SECONDARY ELECTRON EMISSION FROM MOLYBDENUM

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Abstract

The secondary electron emission from a very clean molybdenum plate in a simple three-electrode tube has been studied. The number of primary electrons striking the plate was calculated by means of the positive ion calibration method previously reported. The number of secondary electrons per primary reaches a maximum value of 1.15 at 600 volts and then decreases to 1.00 at 2000 volts. One definite discontinuity in the secondary emission curve occurs at 13.5 volts; the others are very small and are not reproducible. The emission increases about 3 percent within a few minutes after heating if the gas pressure is very low and then remains quite constant for a long period of time. The emission decreases with time when there is more gas present. The secondary emission appears to increase by about 4 percent when the temperature of the target increases from the normal operating temperature to 1600°K.

Introduction

THE emission of electrons from metal surfaces due to electron bombardment has been investigated by several observers [1–13] in the past few years. Petry[14] has reported on the secondary emission from molybdenum, and has shown that discontinuities occur at several accelerating potentials in the secondary emission curve. The object of the present investigation has been to study the secondary emission from an exceptionally clean molybdenum plate by using a simple type of three electrode tube that had been calibrated by the caesium positive ion method reported by one of the authors.[15]

Apparatus and Procedure

The electrodes were removed from the bulb used in the calibration experiment and mounted in a Pyrex glass bulb, shown in Fig. 1, in order to permit a higher temperature during the oven bake-out.

[1] A. W. Hull, Phys. Rev. **7**, 1 and 141 (1916).
[2] H. M. Dadourian, Phys. Rev. **14**, 434 (1919).
[3] Horton and Davies, Proc. Roy. Soc. **A97**, 23 (1920); Phil. Mag. **46**, 129 (1923); **47**, 245 (1924).
[4] I. G. Barber, Phys. Rev. **17**, 332 (1921).
[5] Millikan and Barber, Proc. Nat. Acad. Sci. **7**, 13 (1921).
[6] J. T. Tate, Phys. Rev. **17**, 394 (1921).
[7] Davisson and Kunsman, Phys. Rev. **19**, 253 (1922).
[8] H. E. Farnsworth, Phys. Rev. **20**, 358 (1922); **25**, 41 (1925); **27**, 413 (1926); **31**, 405 (1928); **31**, 414 (1928); **31**, 419 (1928).
[9] E. W. B. Gill, Phil. Mag. **45**, 864 (1923); **46**, 994 (1923).
[10] L. E. McAllister, Phys. Rev. **21**, 122 (1923).
[11] O. Stuhlman, Phys. Rev. **25**, 234 (1925).
[12] H. E. Krefft, Phys. Rev. **29**, 908 (1927).
[13] J. B. Brinsmade, Phys. Rev. **30**, 494 (1927).
[14] R. L. Petry, Phys. Rev. **26**, 346 (1925).
[15] J. M. Hyatt, Phys. Rev. **32**, 922 (1928).

The source of the primary electrons was a straight tungsten filament, *F*, 0.0178 cm (7 mil) in diameter and 2.5 cm long. This filament was mounted on the axis of a cylindrical grid, *G*, 0.76 cm in diameter and 4.45 cm long. The grid was made of 0.0127 cm (5 mil) molybdenum wire wound in a spiral with 40 turns per 2.5 cm, and was supported by four molybdenum wires, 0.0508 cm (20 mil) in diameter. The cylindrical plate, *P*, which was mounted coaxial with the grid, was 1.27 cm in diameter and 4.45 cm long.

The tube was exhausted by means of a two stage condensation pump backed by an oil pump and then baked out at 450°C for two hours. The filament was flashed and the grid cleaned up by electron bombardment. The plate was then heated by induction to a temperature of 1600°K as measured by a calibrated tungsten filament. The heat treatment of the plate continued until there was no trace of gas evolved during heating, as indicated by the sticking of the mercury column to the top of the McLeod gauge. The tube was then sealed off the pump and tested.

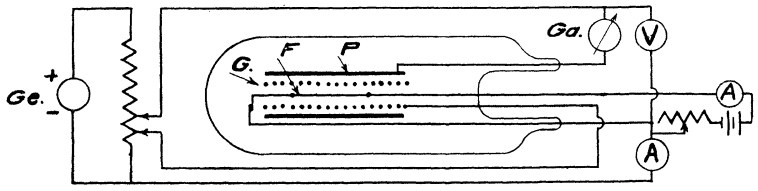

Fig. 1. Diagram of tube and electrical connections.

