California Institute of Technology

Pasadena, California

SECONDARY EMISSION FROM METALLIC SURFACES DUE TO POSITIVE ION BOMBARDMENT

Master Thesis of

Arthur L. Klein

1924

Made on cover in pink

Secondary Emission from Metallic Surfaces due to Positive Ion Bombardment

...

Arthur L. Klein.

Presented as partial fulfillment of the requirements for the degree of Master of Science, at the California Institute of Technology.

May 27, 1924

Secondary Emission from Metallic Surfaces due to Positive Rays.

This work was entered upon at the instance of Prof. R. A. Millikan. The purpose and importance of the work is best seen by considering the various means of ionizing an atom in the solid state. The various methods are:

1. Thermal. (Temperature ionization).
2. Exposure to radiation. (Photoelectric Effect).
3. Strong potential gradients.
4. By bombardment.

The fourth topic may be subdivided by considering the various bombarding agencies as follows:

a. Electrons.
b. Positive ions.
c. Neutral projectiles.

The effect of electron bombardment is well known due to the work of Millikan and Barber, McAllister, and others, while the effects of positive ions are comparatively unknown. The fact that secondary emission due to positive ion bombardment occurs at high primary energies is well known, but the minimum amount of energy necessary to remove an electron from a given surface, the number of electrons removed per bombarding positive at any energy, and as to whether secondary positive emission occurs at low energies, are all unknown. The subject of ionization due to neutral projectiles is still more nebulous, but it is out of the field of this particular problem.

It will probably be best at this point to take up the history of the case of positive bombardment. The second-

ary emission due to positive rays has been studied by many persons. Tuchtbauer,(1), Campbell,(2), Saxen,(3), Glimme and Koenigsberger,(4), Saxton, (5), Hahn,(6), and especially Baerwald,(7) have studied the matter. Baerwald has studied particularly the secondary emission due to slow canal rays (7b) and he found a series of relations between the secondary emission and the primary, which he set forth as follows:

1. The quantity of secondary emission is proportional to the primary intensity.

2. The velocity of the secondary radiation is independent of the primary intensity and depends only on its velocity.

3. The existence of secondary radiation could be detected with primary velocities as low as 900 volts and in this case its velocity was from 4 to 6 volts.

4. The amount of secondary radiation was found to be independent of the material of the target and to depend only on the intensity of the primary beam.

His results also seemed to indicate that emission took place with a primary potential as low as 20-30 volts, altho the curve becomes asymptotic and does not break off suddenly. The invariance of the secondary emission with respect to the material of the target, seems strange in that we know that various materials have various work functions, and especially since McAllister (8) found that the secondary emission from new and old copper surfaces was different when they were bombarded by electrons. But perhaps this invariance is not so strange when we consider that Baerwald always worked at po-

tentials of the order of a 1000 volts and he might not have been able to detect the few volts difference in various materials.

Hahn's work is of great interest. He bombarded a thin piece of gold leaf with positive rays from a discharge tube and observed the emission on the rear side of the gold leaf. He found not only a large electron emission of up to eight electrons per incident primary ion, but also a secondary positive emission of perhaps three secondaries per primary. The piece of work was very brilliantly done, but unfortunately he was unable to work at low voltages and thus get the threshold value. These two pieces of work represent the present status of the problem.

EXPERIMENTAL DIFFICULTIES

The first and greatest difficulty that arises is the procurement of a steady and plentiful source of low speed canal rays. Altho Baerwald in his 1919 paper used a tungsten filament to supply his ions they appeared not to be very plentiful, as he had to use sensitive instruments to measure his effect, and even then was apparently only able to work at high voltages. The writer started out to use a platinum equipotential emitter consisting of a tube 3 mm in diameter and 6 cm long. This was very unsatisfactory, as after being exposed to the air and then heated, it would give a measureable emission for about twenty minutes and then go dead. During the twenty minutes the emission decreased exponentially. In the case of activation of the emitter with hydrogen it was a little better but still very far from being usable. This

method was quite impractical as the glass and metal parts could not be baked out without destroying a considerable part of the active life of the emitter.

