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A method of quantitative chemical analysis using a photon counter

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NOTE TO USERS

A METHOD OF QUANTITATIVE CHEMICAL ANALYSIS USING A PHOTON COUNTER

By

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INTRODUCTION

Introduction

The use of spectrum analysis in qualitative and quantitative chemical determinations has become increasingly important within the last few years. Previous to that time its use was largely restricted to that of a qualitative nature. With the development of more reliable methods of quantitative spectrum analysis, and with the increasing importance placed upon the control of small concentrations of elements present in alloys and similar industrial products, the importance of spectrum analysis to the chemist has increased tremendously.

Review of Literature

The successful application of spectrum analysis to quantitative determinations of the elements depends upon an accurate measurement of the intensity of the characteristic spectrum line or lines of those elements. Numerous methods have been developed for measuring such intensities. Most of these methods are dependent upon the use of the photographic plate as a recording medium. In most cases the intensity of the characteristic line or lines is compared with some standard intensity. One of the first methods developed was that of Ger-

loch (1) known as the "internal standard" method. This was later modified by Gerloch and Sweitzer (2)(3) to depend upon the comparison of intensities of "homologous pairs" of lines. Schiebe and Neuhasser (4) and later Twyman and Fitch (5) and Twyman and Simeon (6) used a logarithmic sector for measuring variations in intensities. Lundegardh (7) describes a method in which a photoelectric cell and amplifier are substituted for the photographic plate. He excites the powdered sample by using an oxyacetylene flame. These and numerous other methods have been improved and are still in the process of improvement. Rather complete surveys with bibliographies of the recent progress of quantitative spectrum analysis and its application to special problems can be found in reviews by Schleicher (8) and Waibel (9).

When a Geiger-Müller (10) tube is modified by the addition of a window and a light-sensitive surface, it becomes an extremely sensitive instrument for measuring small intensities of light. The incident light striking the sensitive surface of the cathode causes photoelectrons to be emitted. Each of these photoelectrons ionizes the surrounding gas in passing from cathode to anode. This ionization results in a drop in the resistance between the electrodes, causing a small discharge which can be amplified and recorded. Thus the number of discharges or of resulting impulses per unit of time is a measure of the incident light.

Rajewski (11) developed a counter with which he was able to detect 12 quanta of light per cm^2 per second at 2650 A. He reported detection of light from mito-genetic rays and from photochemical reactions. However, the cathodes of his counters were so large that they had a large "dark rate". This spontaneous counting while in darkness is due to radioactivity, cosmic rays and similar types of radiation. Such a large dark rate is objectionable as it is subject to numerous variations, and prevents the detection of very small light intensities whose count would be superimposed upon such a background.

Locher (12) reduced this "dark rate" to as low as 0.7 per minute for copper and silver. He used smaller, cylindrical cathodes (having a length of about 11 mm. and an internal diameter of about 7 mm.) and yet retained the sensitivity obtained with the larger ones. Longitudinal slots about 4.5 mm. wide were sawed along an element of each of the cylinders to admit the light. The minimum intensity which he could measure was about 1/20,000 of that obtainable with a photo cell and electrometer. He obtained his best results with cathodes of silver and copper.

Ollano (13) constructed a number of counters having various types of cathodes with which he obtained sensitivities of 10^3 to 10^6 quanta per cm^2 per <u>minute</u>, depending upon the cathode materials and the wave length of the incident light.

Hausser and Kreuchen (14) tested the sensitivity of their

photon counters by passing the light from a standard Hg lamp through a double prism quartz monochromator. The intensity of the 2537 A Hg line at the second slit was measured with a thermopile and found to be 1×10^{13} quanta per sec. When subjected to this intensity the photon tubes gave about 10^9 impulses per second which was much faster than could be counted by mechanical means. By inserting a double quartz reflector between the second slit and the photon tube, the initial intensity of 10^{13} quanta per second was reduced to a value that could be registered by the counter. Sensitivities of 10^4 to 10^6 quanta per cm^2 per second at 2537 A were found for Cd and Zn cathodes. Karev and Rodionov (15) by much the same method obtained a sensitivity for Al cathodes of about 10^8 to 10^9 quanta per second at 2537 A. Reiss (16) subatituted a bolometer for the thermopile. He found the sensitivities of Cd photon cells to vary from 10^4 to 10^7 quanta per second depending upon the method of construction and the wave length of the incident light.

Strum (17) did not use cylindrical cathodes but used a flat plate with a platinum point as an anode. He measured the intensity of the incident light in much the same manner as Karev and Rodionov. The sensitivity of his counter tubes varied from 10^{-9} to 10^{-10} ergs per cm^2 per second.

Recent work by Kreuchen (18) checks that of previous tests

especially in the region of 2500 A. He extended the measurements of sensitivity into the extreme ultra violet by use of a vacuum spectrometer. Apparently most cells become more sensitive with decreasing wavelength. Audubert and Reithmuller (19) and later Audubert (20) made numerous tests of the spectral sensitivity of the various cathodes used in photon counters. In most cases the maximum sensitivities were obtained in the region of 2500 A. They constructed and tested 50 cells. All had a sensitivity of at least 5×10^{-6} ergs/cm^2/sec., twenty a sensitivity of 5×10^{-8}, six a sensitivity of 5×10^{-10}, and two a sensitivity of 5×10^{-11}.

There appears to be a gradual increase in the sensitivity of photon cells as the technique of constructing and using them is improved. However, one appears to be justified in assuming that a sensitivity of 10^{-8} ergs/cm^2/sec. is quite possible for a photon counter.

Problem

The sensitivity of the photon counter for measuring small light intensities is indicated by the above survey. The photon counter also measures the total light flux per unit of time for a given period. These two characteristics have suggested its use in measuring intensities in quantitative spectrum analysis. The present investigation was undertaken in an attempt to

adapt the photon tube to the quantitative chemical analysis of a simple compound. The work necessitated the construction of a suitable photon tube with amplifier, a source of high, direct current voltage, and a counting mechanism for recording the impulses. It was also necessary to develop a method of using the counter to measure intensities of spectroscopic magnitude.

EXPERIMENTAL

Description of Apparatus

Excitation unit.

The graphite electrodes containing the sample are held in an adjustable holder. An optical focusing arrangement is used to align the electrodes with the slit of the monochromator. The power for exciting the arc is obtained from a set of lead storage cells. The total potential obtainable is 114 volts. A variable resistance is connected in series with the arc enabling one to adjust the amperage through the arc. The intensity of the light from the arc must be adjusted to fall within the effective counting range of the photon tube by varying the distance between the arc and the slit of the monochromator. This use of the inverse square law as a means of adjusting the intensity allows one to dispense with any other photometric device for decreasing the intensity.

Monochromator.

A Gaertner single prism, constant deviation type of quartz monochromator was used. The monochromator, photon tube, amplifier, and counting mechanism are shown in Fig. 1. A schematic arrangement of the apparatus is shown in Fig. 2.

Photon tube.

Several types of photon tubes were constructed similar to those described by Rajewsky (21) and Locher (12). The tube shown in Fig. 3 which was used for most of the work on this problem is similar to that of Locher. The outer jacket of the tube is made from 48 mm. pyrex glass. A quartz window, cemented upon the end of the tube, allows the light to enter. The inner tube supporting the cylindrical cathode is of 12 mm. pyrex tubing. The ground glass joint, sealed with piscein wax, allows the cathode cylinder and its supporting tube to be removed. The cathode cylinder which is about 11 mm. in length and 7 mm. inside diameter has a 2 mm. slit cut along an element of the cylinder allowing the light to enter. The cylinder is held in a special clamp to allow for adjustments in centering it about the anode wire. Electrical connection is made to the cathode by means of a 40 mil tungston wire sealed through a Nonex glass bead and brazed to a copper lead. This copper lead is soldered to an ordinary grid cap. The wire anode is held taut by a spring made from 8 mil platinum-iridium wire. Twenty mil tungston wire is sealed through the pyrex glass and connected to special grid caps. Small hooks on the end of the tungston wires allow the replacement of the anode wire and spring. Five mil platinum wire carefully polished with rouge was used for the anode wire. A side arm connects the photon

tube to the vacuum system.

A Cenco Hyvac oil pump and an electrically heated mercury diffusion pump are used to evacuate the tube. A mercury manometer is included to control the pressure of the gas admitted to the system. A two-way stopcock allows one to admit to the tube any gas desired. When a new electrode is placed in the tube, the tube is evacuated, "baked out" as thoroughly as possible with a hand torch, and allowed to cool. A small induction coil is connected across the electrodes and dry hydrogen gas is admitted to the tube. The pressure of hydrogen is so adjusted as to obtain a glow discharge at the cathode cylinder, about two minutes being sufficient time for its sensitization. The tube is again evacuated, then filled to the desired pressure with helium gas.

Air, nitrogen, argon and helium were tried in the counter. Of these, helium appears to be the most satisfactory and is the gas used in the tube at the present time. Although the pressure is not a critical factor, various pressures from 2 cm. to 14 cm. were used, 8 centimeters being maintained throughout the recorded experimental work. Electrodes of copper, silver, magnesium, nickel and brass were tried. For wave lengths in the region of 2500 A, the silver cathodes are most satisfactory. They have a lower "dark count" and a greater sensitivity than any of the other metals tried with the possible exception of

copper. An added advantage of silver is the ease with which any oxide formed in polishing or handling can be reduced when subjected to the glow discharge in hydrogen.

When in use the tube is surrounded by a metal case which acts as an electrostatic shield and also prevents stray light from entering the cell. However, when working in the region of 2500 A, the amount of light transmitted by pyrex is negligible. The tube and entire vacuum system are assembled in one unit, in order that they may be moved when necessary.

High voltage source.