While the observations were being made, the tube was immersed in liquid air contained in an unsilvered vacuum flask, which was surrounded by the coil of a high frequency induction furnace. This enabled the plate to be heated while the tube was immersed in liquid air.

A diagram of the electrical connections is shown in Fig. 1. The filament was heated by the current from a storage battery and the electron emission from it was measured by a milliameter, *A*, (1 m.a. full scale). The grid and plate potentials were supplied by means of motor generator sets, *Ge*, that were found to be remarkably steady. During all of the experiments, the potentials of the grid and plate were maintained positive with respect to the filament. The grid potential was always at a value 4/3 that of the plate to ensure that the grid collected all the secondary electrons emitted by the plate. A galvanometer, *Ga*, in the plate-filament circuit served to measure the plate current. The electron-emission from the filament was maintained at about one milliampere to give the same space charge effect as was produced by the positive ion current of 2 microamperes in the positive ion calibration previously reported. This current was calculated from the relative masses of the caesium ion and the electron.

Before any observations were recorded, the plate was heated to about 1600°K while the tube was immersed in liquid air. The plate current was then observed for a plate potential of 350 volts and it was found that the current became quite steady after the furnace had been turned off for 2

minutes. The plate was repeatedly heated at intervals until the same value of the plate current was found at the end of each of several heatings.

In order to determine the number of secondary electrons per primary for the plate as a function of the accelerating potential the following experimental procedure was adopted. The plate potential was set at a given value and the grid potential was made 4/3 of it. The temperature of the filament was adjusted to give 1 milliampere emission. Then, while the filament current was on but the plate and grid potentials off, the plate was heated to about 1600°K for 1 min. The plate and grid voltages were applied and at the end of 3 min. the emission and plate currents were observed. This was repeated for increasingly greater accelerating potentials up to 2000 volts. At the end of a run the plate current was again observed for the plate potential of 350 volts. If the current did not check its initial value to within one percent the data were discarded.

This run was repeated with the tube four times, two of them were made after the tube had been opened up and re-exhausted each time. The degree of vacuum differed some in the five determinations, but tests using the tube as an ionization gauge indicated that the pressure was lower than 10^{-7} mm Hg.

We are assuming that the electron current is divided between the grid and plate in the same ratio that the positive ion current was found to be distributed as previously reported.[15] Taking 0.724 milliamperes as the primary electron current to the plate for an emission current of 1 milliampere, we find the secondary electron current by subtracting the observed plate current from 0.724, or by adding it to 0.724 if the plate is losing more secondary electrons than it is receiving primary. This secondary current divided by 0.724 gives the number of secondary electrons per primary electron at the plate.

Results

The curve in Fig. 2 shows the number, n, of secondary electrons, I_s, per primary, I_p, as a function of the accelerating potential, that was calculated from observations made under the best vacuum conditions that we had. There was no measurable trace of gas present in the tube during the run. The maximum value of n for molybdenum, 1.25, reported by Petry[14] is comparable with our value but it occurs at about 360 volts instead of about 600 volts as Fig. 2 shows. Points calculated from data taken in various other runs are also shown in the figure. The amount of gas present in the tube before it was immersed in the liquid air was slightly different in each case. The general shape of the curves is the same, but the secondary emission is less when the gas in the tube has not been cleaned up so well.

In order to determine whether there were any discontinuities in the secondary emission curve, observations were made with a commutator in the circuit to turn off the filament current while the grid and plate potentials were applied. This insured an equipotential surface over the cathode. The plate had been heated thoroughly and the tube was immersed in liquid air. Readings of the emission and plate currents were made at intervals of 1 volt for the accelerating potentials. The run was not completed in one day but was pieced

