDE WALLS OR GRID OF THE TUBE IS ILLUMINATED

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Abstract

When a floating grid mounted between a plate and filament in a spherical tube, is coated with potassium and illuminated, it loses a negative charge and produces a considerable increase in the plate current, equivalent to that due to maintaining the unilluminated grid at a positive potential of a few volts relative to the filament. In the case of a long tube with a constricted cylindrical portion between the plate and filament ends, an illuminated coating of potassium on the walls reduces the tendency of the walls to charge negatively and hence facilitates the passage of the current through the tube. As the filament current is increased for a given plate voltage the current reaches a maximum, then suddenly drops to a minimum, due to the combined action of space charge and photo-electric emission.

Introduction

The discovery by Case[1] of the increased thermionic current from the filament in an audion bulb when it was illuminated, led to investigation of the action of light on vacuum tubes by Merritt,[2] Miss Meacham,[3] Gibbs,[4] Arnold and Ives.[5] Later Case constructed a vacuum tube with a deposit of potassium on the plate and walls of the tube. This tube behaved in a characteristic manner when the intensity of illumination on the potassium was varied. There was a diminution in the plate current as the illumination was reduced, which was suspected to be due to the patches of potassium on the walls charging up negatively as electrons were received by the surface. When the illumination was increased, the increase in the plate current was probably due to the loss of photo-electrons from the potassium, causing its potential to become more positive. Thus the insulated patches of potassium appeared to serve as a grid in a three electrode tube.

The following experiments were made to test this view.

[1] Case, Phys. Rev. **17**, 398 (1921)
[2] Merritt, Phys. Rev. **17**, 525 (1921)
[3] Miss E. L. Meacham, Master's thesis, Cornell University, Sept. 1921
[4] R. C. Gibbs and Miss Meacham, Phys. Rev. **19**, 415 (1922)
[5] Arnold and Ives, Proc. Nat. Acad. Sci., **7**, 323 (1921)

Method of Experiment

The grid of the tube shown in Fig. 1 was coated with potassium by evaporating a piece of potassium while the other parts of the tube were heated. This tube was used in the ordinary circuit for determining the characteristic curves of vacuum tubes, the current measuring instrument being a galvanometer of about 9,000 megohms sensitivity.

The first test, which was made with the grid floating and unilluminated, showed that the plate current was too small to measure until the filament plate potential was increased to 50 volts. The plate current, with the grid illuminated by a 100-watt lamp at a distance of 150 cm, however, had reached a value within a few per cent of saturation at 20 volts. These facts are shown by curves F and E in Fig. 2. The other curves in Fig. 2 show the relations between the plate current and filament-plate potential while the grid was maintained at definite potentials with respect to the filament.

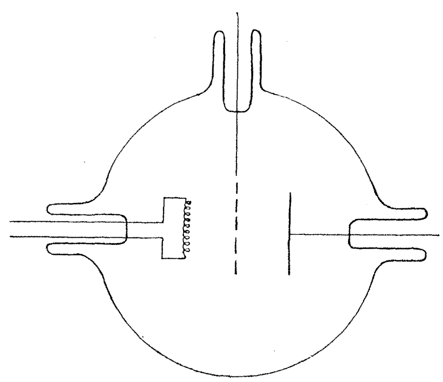

Fig. 1. Diameter of tube 11 cm; filament and plate 4 cm apart.

These curves show that an increase in the potential of the grid when dark gives rise to an increase in the plate current. Since this is true and since the illumination of the floating grid causes a corresponding increase in the plate current, the effect of the illuminated grid must be equivalent to maintaining the grid at a small positive potential relative to the filament. This must be accomplished by the discharge of the photo-electrons from the grid when illuminated. Further experimenting showed that the increase in plate current became almost zero when the grid was illuminated if it was maintained at a potential of 4 volts or above with respect to the filament.

When the intensity of illumination on the floating grid was varied, it was found that there was a linear relation between the plate current and light intensity. Since the effect of changing the intensity of illumination on the potassium-coated grid is to change its potential over a small range, the above linear relation must correspond to a portion of the ordinary plate current-grid potential characteristic.

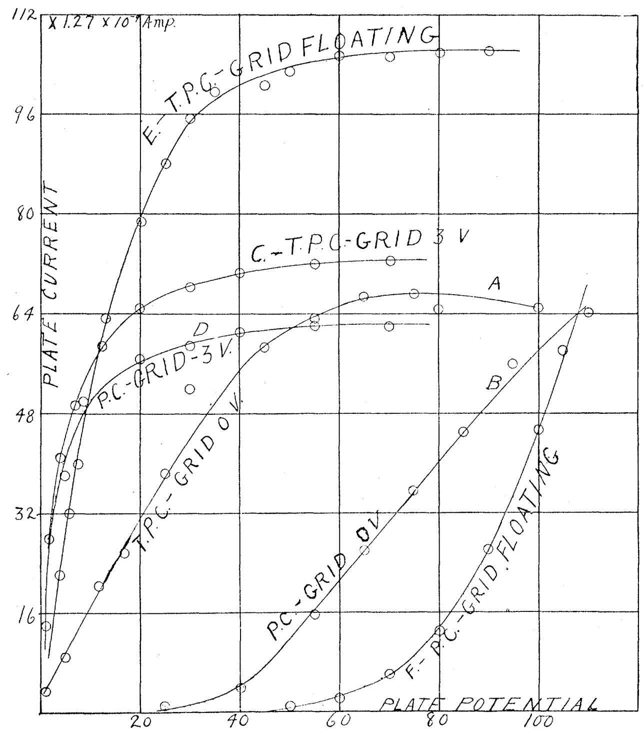

Fig. 2. T.P.C. means total plate current with grid illuminated; P.C. means plate current with grid unilluminated.