At this juncture Langmuir and Kingdon (9) published their article on the effect of the vapor of caesium and the other alkali metals on the emission from a filament. This work indicated a solution of the problem of positive ion emission. Their method consists in the introduction of the metallic caesium into the apparatus, so that its vapor could come in contact with the filament. The vapor pressure of caesium as given by them is approximately 10^{-6} mm of Hg at 25°C., the caesium having an ionizing potential of 3.90 volts which is lower than the work function of tungsten, 4.52 volts, when a caesium atom approaches near to the tungsten, the tungsten robs the caesium of its valence electron, and the caesium ion remains absorbed on the tungsten, held by the strong electric attractive forces. It was then found that on heating the filament to about 600°C it would emit an electron current that would attain a saturation value of .3 amp/cm^2 of emitting surface. As the temperature increases the electron current decreases and at a temperature of 700°C neutral caesium atoms are evaporated. As the temperature is further increased positive ions are given off by the emitter. Above this critical temperature every caesium ion hitting the filament is condensed and re-emitted, the rate of production of positive ions is equal to the rate at which the atoms strike the emitter. On performing the obvious kinetic theory calculation, one obtains as the saturation current:

$$i_+ = 0.367 \frac{p}{\sqrt{T}} \text{ amp/cm}^2$$

It is found that the rate of production of positive ions is independent of the emitter temperature as long as it is above the critical value.

In using this method the caesium was made in a small combustion tube attached to the apparatus. The combustion tube was filled with a charge of metallic calcium and caesium chloride. When the tube was heated to a temperature of about 700°C a reaction occurred resulting in the production of metallic caesium. Thecaesium appeared as a golden metallic deposit in the cooler parts of the tube. Due to the small amount of the metallic vapor necessary, it sufficed to leave the caesium in the combustion tube as enough vapor would diffuse into the remainder of the apparatus.

This method worked well with tungsten emitters, but platinum was not very satisfactory as it did not last. The only difficulty with the method is that the caesium vapor forms a monomolecular layer over all metals whose work function is higher than 2.90. As the metal used for the target was nickel it became coated with a layer of caesium atoms. When the positive ion bombardment falls upon the target it does not hit the nickel but it hits the layer of caesium atoms, so that it is more or less of an open question as to whether the secondary electrons knocked off, come from the nickel or from the caesium. The writer hopes to determine the effect of this layer, by observing the emission from the target under electron bom bardment, with and without the presence of caesium.

Description of Apparatus

The first apparatus used was one similar to that of Millikan and Barber (10). It consisted of a cylindrical platinum equipotential emitter, 3 mm in diameter and 6 cm long, surrounded by three coaxial cylinders 10 cm long and of diameters 1.8 cm, 2 cm, and 3 cm respectively. We will call the first two of these cylinders A and B, and the third, the target or T. (See fig. 1.) All of our four cylinders being coaxial we will have a symmetrical field in between them, if we neglect the ends. Cylinder A had sixty-three 1 mm holes bored in it in nine rows of seven holes each, the rows being 7 mm center to center. These holes occupied a distance of 5.6 cm in the center of the tube. Tube B also had sixty-three holes bored in it to register with those of cylinder A, but these holes were 2 mm in diameter, so that an ion going through a hole in A would not be able to strike B. These two cylinders, A and B, thus form a system of grids, the second of which is completely screened from bombardment by the emitter. The radiation coming through the holes in A then strikes the target cylinder T and any secondary emission from it is caught by means of an accelerating potential upon the cylinder B. The problem then was to support these cylinders so that the holes in A and B registered, and yet to keep all of the cylinders thoroughly insulated from each other. The emitter consisted, as has been said, of a platinum tube. This tube was heated by a central tungsten wire 18 mils in diameter. The wire was placed in the tube and all of the space between it and the tube was filled with alundum cement. One end of the emitter was held rigidly from the glass bulb while the other was guided but allowed to expand by means of a phosphor-bronze leaf spring. This assembly was supported by means of a glass cage

consisting of two rings with three connecting parallel glass rods. Each cylinder was attached at each end to the corresponding glass ring by means of three tungsten wires sealed into the ring. This gave ample insulation and far too much rigidity, for when the apparatus was used the thermal expansion of the tubes broke the wires loose from their seals in the glass.