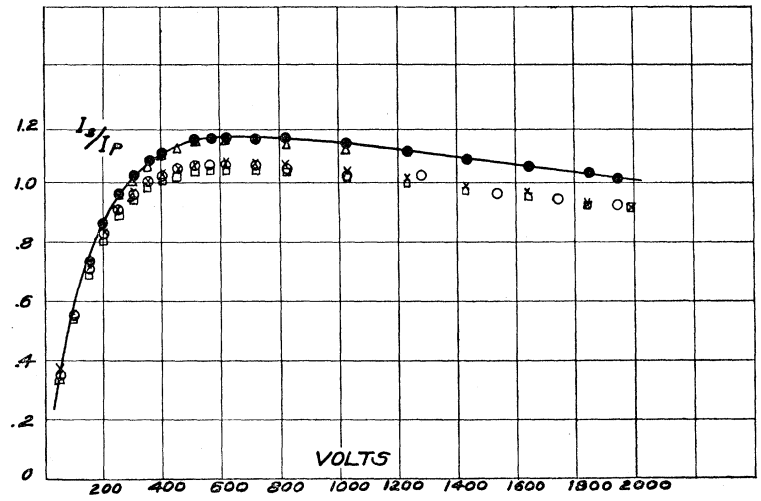

Fig. 2. Number of secondary electrons per primary as a function of the accelerating potential. Run 1, marked with circles, was taken when the tube contained a slight amount of gas before immersion in liquid air. Run 2, marked with squares, was taken when the tube contained slightly more gas than in Run 1. The tube was immersed in liquid air. Run 3, marked with crosses, was taken after the tube had been re-exhausted. The tube was immersed in liquid air. Run 4, marked with triangles, was taken after the tube had again been re-exhausted, with the tube on the pump and not immersed in liquid air. Run 5, the curve marked with black circles, was taken after the tube had been withdrawn from the pump and immersed in liquid air. No measurable trace of gas was found at the end of the run.

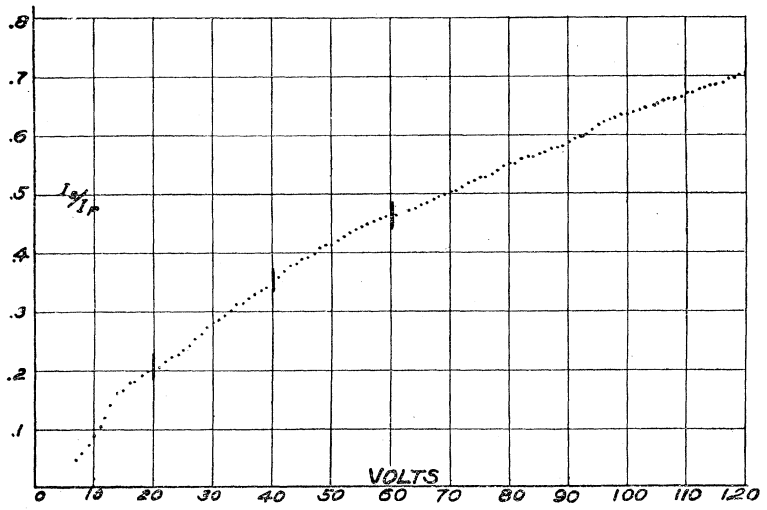

Fig. 3. Secondary emission data taken with equipotential cathode and at 1 volt steps. The parts of the curve between the vertical dividing lines were taken at different times.

together from data taken on several days; care being taken that former observations were checked by the new ones. However, in spite of these precautions, there are discontinuities where the data overlap. Fig. 3 shows that there is only one outstanding break which comes at 13.5 volts. The other small changes in the slope are probably of the same order as the experimental errors. The break at 13.5 volts was reproduced in different runs, but the others were not. Even though the surface was as free of gas as it is probably possible to make it and the vacuum conditions the best obtainable, it does not seem worth while to attach any significance to the breaks in the curve.

Change in I_s/I_p With Time

It was observed that the plate current changed with time after the plate had been heated to a bright red heat. After the data shown in Fig. 2 had been obtained, the plate was heated to about 1600°K for one minute and then the plate and emission currents were recorded at the end of definite time intervals for an accelerating potential of 350 volts. The calculated values of I_s/I_p are