The potential required for the field of the counter tube is furnished by a direct current power pack similar to that described by Schmitt (22). The circuit is shown in Fig. 4. The power transformer has a maximum potential of 2,000 volts across the secondary. Half-wave rectification is obtained by an 866 mercury vapor rectifier. The filter system consists of two 300 henry, 15 ma. chokes and three 1 m.fd. condensers. All transformers and condensers are insulated for 2000 volts. Voltage fluctuations are reduced by use of a '57 tube as a voltage regulator. It is biased by a 90 volt B battery. Fluctuations in voltage are negligible even for line voltage variations of 10 - 15 volts. The output voltage can be varied from zero to nearly 2000 volts by means of the two mechanical-

ly coupled potentiometers P_1 and P_2 and by means of the two rheostats R_5 and R_6. The output voltage is measured by a 0-1 milliammeter in series with a megohm resistor. The maximum current output of this rectifier is quite small but as a low current, high voltage source it is quite reliable. All parts of the rectifier are mounted on bakelite and enclosed in a metal case as shown in Fig. 5.

Amplifier.

The impulses from the photon tube are very small, making it necessary to have a sensitive amplifier to detect and record them. Several types of high gain amplifiers were tried. The one finally adopted is a modification of that used by Locher (23). The amplifier consists of a two-stage resistance-coupled circuit as shown in Fig. 6. A high gain 257 tube was used in the first stage and a 2A5 in the second stage. The latter was used to drive the speaker and the counting mechanism.

The photon counter is connected to the amplifier by a 10 μμ fd. condenser. A 300 megohm resistor is connected in series with the photon tube and the high voltage power pack. The operation of the counter is as follows:

> Initially the resistance between cathode and anode of the tube is quite large. When a photoelectron is emitted by the cathode surface, it starts across to the

anode. Due to the large potential difference between the electrodes the electron ionizes the gas which lies along its path. This ionization decreases the resistance across the tube causing the voltage drop between the electrodes to become small compared to that across the 300 megohm resistor. The helium gas deionizes and the resistance and voltage across the tube increase again to their former values. The time constant for this rise depends upon the product of the capacity of the condenser and the ohmage of the resistor. It is about 3×10^{-3} seconds for this circuit.

The filter system shown for the grid bias resistor is found necessary to reduce "feed back" into the 257 tube. The screen and plate circuits are also well filtered. The power supply for the amplifier including transformers and filter system is removed to a distance to prevent the amplifier from being affected by induced currents and mechanical vibrations. All leads from the high voltage source, photon tube and power pack are shielded and the shield grounded. By having the speaker connected in the plate circuit of the 2A5 the impulses passed on to the counting mechanism may be noted. The amplifier was checked with an oscillograph. The impulses from the photon tube are very sharp and definite after amplification as long as the number of impulses per second does not exceed

seven to eight hundred. For a large number, a second impulse may start before the gas in the photon tube has completely deionized. This results in a "drawling" of the impulses with subsequent difficulties in recording.

Counting mechanism.

Thyratron "Scale of Two" circuit. Since the impulses from the amplifier are at times more rapid than can be resolved by the mechanical recorder, it is necessary to have some means of reducing the number of counts per unit of time to such a value as can be recorded. The Wynne-Williams (24) "Scale of Two" thyratron counting circuit offers such a mechanism, since the impulses entering the counter are reduced by a "scale of two" for each pair of thyratrons employed. In the counting mechanism whose circuit is shown in Fig. 7, a modification of the Wynne-Williams circuit was used. Four thyratrons were used, thus requiring four impulses from the amplifier to complete the cycle in the last pair of thyratrons.

In the following paragraphs the operation of the thyratrons is explained. Assume that there is initially an arc across thyratron A, and that thyratron B is extinguished. When a positive voltage is applied to both grids of the thyratrons, an arc is struck in B which results in a sudden drop in its anode potential from about +220 to +15 volts. The resulting

negative surge in B is transferred through the condenser C_{AB} to the anode of A, causing the voltage to drop to such a value as to extinguish the arc in that thyratron. The next impulse causes A to arc and B to be extinguished thus completing the cycle. If we consider a series of impulses such as 1, 2, 3, 4, 5 and 6, thyratron A can be said to respond to odd impulses 1, 3 and 5 and B to even impulses 2, 4 and 6.

If now we connect a second pair of thyratrons C and D, to the first pair through the resistance Z, we will have a positive impulse transmitted to the second pair every time that B arcs. Thus on every even numbered initial impulse, an impulse is transmitted to C and D. This pair in turn takes two impulses to complete a cycle. If even numbered impulses 2, 4, 6 and 8 are transmitted by B to the second pair, the thyratron C will respond to 2 and 6 and D will arc on 4 and 8. Thus four impulses must be applied to the counter in order that thyratron D complete a cycle.

The magnetizing coils of the mechanical recorder are connected in the anode circuit of the last pair of thyratrons. Each time that C or D arcs, the anode current energizes the coil in that particular anode circuit: when extinguished the current ceases to flow.

Mechanical recorder. The mechanical recorder used is a modified form of that suggested by Van den Akker (25) for count-

ing impulses from a Geiger-Müller tube. It is shown in Fig. 8. It consists of two permanent magnets between whose poles a small vibrator of transformer iron is placed. The vibrator is prevented from touching the poles by two small brass stops. Around the vibrator is placed a helix composed of two separate coils of wire. These coils are wound simultaneously and contain the same number of turns. Each coil consists of approximately 70,000 turns of No. 36 enameled copper wire producing a d.c. resistance of 12,000 ohms. Each of these coils is connected in the anode circuit of one of the last pair of thyratrons. If one of the thyratrons is glowing, the plate current flowing through the coil in its anode circuit causes the end of the vibrator to become a south pole which is therefore repelled by the south pole of the permanent magnet and attracted by its north pole causing the vibrator to move across to the latter pole. The coil in the anode circuit of the other thyratron is so connected that the anode current flows through it in the opposite direction. When this thyratron glows, an opposite polarity is induced in the vibrator and it is driven in the opposite direction. Thus as first one and then the other of the last pair of thyratrons is lighted the vibrator is driven from one pole to the other of the permanent magnet.

The movements of the vibrator are recorded by a stop watch. The balance wheel of the watch is removed and the end of the vibrator connected to the escapement lever of the watch.

A movement of the vibrator actuates the escapement lever allowing the hands of the watch to move one unit on the scale or dial which reads in tenths of a second. A reading of 1 second corresponds to 10 vibrations or impulses from the photon counter. This counter will easily record 60 cycle current, i.e., 120 vibrations per second.

Possible improvements in apparatus.

Several improvements in apparatus have been suggested by work with the apparatus and by recent publications. The high voltage power source could be much simplified and the B batteries eliminated by the use of neon lamps to secure a constant voltage bias as suggested by Gingrich (26). The "Scale of Two" thyratron circuit might be improved by adopting the modifications suggested by Lewis (27). It would be more convenient if one used a photon tube without ground joints and wax seals. Figure 9 shows such a tube constructed with a Corex D window sealed to pyrex. The tube, filled with 8 cm. of helium gas and sealed, has a sensitivity at 3000 A comparable to the tube described above, but the Corex D window will not transmit light of as low a wavelength as 2347 A for which a tube with a quartz to pyrex graded seal would be quite desirable.

Method of Procedure

Preparation of electrodes.

The electrodes are made from graphite purchased from the Acheson Graphite Corp. This graphite is made especially for spectroscopic work. Rod 1/4 inch in diameter is used to prepare the electrodes. The upper electrode is a piece of this rod cut square across the end. The lower electrode has a cup in the end to hold the material to be analyzed. This cup is cut by a drill bit held in a special jig. Several types of lower electrodes were tried. The two types shown below were found to be most satisfactory.

Type A is that used by Dr. H. A. Wilhelm of this department for work in quantitative spectrographic analysis. Type B is a modification of Type A used to cut down the time necessary to completely burn the cup. Both types are prepared in special jigs to secure uniform dimensions and shape. Such uniformity is necessary as a small variation in an electrode will change the

excitation conditions within the arc. After shaping, the electrodes are heated to a bright red with a gas-air torch in order to secure more uniform absorption in the following operations. After cooling, the small neck of the electrode and the bottom of the cup are treated with a solution of pyrolin dissolved in acetone. This treatment prevents the solutions used later from penetrating below the neck of the electrode. The treated electrodes are placed in a heating block of graphite which is maintained at a temperature slightly above 100°C. to hasten the evaporation of solutions added to the electrodes.

A solution containing 1 mg. of Be per cc. was made by treating 2.77 gm. of BeO with 10 cc. of concentrated HCl, heating until all the beryllium dissolved, evaporating the excess HCl and diluting to one liter. Further dilutions were made to obtain solutions containing 0.1 mg., 0.01 mg., and 0.001 mg. per cc. Small capillary pipettes calibrated to deliver 0.05 cc. were used to add the solutions to the electrodes. The solution penetrates into the sides of the cup in the electrode but is prevented from penetrating below the small neck by the pyrolin treatment. As soon as the electrode is dry, it can be placed in the electrode holder for excitation.

Adjustment and Excitation.

After the electrodes have been placed in their holders, they must be aligned with the slit. A light and lens are

permanently mounted so that an image of the electrodes is brought upon the slit when they are in the correct position. Definite spacing between the electrodes is secured by adjusting them until their images coincide with fixed marks upon the slit of the monochromator. The distance from the electrodes to the slit is adjusted so that the intensity from a pure carbon electrode is about 50 counts per minute. This distance of 110 cm. is kept fixed for all of the present measurements.

The openings in both slits of the monochromator are kept very small since a slight variation in the width of the slit causes a large change in the resulting intensity. For all of the work the slits were set at 0.08 mm. The prism of the monochromator is rotated until a maximum intensity or maximum count is obtained in the region of 2348 A with electrodes containing BeO. A very distinct maximum is observed as one varies the settings in passing by the 2348 A Beryllium line.

The voltage across the photon tube is adjusted to a value just under that which will give a continuous discharge at which point maximum sensitivity for the tube is attained. A small vial of radioactive material placed near the photon tube provides a convenient method for making adjustments of voltage and also serves as a standard for later adjustments. The voltage can be varied until the same count is obtained as that used previously. The bias on the thyratrons is adjusted to register only definite impulses from the photon tube and to exclude all

other small impulses or oscillations that may be "picked up" by the amplifier. The watch of the mechanical recorder is set at zero in order to record the total number of impulses in the period of excitation.