The second apparatus was then designed taking thermal expansion into account, and ease in removing the emitter. In this apparatus as in the previous one the glass cage was sealed to the end of the containing bulb, but the bulb was designed so that the entire grid and target system together with its supporting cage and seals could be removed en masse by breaking one large ring seal, in the same way that the filament can be removed from an ordinary electric light bulb.

The emitter was supported from the top seal and the bottom was guided by an eyelet supported from the lower glass ring. (Fig. 2.) A flexible lead went from the bottom of the emitter to the lower seal. In order to remove the emitter the two glass seals were cut and the emitter was lifted to disengage the spur from the guiding eyelet and the emitter lowered out through the hole where the nottom seal had been. The emitter in this design was the same as before except that there was no alundum filler inside of it, the heating taking place entirely by radiation. The tungsten wire was prevented from touching the platinum tube by means of quartz beads strung upon it. This design was very satisfactory except for the low melting point of the platinum.

Thermal expansion of the grid and target system was

allowed for in this apparatus by making the top supporting wires hairpin shape so as to allow for radial expansion, and by attaching straight wires to the lower ends, which passed through eyelet guides supported from the lower glass ring. This construction accomplished all that could be expected.

This apparatus failed because of the fact that so much energy had to be put into the emitter to heat it that the grid A was heated to a bright red by radiation. This caused it to expand so much that all of the holes in A and B did not register so that some of the primary beam hit B. Also because A was red hot it emitted electrons which were collected upon B and gave a spurious result. The apparatus was made of copper and it was found that on baking out some of the copper sublimed onto the glass walls of the vessel and onto the glass supporting cage, making it conducting and short circuiting the insulation.

The third and present apparatus was designed to overcome these difficulties. The new tube design (Fig. 3.) has a quite different appearance from the old. The apparatus is made entirely of nickel to obviate the difficulties with copper. Instead of having numerous holes we have one slot 1.5 mm wide going completely around the tube except for the small amount of metal necessary to hold the grid A together. This design has several advantages, it enables a short filament or emitter to be used, it allows a larger effective primary current to reach the target, it does away with the difficulties of registration, and it allows the use of an ordinary filament as the emission is all taken in at one place, and so is essentially equipotential. The grid or rather cylinder A is 3 cm in diameter and 10 cm long, the other cylinders are all 5 cm long. A is made longer so that it

will have more surface to radiate and thus remain as cool as possible. An additional grid C is used in this tube. It's purpose is to catch any radiation from A and prevent it from getting to B. This radiation may consist of two parts, that from the edges of the slit in A and that from A due to its being at high temperature. The cylinder C is 3.5 cm in diameter and 5 cm long, its slot is 3 mm wide. The small pieces of metal that hold C together are so placed in back of the corresponding ones of A that no radiation can strike C. The tube B really consists of two parts, B' and B", there is no connection between the two inside of the tube itself. They are 4 cm in diameter and are so placed that there is an interval of 6 mm between the two, thus enabling the primary rays to strike the target T without hitting either one of them. The target T consists of a tube 5 cm in diameter and 5 cm long.

These tubes are supported as in the second apparatus from a glass cage. The method of attachment of the wires to the glass is different from that used before. The wires from the upper ends of the grid and target system go to the ring and enter little glass cups into the bottom of which they are sealed. The cups make the leakage path longer and improve the insulation. At the lower end the wires enter the cups and enter holes in the bottom of the cups in which they slide and are thus guided to allow for thermal expansion.

The emitter in the new apparatus is supported entirely from the bottom. It can be withdrawn from the tube intact by breaking one seal about 4 cm in diameter. The emitter leads are carried through the glass by means of copper disk

seals, which allow the passage of heavy currents. The emitter itself is supported by a simple and compact arrangement of glass tubes as shown in the figure. The tube for the production of caesium is sealed onto the bottom of the emitter support.