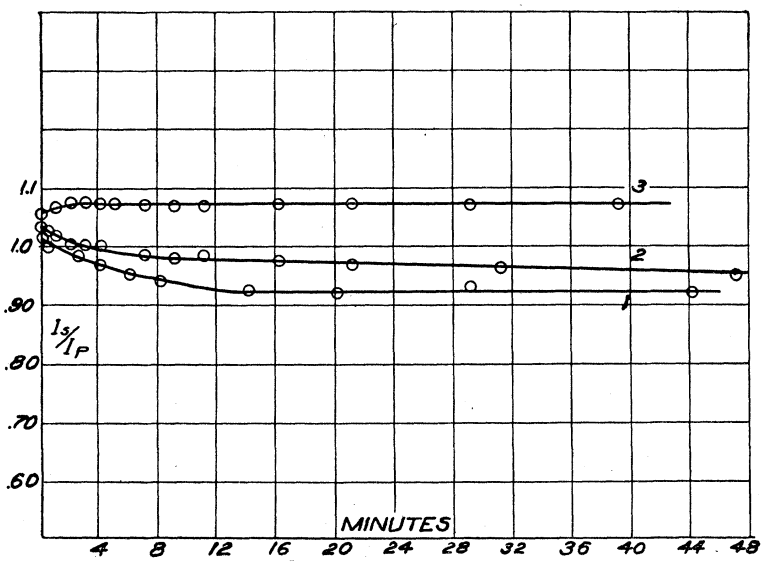

Fig. 4. Change in secondary emission with time after the plate started to cool. Curve 1 was taken immediately after Run 2, Fig. 2; curve 2, after Run 3, Fig. 2; curve 3, after Run 5, Fig. 2.

plotted in Fig. 4. The change in I_s/I_p was probably due to the re-absorption of gas on the plate. When there was a small measurable trace of gas present, I_s/I_p decreased with time and the more gas present, the more rapid the decrease. When there was no measurable trace of gas present, the ratio increased slightly for the first 2 minutes and then remained constant for a period of 40 minutes.

Change of Secondary Emission with Temperature

It was found possible to make determinations of secondary emission while the plate was being heated to incandescence by the high frequency furnace. The tube circuits present a high impedance to the radio frequencies at which the furnace operates. When the furnace was turned on and off, no change in the reading of the instruments could be detected before the plate had time to change appreciably in temperature. With the tube immersed in liquid air, the emission and plate currents were observed at 20 sec. intervals from the instant the furnace was turned on. The plate reached its equilibrium temperature of approximately 1600°K in about 30 sec. The calculated I_s/I_p ratio is shown in Fig. 5, curve 1. The data shown in curve 2 were obtained a few minutes after the completion of the first run.

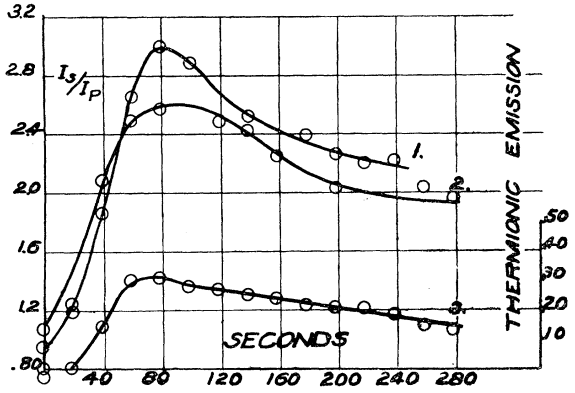

Fig. 5. Curves 1 and 2, secondary emission from plate while being heated; curve 3, thermionic current from plate while being heated with filament cold.

It seemed probable that thermions as well as secondary electrons were being liberated from the plate at this temperature. While the plate was being heated with the filament cold, the plate current was observed as a function of time. This thermionic current from the plate is shown in curve 3, Fig. 5. It is significant that the maximum of the curve coincides with the maximum of the I_s/I_p curve. The change with time must be due to driving off the absorbed gas from the plate.

In order to correct the observed current for the thermionic emission from the heated molybdenum plate, the following experiment was performed. After the plate had been thoroughly heated and cooled to its equilibrium temperature I_s/I_p was determined. The plate was then heated to incandescence for several minutes until a steady value of the plate current was obtained. This plate current and the corresponding emission current were recorded. Then, without turning off the furnace, the filament current was turned off, and the thermions that were liberated from the plate were collected by the grid; since the grid potential was 4/3 that of the plate. The former plate current, obtained with the filament heated, was then corrected for the

thermions from the plate. The results of this determination for an accelerating potential of 300 volts give values of I_s/I_p for the cold plate of 1.10 and for the hot plate of 1.14. This shows a change of 3.6 percent in the secondary emission and, if the surface could be entirely cleaned, the indications are, that the change would be zero.

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