The arc is struck by using a graphite rod. Simultaneously the watch used for timing is started. The counting mechanism will start as soon as light strikes the photon tube. The period of excitation can be determined in two ways. One may either select a certain time, for example two minutes, for all excitations, or may continue until the entire electrode cup is burnt. With the type and size of electrodes used these two methods give quite similar results. The time required for complete burning is about 2-1/2 minutes. The usual procedure is to run several blank electrodes both before and after those containing the samples. The blank electrodes are prepared in exactly the same manner as those containing the beryllium samples. Thus one obtains a count from the blanks which is characteristic for all the electrodes of that type.

Plotting results.

The actual count registered by the counting mechanism is corrected by subtracting the count obtained for the blank electrodes. This corrected count is plotted against milligrams of beryllium present. The graphs obtained represent the

variation of the number of counts with the number of milligrams of beryllium present upon the electrode.

DISCUSSION OF RESULTS

Eight different test runs were made using the experimental arrangement and method just described. The results of a part of these runs are shown in the tables and graphs in the appendix. Run No. 1 was made using weighed amounts of BeO on each electrode. The results checked fairly well but the method was too tedious and did not permit samples of less than one hundred micrograms to be weighed with any accuracy. The results of the second run were discarded due to a mistake in making standard samples.

The results of the third run, which are shown in Table I and Graph I, show the best correlation between the samples of all the test runs. The electrode caps were entirely covered with the pyrolin lacquer. The sensitivity of the counter was held quite low, thus the maximum count obtained was relatively small. Results of the fourth run were not considered since the mechanical counter did not function properly.

Tables II and III and the corresponding graphs show the results of the fifth and sixth runs. The cups of the Type B electrodes used, were completely burned. These cups had only the bottoms and necks treated with lacquer. The concentrations in run No. 5 were greater than those in No. 6. In the latter, considerable difficulty was encountered as small portions of the cups were thrown from the arc unburned. The re-

sults of the last two runs are shown in Tables IV and V and their corresponding graphs. Before these runs, the sensitivity of the photon counter was increased resulting in a larger total count for a given concentration of beryllium. In these last two runs, Type A electrodes were used with the same lacquer treatment used in runs No. 5 and No. 6. However, in the last run the electrodes were modified by having a small hole drilled through the neck to facilitate their impregnation with lacquer.

In the graphs of the results, those points lying at a distance from the lines are in most cases on the left side, indicating a smaller number of counts for that particular sample than that found for the majority of samples of that concentration. This small count is probably due to incomplete burning of the beryllium in that sample. Incomplete burning may be caused by the solution soaking through the lacquer coating and carrying the beryllium below the neck of the electrode or the excitation conditions such as voltage and electrode spacing may vary enough that the period used is not sufficient to burn below the point where the lacquer was applied.

SUMMARY

The results obtained in this work indicate that there is a quantitative relationship between the number of counts obtained from the photon counter and the amount of material placed upon the electrodes. The general form of the curves obtained is similar in all cases observed. However, variations in exciting conditions and in the photon counter adjustments caused quite a variation in actual values.

CONCLUSIONS

1. The photon tube is satisfactory as a means of measuring light intensities from an element excited in an arc.

2. The recording mechanism used for recording impulses from photon tube worked satisfactorily.

3. With further development of technique of excitation, the photon tube should make an accurate method for quantitative analyses.

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APPENDIX

Table I

Run No. 3 — Electrode Type A
Time - 2 Minutes — Treatment-total Lacquer

Milligrams of Be	Counts Actual	Counts Correct	Counts Actual	Counts Correct	Counts Actual	Counts Correct
0.10	225	118	223	116	231	124
0.05	206	99	209	102	lost	
0.03	178	71	190	83	190	83
0.01	146	39	141	34	142	35
Blank	107	107	107	107	107	107

Table II

Run No. 5 — Electrode Type B
Time - Complete Burning — Treatment Lacquer

Milligrams of Be	Counts Actual	Counts Correct	Counts Actual	Counts Correct	Counts Actual	Counts Correct
1.0	263	203	265	205	265	205
0.5	228	168	190	130	lost	
0.2	Electrodes not adjusted					
0.1	130	70	186	126	189	129
Blank	60	60	61	60	55	60

Table III

Run No. 6 — Electrode Type B
Time - Complete Burning — Treatment Lacquer

Milligrams of Be	Counts Actual	Counts Correct	Counts Actual	Counts Correct	Counts Actual	Counts Correct
0.5	265	182	268	185	270	190
0.1	—	—	186	103	—	—
0.05	140	57	195	112	—	—
0.01	—	—	115	32	—	—
0.005	121	38	—	—	121	38
Blank	86	83	82	83	80	83

Table IV

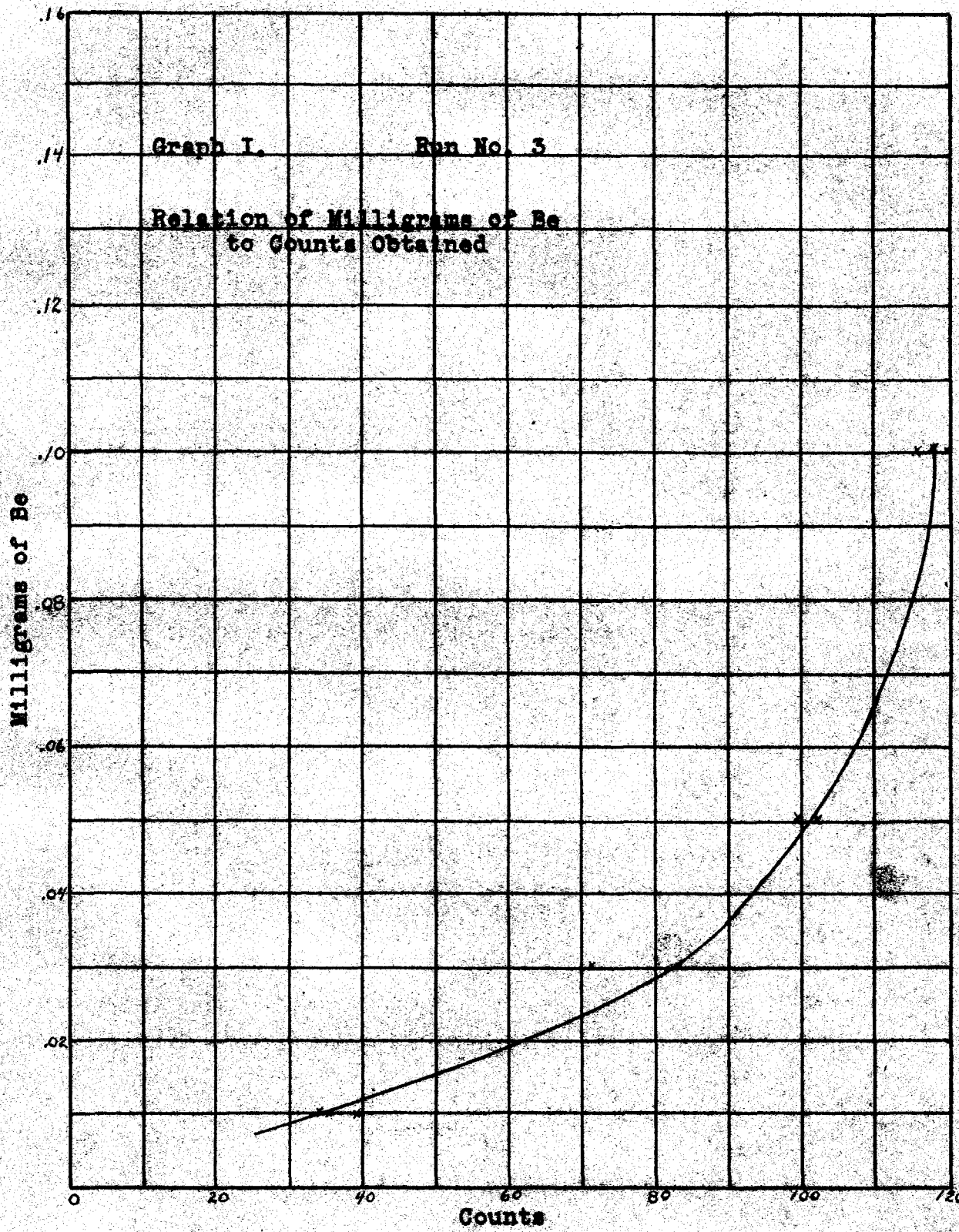
Run No. 7 — Electrode Type A
Time - 2 Minutes — Treatment Lacquer