So far two designs of emitters have been used in this tube. The first was a system of four parallel filaments of 10 mil tungsten wire. These filaments were quite satisfactory till they burnt out except that they did not make an equipotential source, and that they were very difficult to construct and repair. The second emitter was a thimble of platinum 4 mm in diameter and about 2.5 cm long. This emitter was rather satisfactory but didn't last well due to the low melting point of the platinum. In this design the current after traversing the interior filament comes back through the outside thimble. As the resistance of the filament is a great deal more than that of the thimble there is no appreciable potential drop along the thimble so that the emitter is practically equipotential. (See fig. 4.) The new emitter now under construction will be the same as the second design above, except that the thimble will be made of molybdenum.

This tube has behaved very satisfactorily except that there were impurities in the nickel which evaporated out, when the tube was in use and short circuited the insulation. These impurities seemed to consist of metals of rather low melting points, as they sublimed at 400°C. After this experience the metal parts of the tube were baked out to a red heat in an induction furnace, thanks to the kindness of

Mr. A. H. Warner. The tube was then washed in aqua regia to remove the deposits on the glass and it was ready to use again.

The evacuating system used for all of the tubes consisted of a Hyvac pump for the fore vacuum, a two stage diffusion pump, a McLeod Guage, and a liquid air trap. The evacuating system was quite satisfactory and produced a vacuum of less than 10^{-6} mm of mercury. This was more than adequate as it made the chance of collision occuring in the space between the emitter and the target almost infinitesimal.

The electrical apparatus used is without any particular interest, it consists of a Leeds and Northrup type HS galvanometer to read the secondary emission, a Leeds and Northrup type R galvanometer to read the current to the target, miscellaneous voltmeters and ammeters, several potentiometers and resistances, and a motor-generator set capable of delivering 1500 volts direct current.

Methods of Operation

The purpose of the research is to find out as much as possible about secondary emission due to positive rays. The two most important things are the relations between the secondary intensity and velocity, and the intensity and velocity of the primary. In determining the intensity of the secondary emission as a function of the primary energy, the two collectors B' and B" are connected together and kept at a slight positive potential with respect to T. (Fig. 5.) The ions emitted from E are accelerated to A and then further accelerated thru C and hit T, the electrons emitted from T are collected at B by the slight positive potential and the

secondary current is read in G_2. The galvanometer G_1 reads the sum of the primary and secondary currents, while galvanometer G_2 reads only the secondary current. Consequently the ratio of the secondary current to the primary current, or briefly, secondary electrons per primary ion, is given by $\frac{G_2}{G_1 - G_2}$. The field between A and C is simply to keep A enough positive so that any electrons emitted from A will not get thru the slit in C and be collected by B. C being very much cooler than A and not being in the direct beam will not emit any appreciable quantity of electrons.

For the measurement of the velocity of secondary electrons the wiring shown in Fig. 6 is used. This is just the same as before except that B' is separated from B" and that both B' and B" are given an increasing negative potential. B" is maintained slightly more negative than B' in order to force the electrons to B', so that a true stopping potential method may be used. With this connection no electrons can escape down the plane of symmetry between B' and B". By adjusting the potentiometer P_4 we will find the best value so that we get a maximum reading of G_2 for any retarding potential.

To determine the photoelectric current from T due to illumination from the emitter, the emitter is made about 180 volts positive, A is made 120 volts positive and C is grounded. Then if B is made slightly negative, the galvanometer G_1 will read the photoelectric current from T.

The results from this work so far have been rather meager. The most important being that quite large positive currents can be obtained by the caesium method. There is some

evidence that secondary electron emission occurs at primary velocities as low as 30 volts. The method shows great promise and will undoubtedly give satisfactory results in the future.

The writer wishes to thank Messrs. J. Pearson and W. Clancy for their invaluable help in the design and construction of the apparatus used in this problem.