It seemed worth while to investigate the effect on the plate current due to a change in the distribution of the potassium between the filament and plate. As a means of studying this question the tube shown in Fig. 3 was made. The inside of the constricted portion of the tube was coated

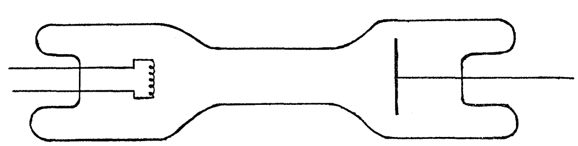

Fig. 3. Length of tube 16 cm; filament and plate 7.5 cm apart; diameter of constricted portion of tube 1.5 cm.

with potassium except for a narrow window through which it could be illuminated. The curves in Fig. 4 show for different filament-plate potentials the relation between the photo-electric current and the filament current when the whole tube was illuminated. There was no current in the dark until a potential of about 260 volts was applied. This was undoubtedly due to the retarding action of the negatively charged walls of the tube.

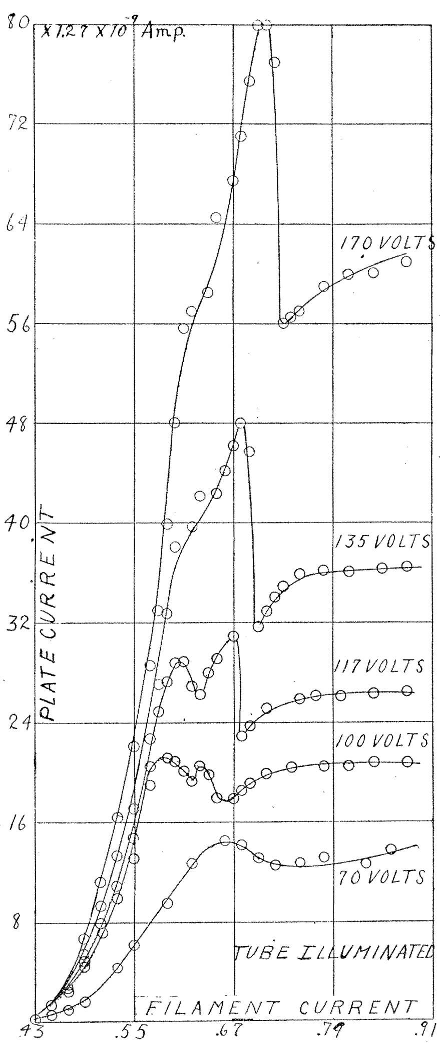

Fig. 4

The outstanding peculiarity about these curves is the sudden drop in the plate current at certain filament currents. The higher the filament plate potential, the higher is the filament temperature at which these drops occur. The observations were repeated twice on different days and the characteristics of the above curves were duplicated except for a small percentage variation in the magnitude of the photo-electric currents. Observations that were taken for successively decreasing filament currents checked those for increasing currents to within a very few per cent.

When the whole tube was illuminated, the greater the light intensity, the hotter the filament had to be for a given plate potential for the drop in the photo-electric current to take place. When a narrow beam of light was thrown on the tube at different distances from the filament, it was found that the farther the illuminated area was from the filament, the hotter the filament had to be before the drop in the plate current occurred.

With these results in mind, the plate potential and filament current were set to give the lowest point on one of the curves in Fig. 4 after the drop in the photo-electric current. A screen was then lowered from the filament end of the tube covering up a portion of the illuminated potassium. The photo-electric current then increased a little and continued to increase as the tube was covered up until the current reached its value before falling; then the current decreased as more of the tube was covered. When the screen was raised to the position giving the maximum current and the filament temperature increased a little, the photo-electric current then fell to a smaller value but came back up when a little more of the tube was covered. This was repeated several times until a little more than half of the potassium was in the dark, after which the current decreased no matter what the filament current. This experiment was repeated several times with the same result.

The following considerations may explain the peculiarity in the curves. An increase in the filament temperature means an increase in the space charge or electron density near the filament. As the supply of electrons increases, the current through the tube increases until the electron density reaches a certain value. Further increase in this density hinders the light from discharging the photo-electrons from the potassium on account of the mutual repulsion of the electrons, the potential of the potassium decreases and hence the current, as is observed. If now the potassium in this region is covered its potential is still low and a potential gradient is established between the dark potassium surface and the illuminated portion near the plate. The electrons now are conducted over the potassium surface until they reach the illuminated portion where they are emitted and travel to the plate under the action of the field, thus bringing the current through the tube to its original value.

To test this explanation, the potassium was driven from a narrow ring around the tube about halfway between the filament and plate by heating that part of the tube. The photo-electric filament current characteristics of the tube under these conditions were similar to those shown in Fig. 4. There were no indications of an increase in the current as part of the tube was covered, but a considerable portion of the potassium could be covered with but a small decrease in the current. This was to be expected if the presence of the ring prevented conduction along the surface. While attempting to redistribute the potassium again the tube was broken, and so further investigations to test the theory of the action of the potassium have not been made.

The writer extends to Mr. T. W. Case his appreciation and thanks for the manufacture of the tubes that were used in the investigation. He also wishes to express his gratitude to Professor Gibbs, under whose direction this investigation was made, for his advice and encouragement throughout the work, and to thank Professor Merritt for his suggestions and interest in this problem.

Cornell University,
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