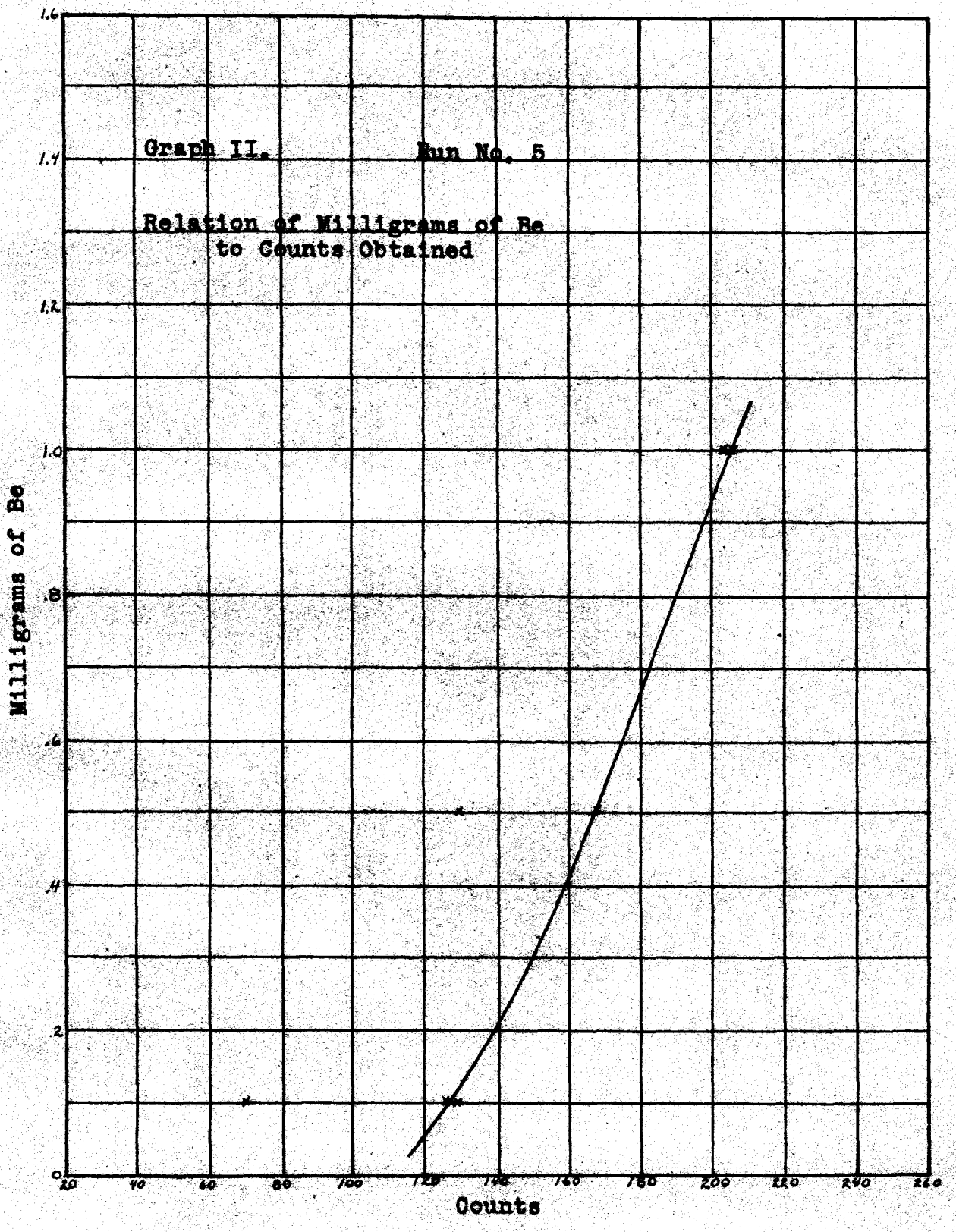
Milligrams of Be	Counts Actual	Counts Correct	Counts Actual	Counts Correct	Counts Actual	Counts Correct
0.5	761	596	792	627	700	545
0.3	478	313	598	433	570	405
0.1	391	226	391	226	338	273
0.05	321	156	338	173	273	108
0.02	268	103	265	100	—	—
Blank	166	165	155	165	165	165

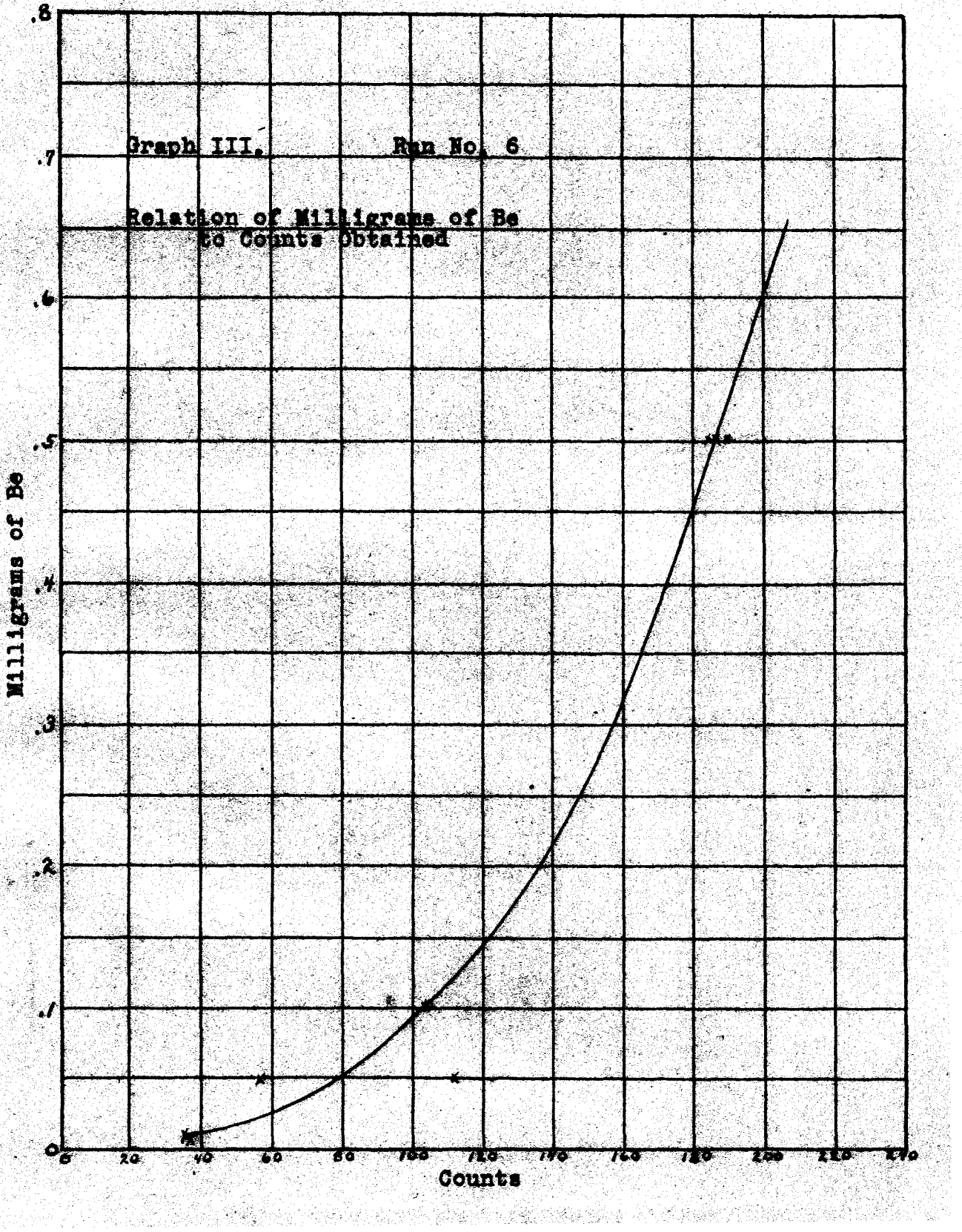
Table V

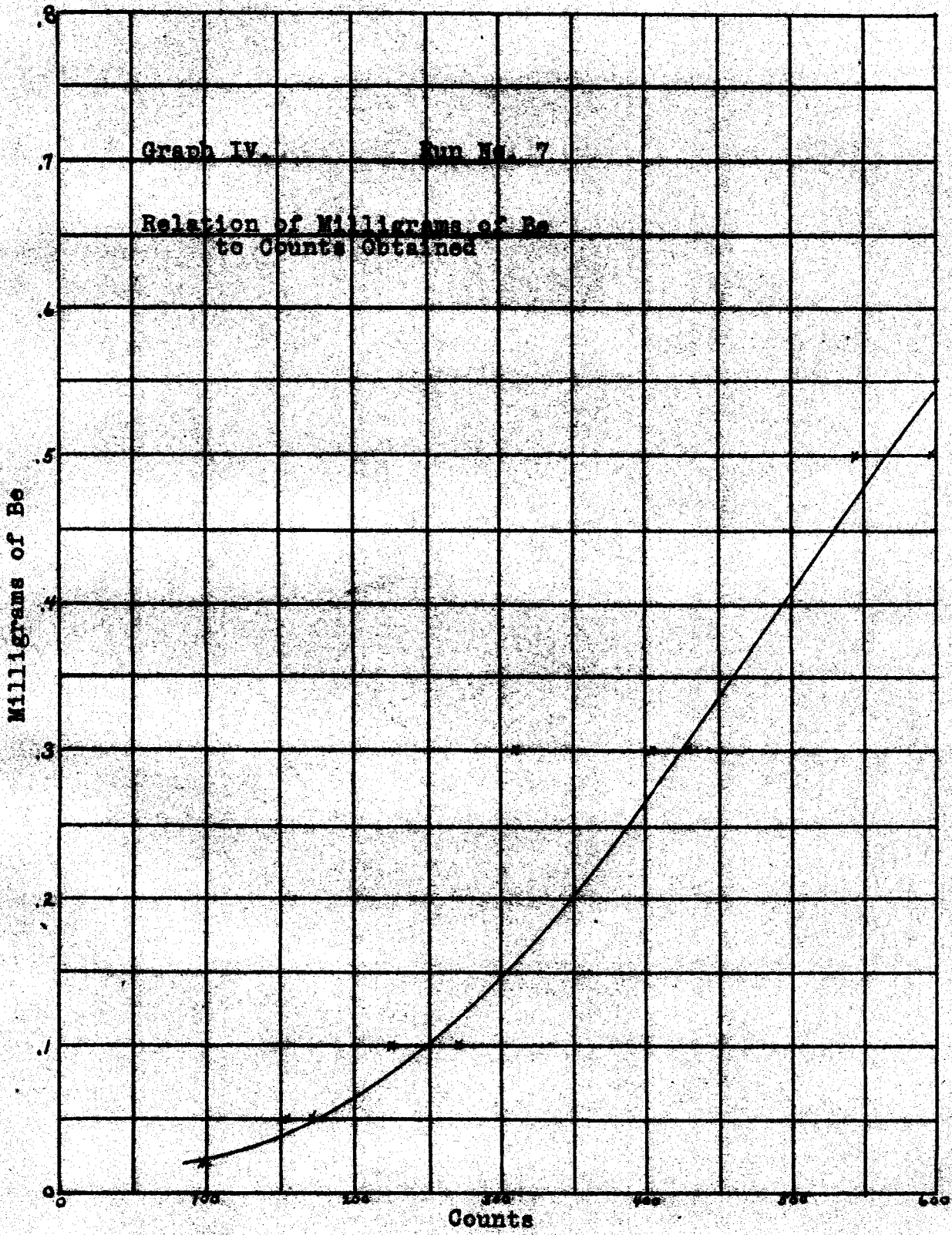
Run No. 8 — Electrode Type A
Time - 2 Minutes — Treatment Lacquer