Bibliography

(1) Fuchtbauer a. Phy. Zeit. S 153 & S 748 1906

b. Ann. Phy. 23 S 308 1907

(2) Campbell a. Phil. Mag. 22 276 1911

b. " " 23 46 1912

(3) Saxen Ann. Phy. 38 319 1912

(4) Glimme and Koenigsberger Zeit. f Phy. 6 276 1921

(5) Saxton Phil. Mag. 44 809 1922

(6) Hahn Zeit. Phy. 14 355 1923

(7) Baerwald a. Ann. Phy. 41 643 1913

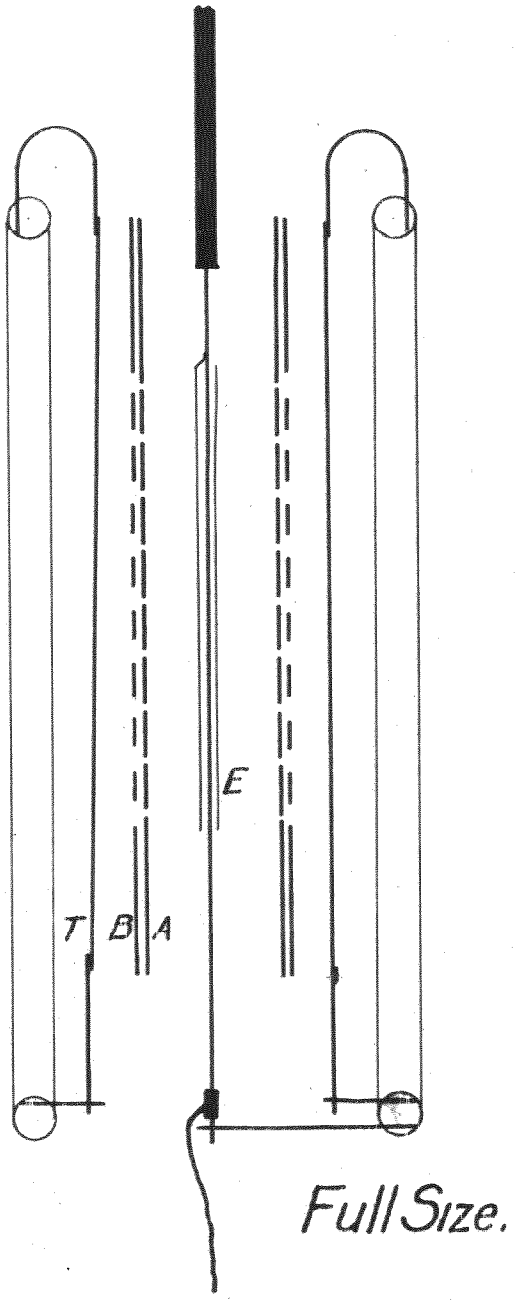
b. " " 60 1 1919

c. " " 65 167 1921

(8) McAllister Phy. Rev. 21 122 1923

(9) Langmuir and Kingdon Science 157 58 1922

(10) Millikan and Barber Pro. Nat. Acad. 7 15 1921



Figs. 1&2.

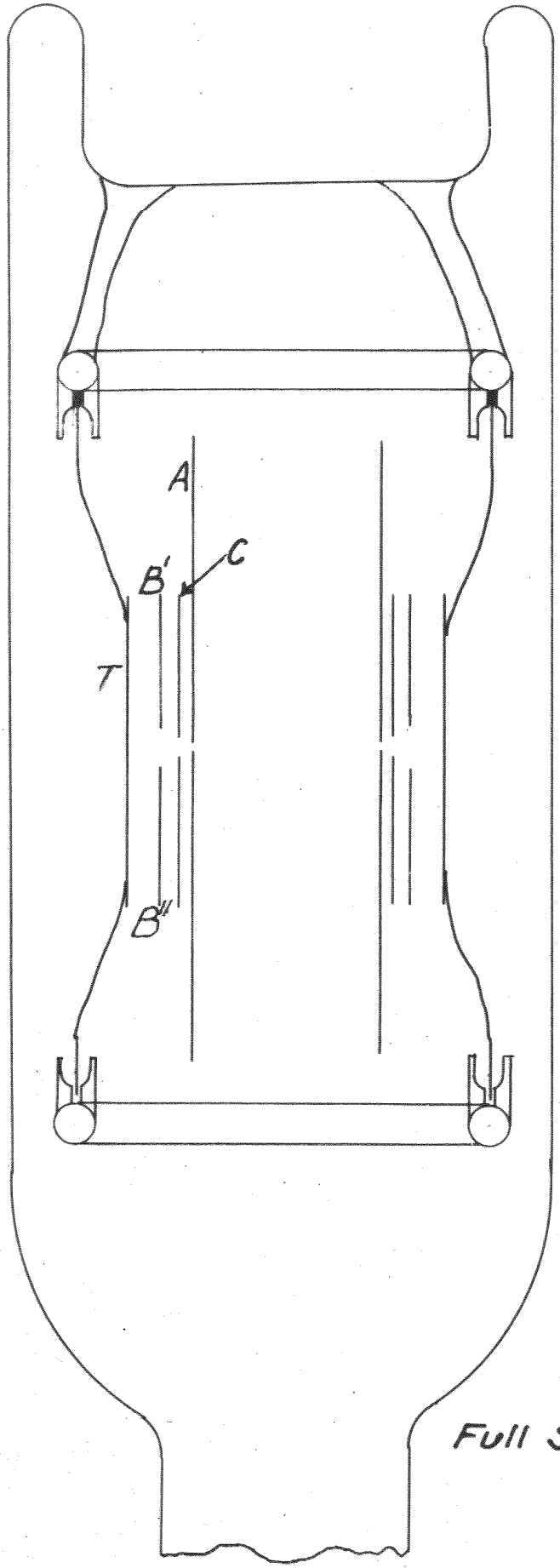


Fig. 3.

Filament Support.