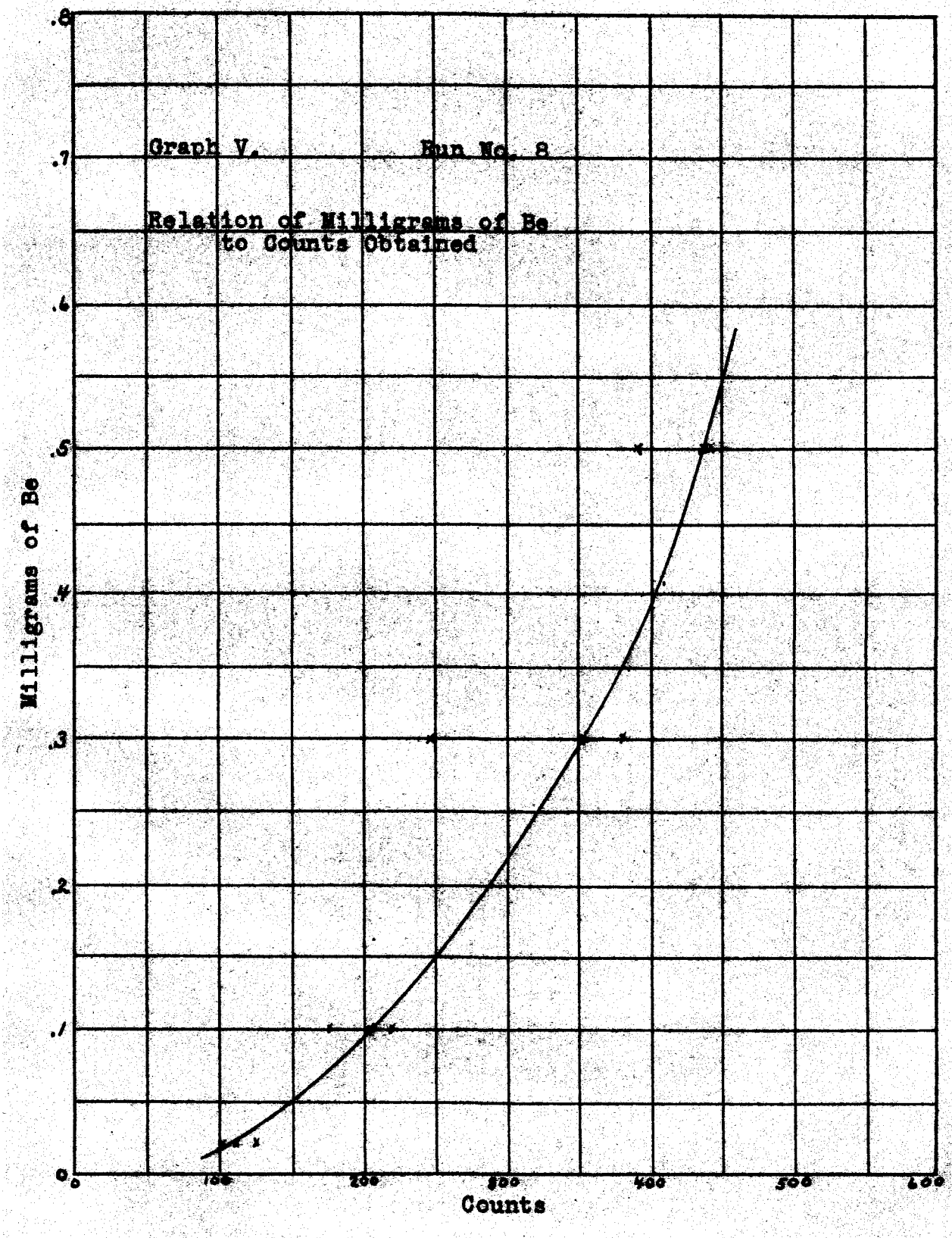
Milligrams of Be	Counts		Counts		Counts	
	Actual	Correct	Actual	Correct	Actual	Correct
0.5	655	438	609	392	658	441
0.3	600	383	466	249	572	355
0.1	424	207	395	178	441	224
0.02	331	114	320	103	345	128
Blank	219	217	201	217	230	217


Graph I. Run No. 3
Relation of Milligrams of Be to Counts Obtained
Milligrams of Be
.16
.14
.12
.10
.08
.06
.04
.02
0
20
40
60
80
100
120
Counts


Graph II. Run No. 5
Relation of Milligrams of Be to Counts Obtained
Milligrams of Be
Counts
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
20
40
60
80
100
120
140
160
180
200
220
240
260


Graph III. Run No. 6
Relation of Milligrams of Be to Counts Obtained
Milligrams of Be
.8
.7
.6
.5
.4
.3
.2
.1
0
0
20
40
60
80
100
120
140
160
180
200
220
240
Counts


Graph IV. Run No. 7
Relation of Milligrams of Be to Counts Obtained
Milligrams of Be
.8
.7
.6
.5
.4
.3
.2
.1
0
0
100
200
300
400
500
600
Counts


Graph V. Run No. 8
Relation of Milligrams of Be to Counts Obtained
Milligrams of Be
Counts
0
.1
.2
.3
.4
.5
.7
.8
100
200
300
400
500
600

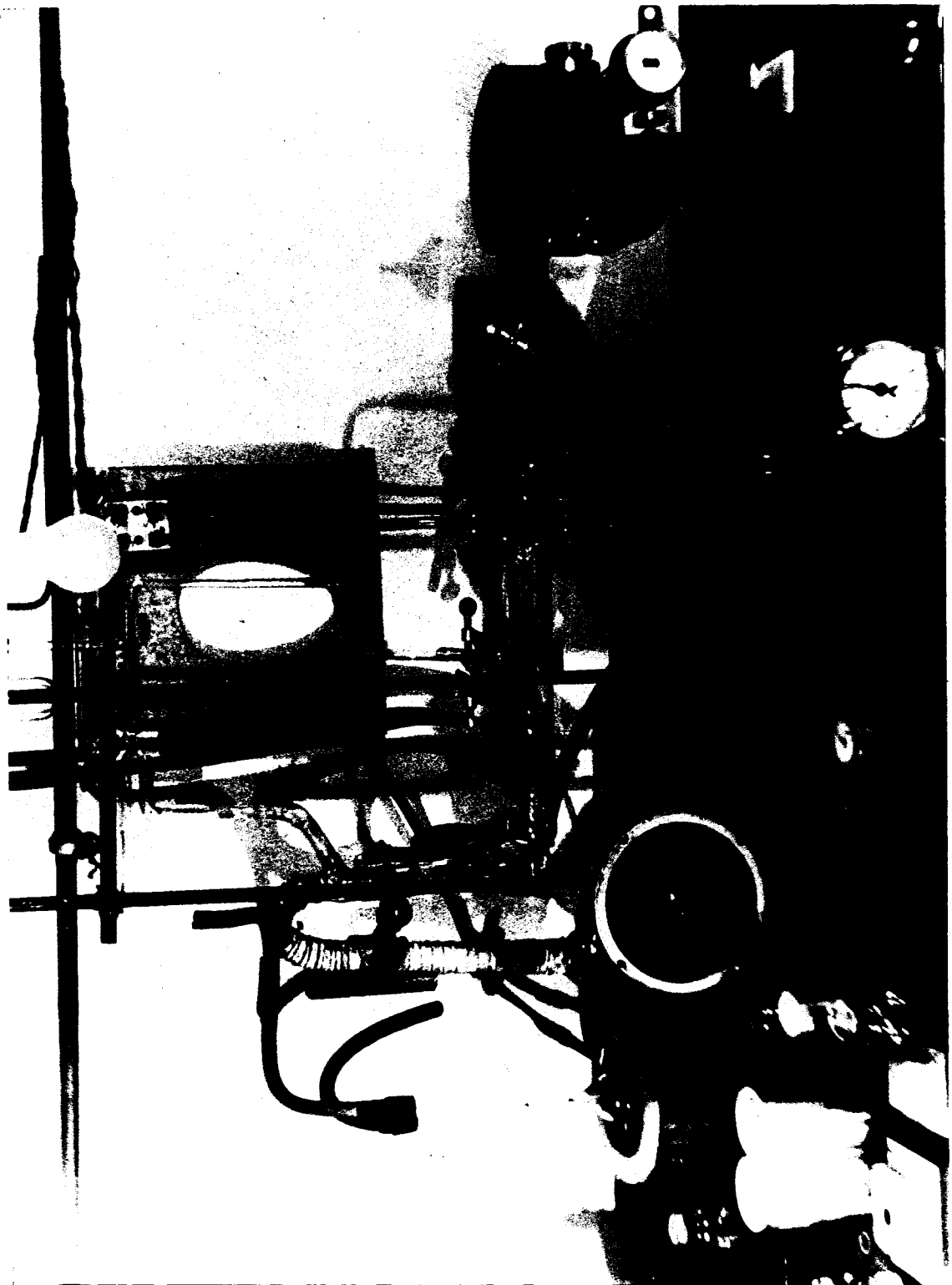


Figure 1. General View of Apparatus.