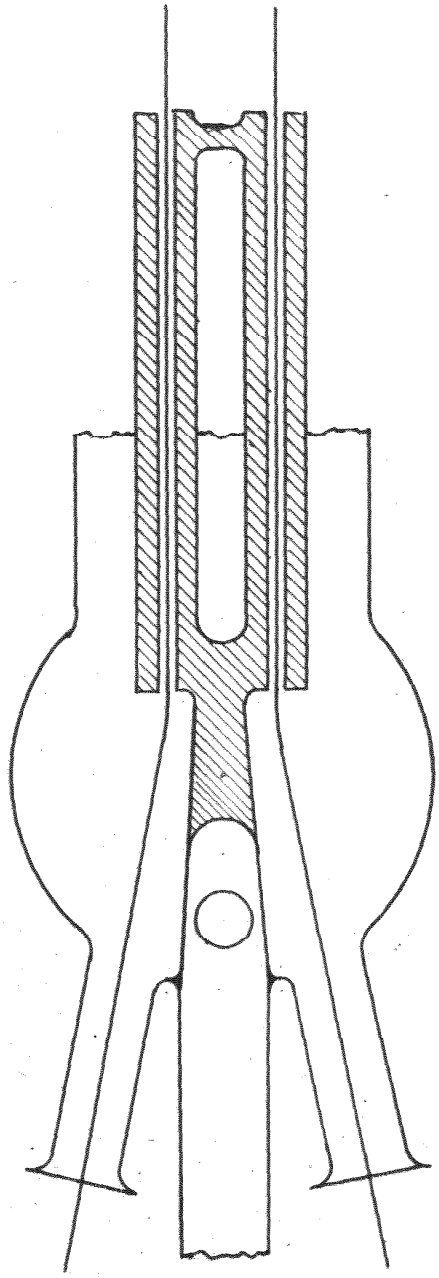
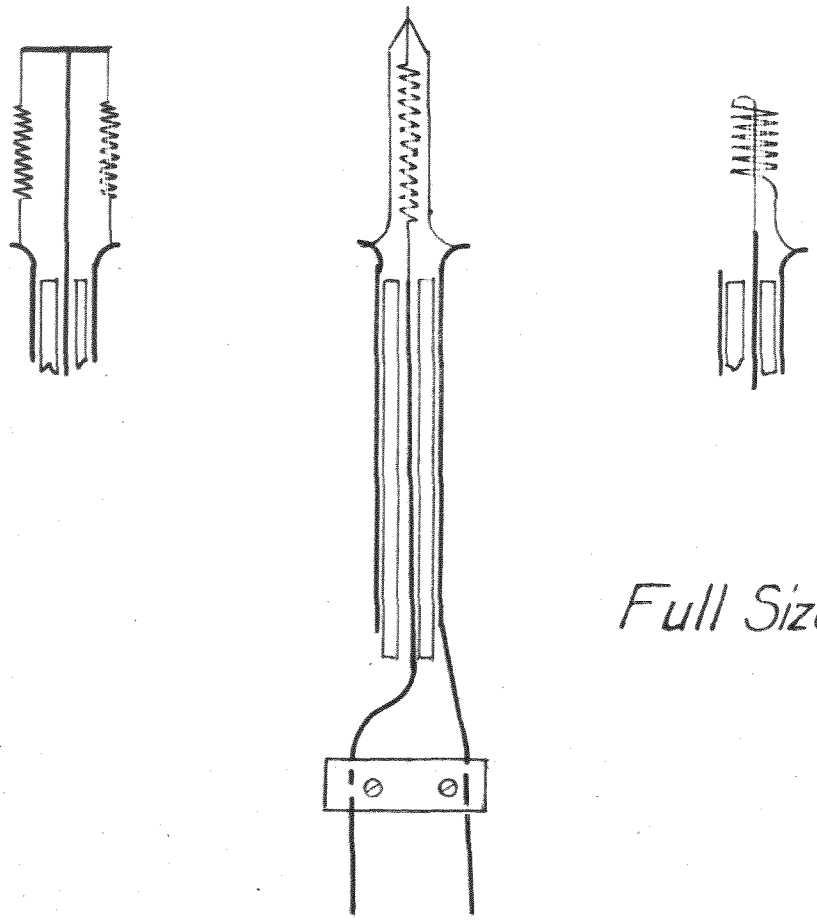