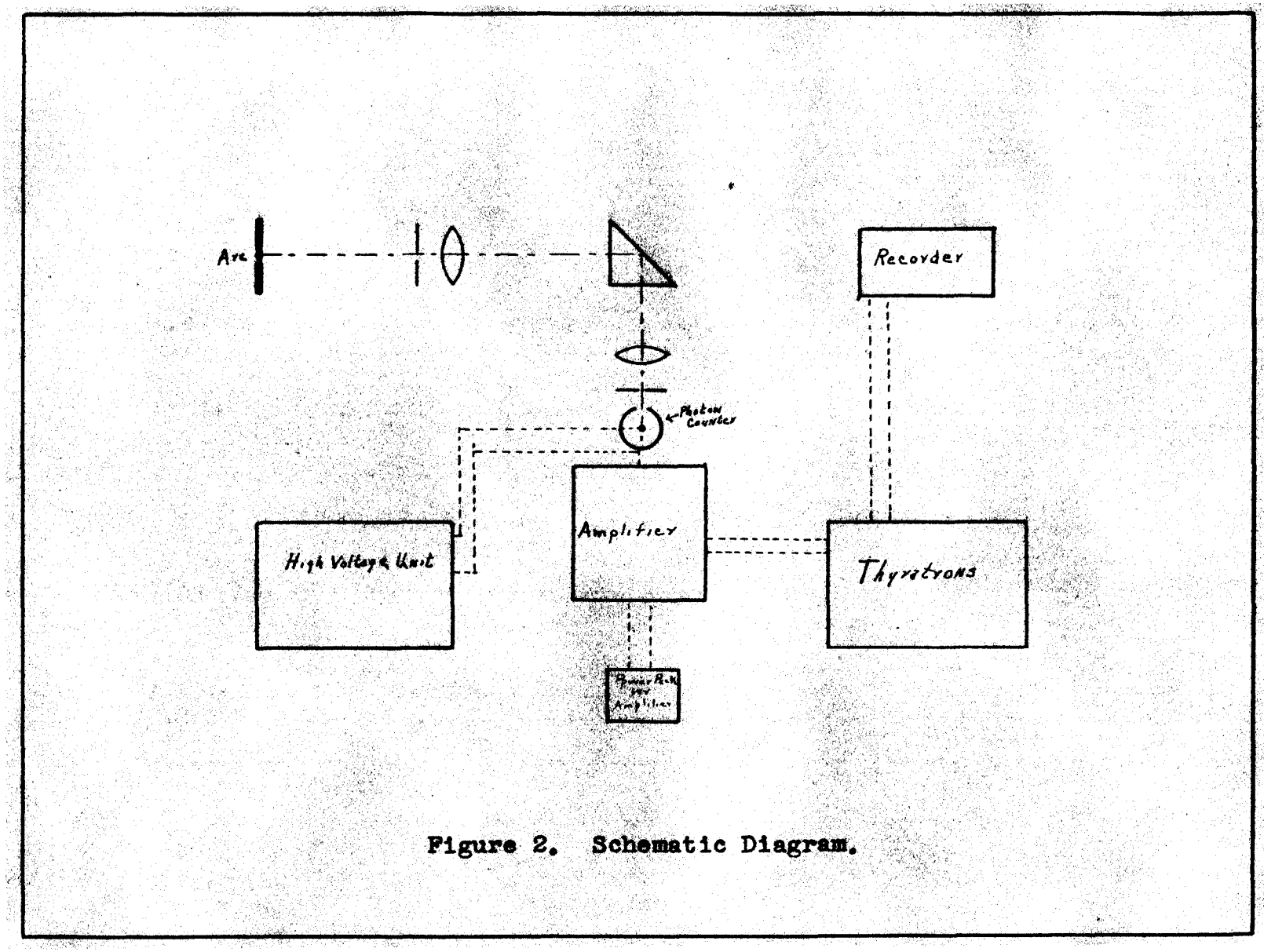


Figure 2. Schematic Diagram.

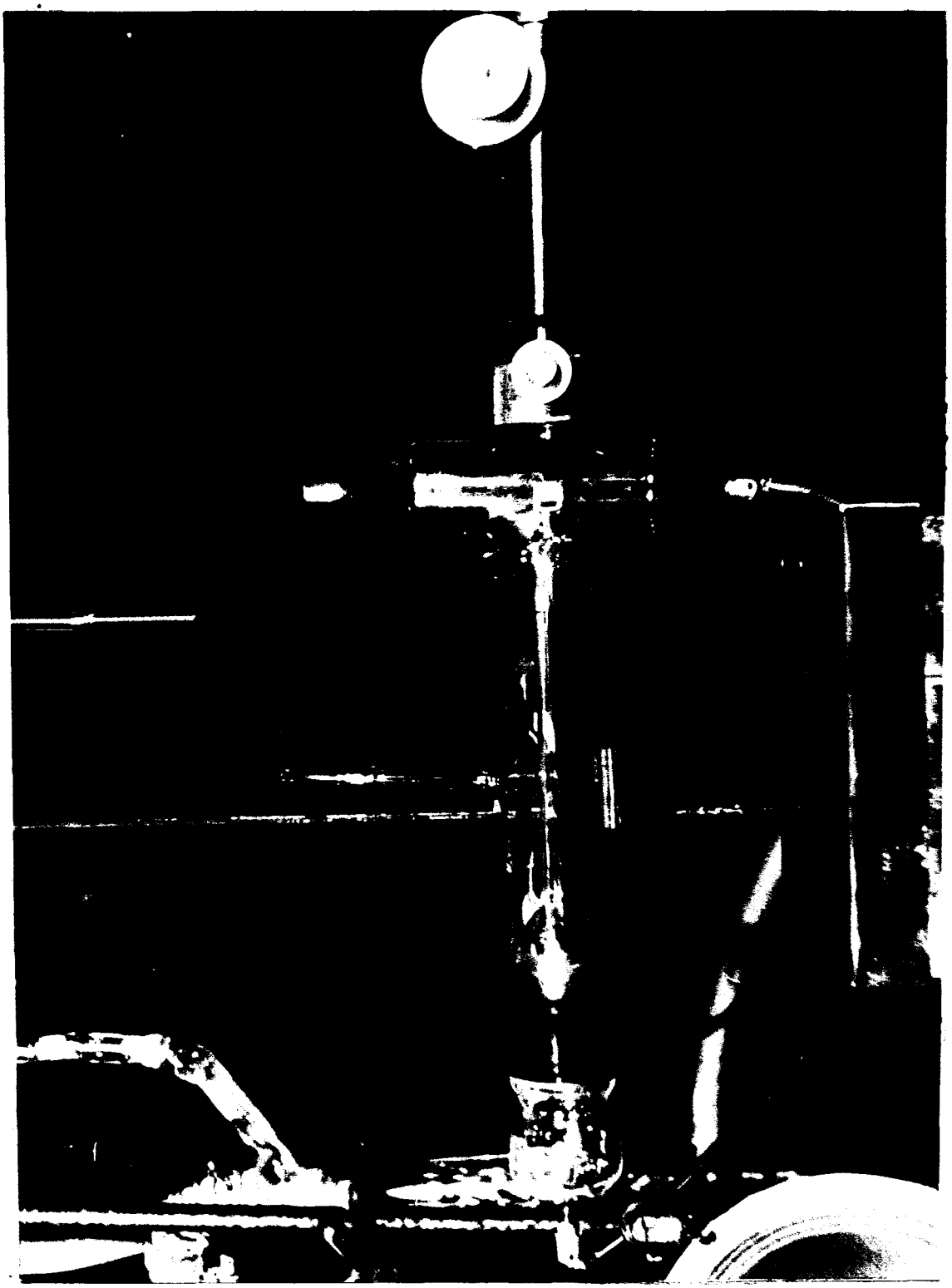


Figure 3. Photon Tube.

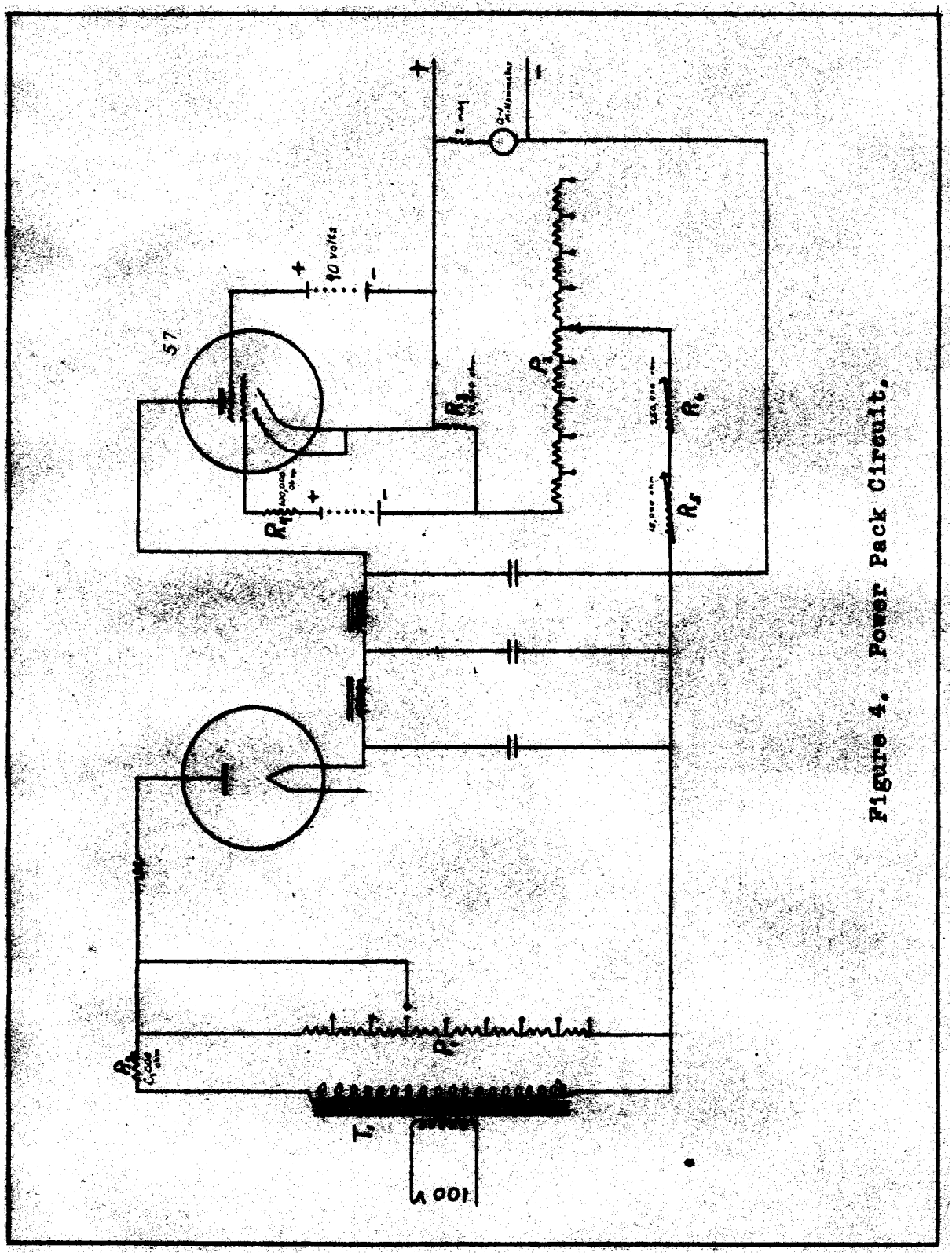


Figure 4. Power Pack Circuit.