Fig. 3a.



Full Size.

Three Emitter Designs.

Fig. 4.

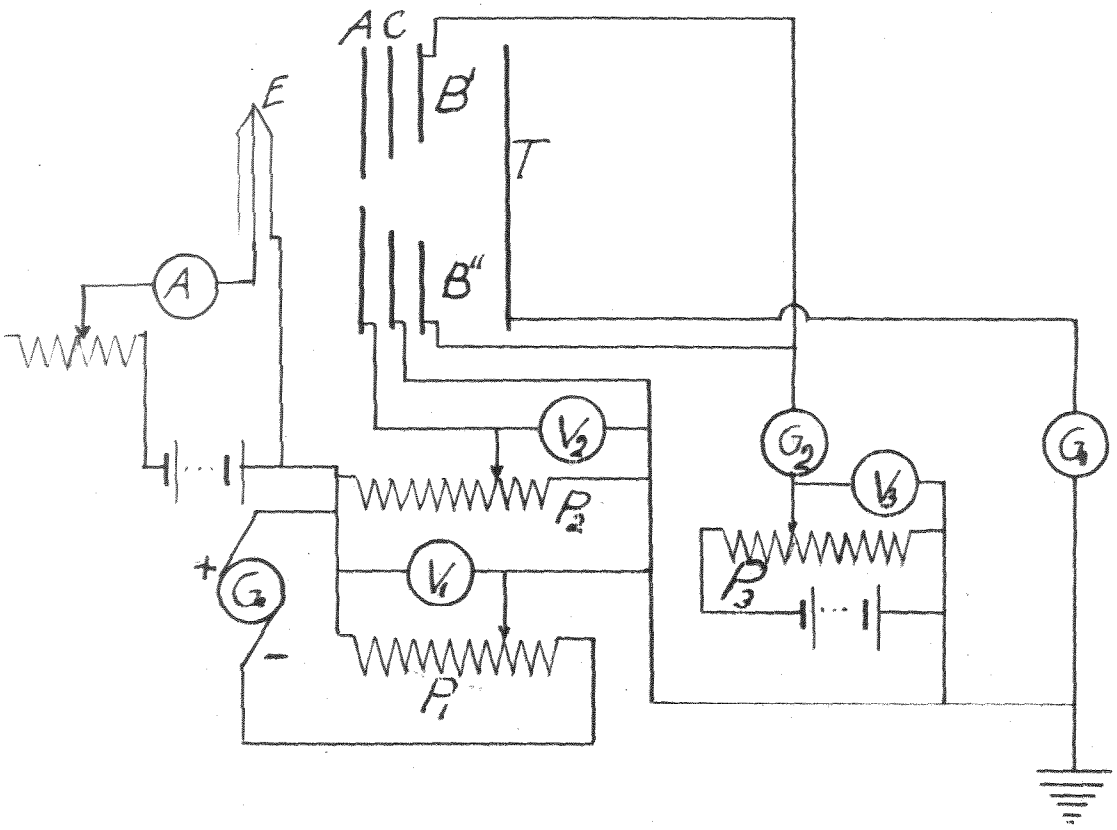


Fig. 5.

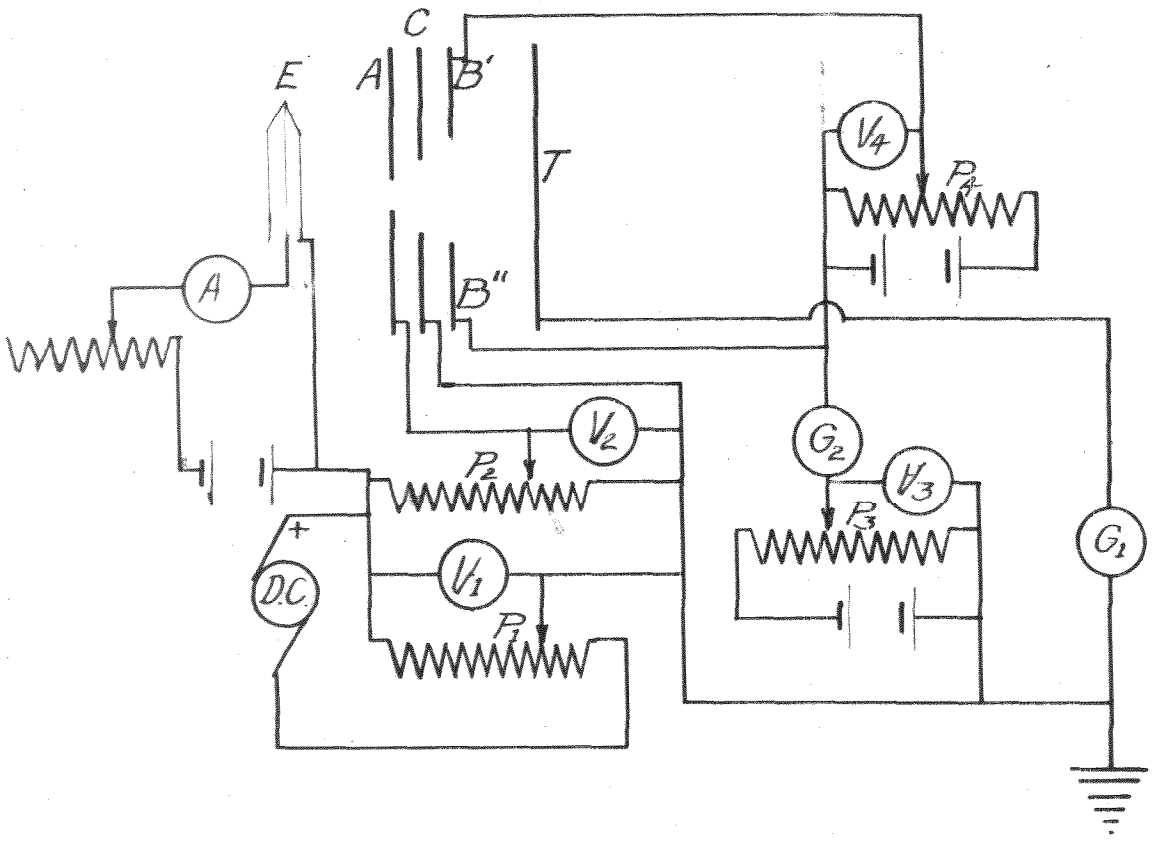


Fig. 6.