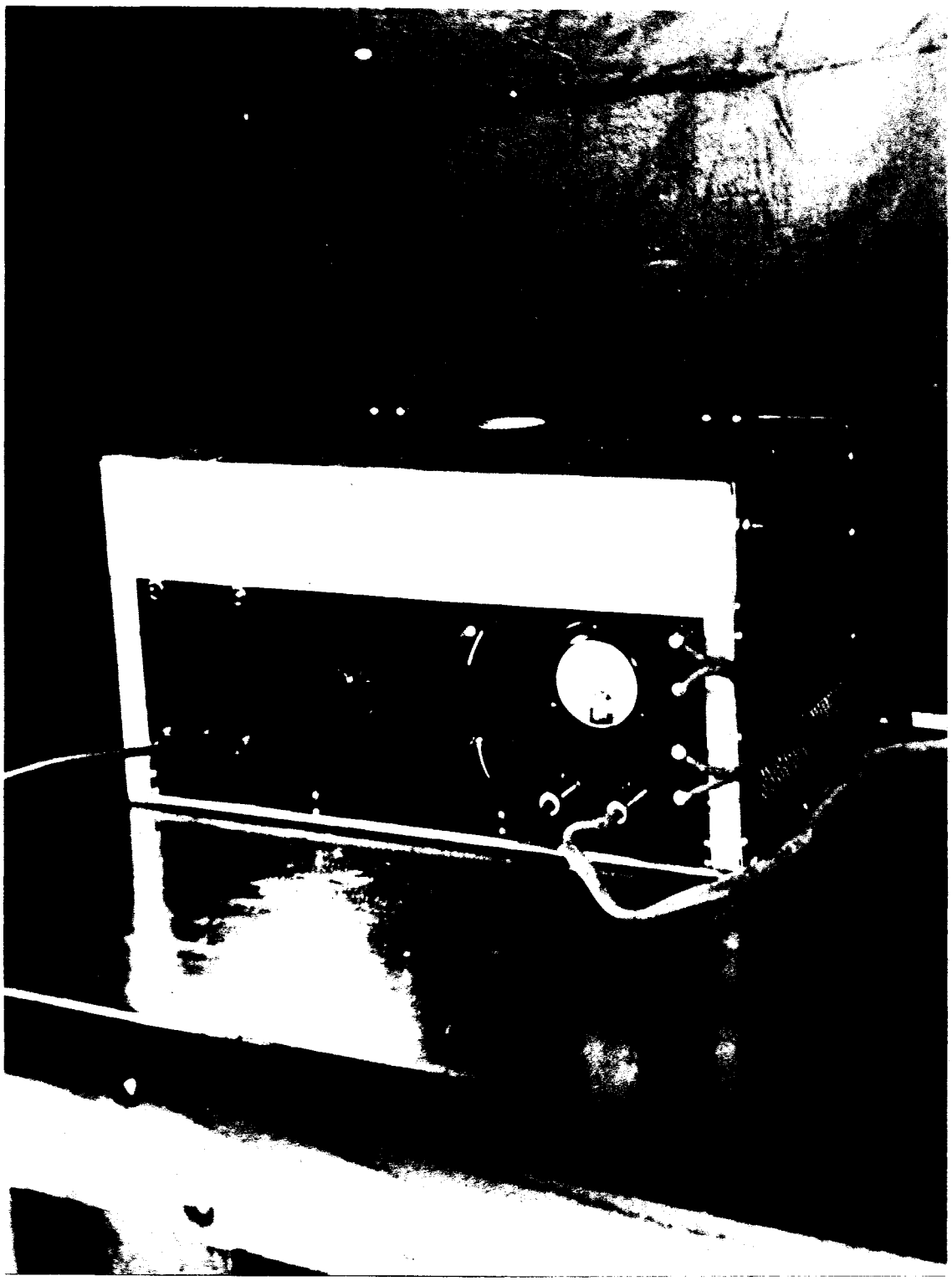


Figure 5. Power Pack.

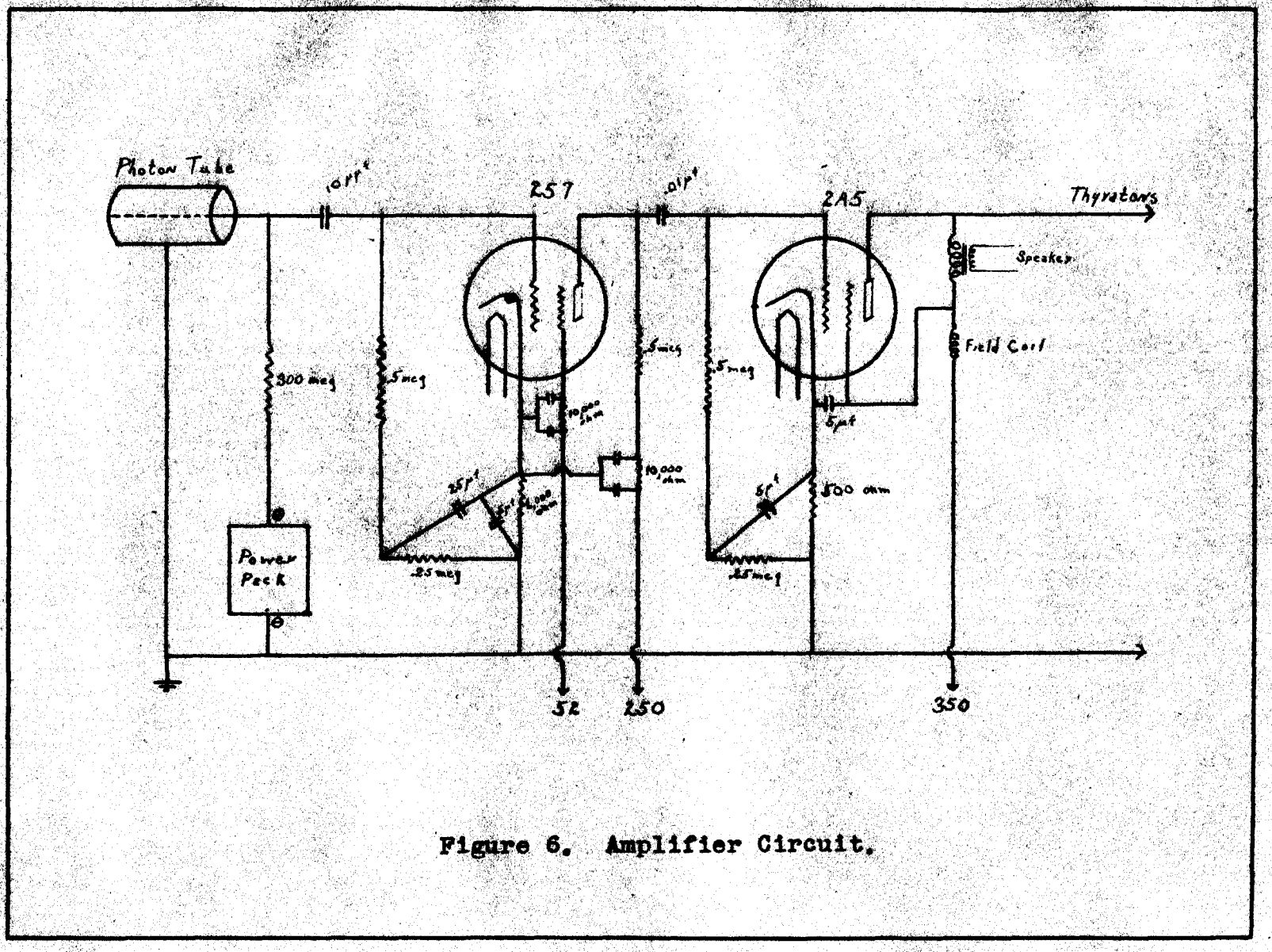


Figure 6. Amplifier Circuit.

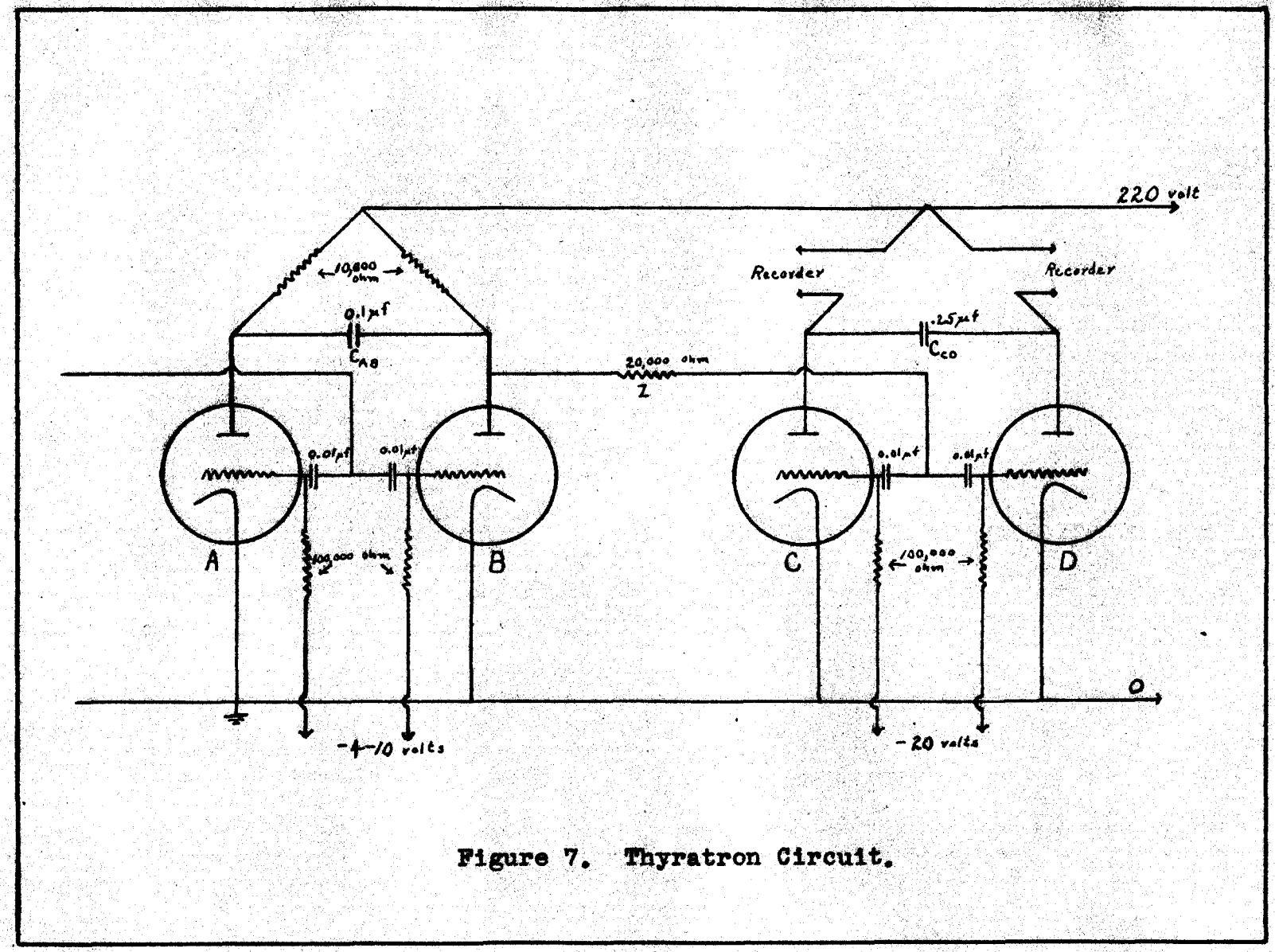


Figure 7. Thyratron Circuit.

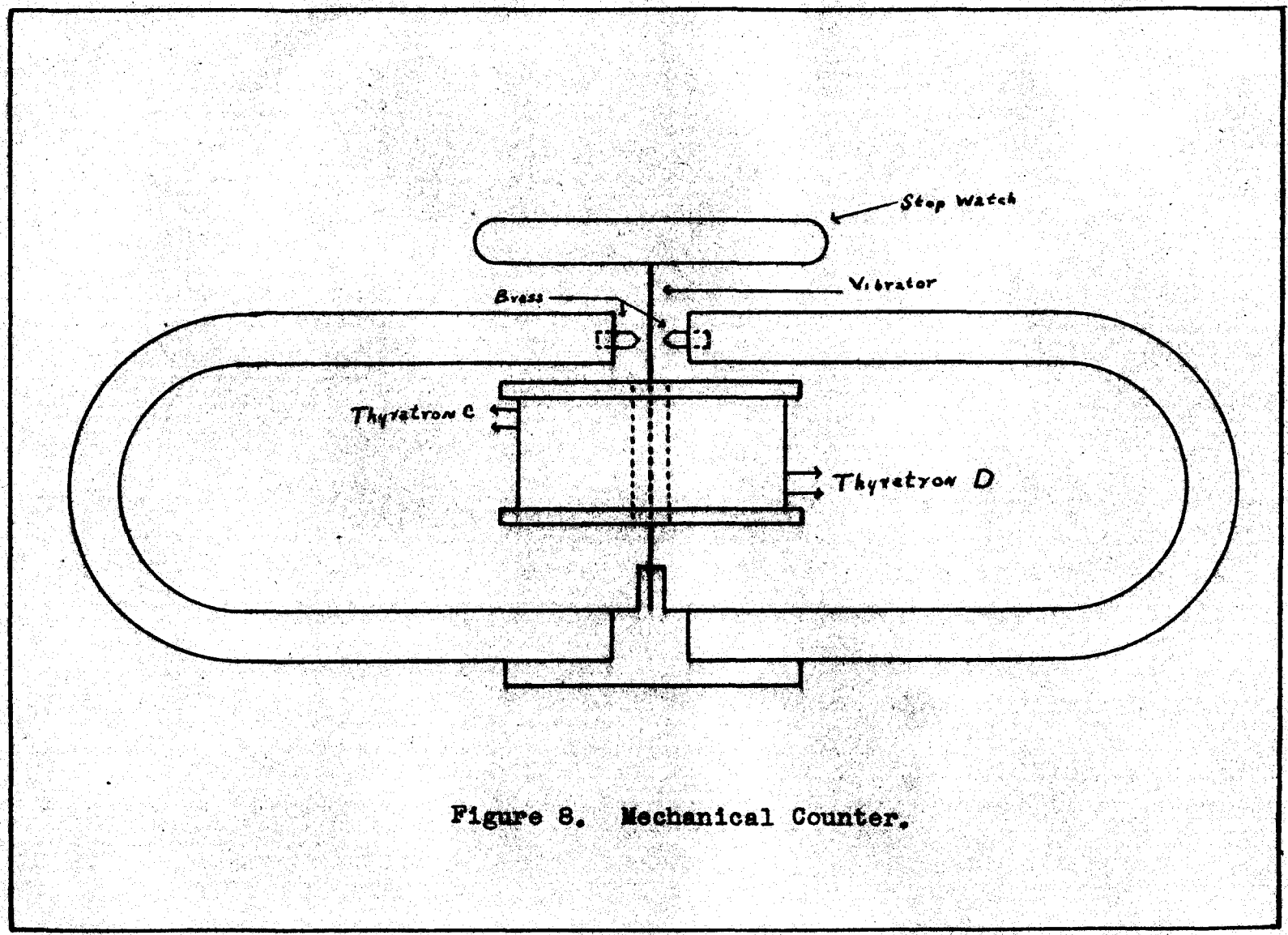


Figure 8. Mechanical Counter.

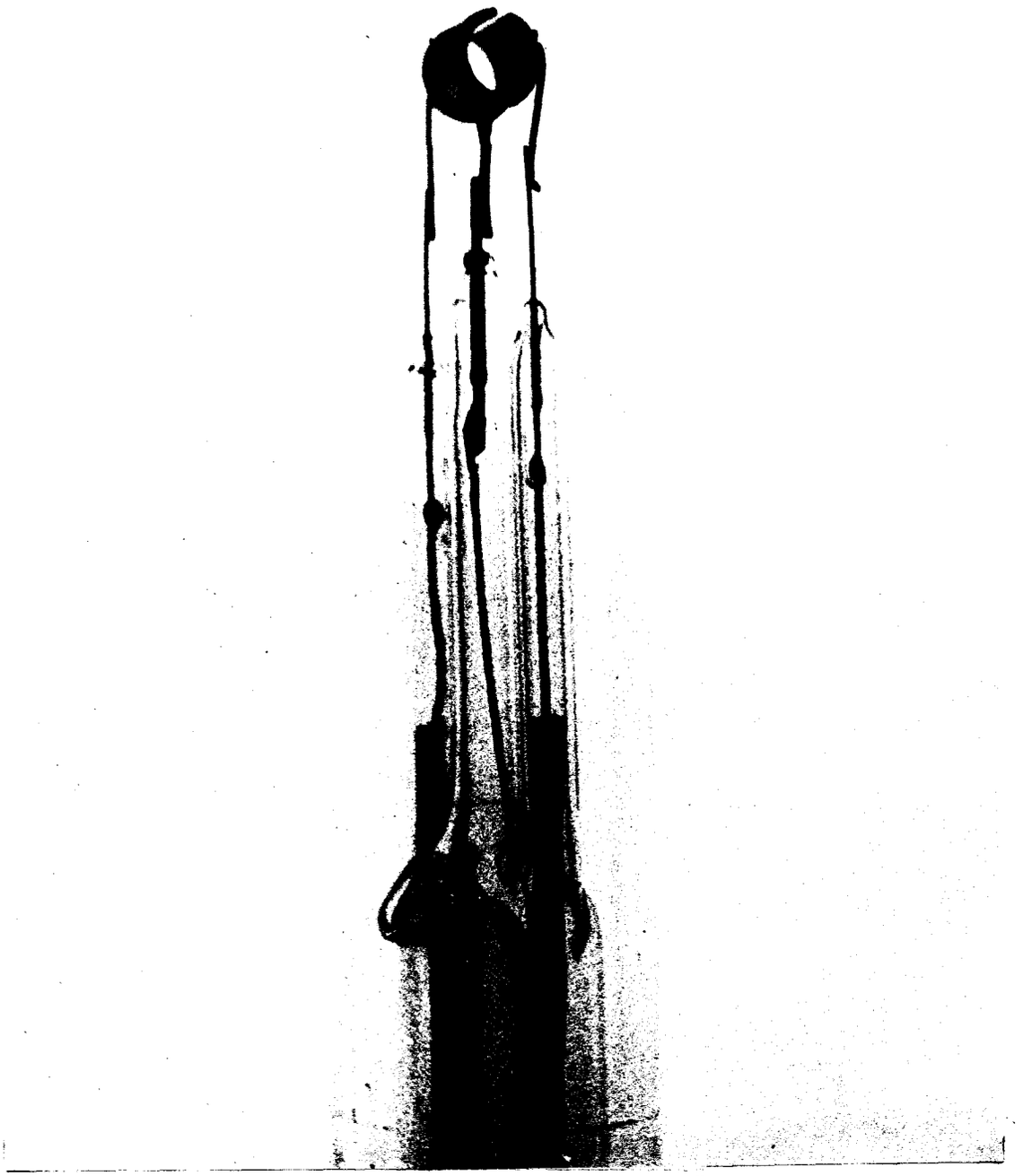


Figure 9. New Type Photon Tube.