MOM
9Au7

u sw

THE ELECTRICAL DISCHARGE FROM A POINTED CONDUCTOR TO A HEMISPHERICAL SURFACE IN GASES AT DIFFERENT PRESSURES.

A T H E S I S

Submitted to the Faculty of the Graduate School of the

University of Minnesota

by

Franz A. Aust

in partial fulfillment of the requirement for the degree

of

Master of Science.

May 1, 1911.

THE ELECTRICAL DISCHARGE FROM A POINTED CONDUCTOR TO A HEMISPHERICAL SURFACE IN GASES AT DIFFERENT PRESSURES.

The experiments to be described in this paper had for their immediate object the investigation of the quantitative relation of the current and potential when an electrical discharge was passing in gases at different pressures to a hemispherical surface from a pointed conductor situated at its center of curvature.

Numerous experiments have been carried on with a discharge passing from a point to a plane, investigating the distribution of the current over different areas,[1] as well as the relation of the current and potential at different pressures.[2] However in such a case the electrostatic field is so complex and the current distribution so changes with the pressure that it is difficult to separate the various factors and study their effect.

In the case of a discharge passing to a hemisphere,

1. Warburg, Am. Phys. Vol. 67, P. 69 (1898).
2. J. Zeleny, Phys. Rev. Vol 26, P. 145 (1908).

however, it has been found[1] that at atmospheric pressure the current distributes itself quite uniformly over the entire surface opposite the point, and that the field for all parts of the surface approximates to that between two concentric spheres. It seemed probable therefore that a more simple relation between the quantities involved would be obtained.

The various phases of the experiment will be taken up in the following order:

1. Description of apparatus.
2. Tests of the apparatus and difficulties encountered.
3. Procedure in the experiment.
4. Results of the experiments conducted with air.
5. Experiments with oxygen.
6. Minimum potentials in oxygen and air and how they are affected by the presence of radium.
7. Luminous appearance of the discharge.
8. Summary.

---

1. J. Zeleny, loc. cit.

I. DESCRIPTION OF APPARATUS.

The spherical surface to which the current passed is shown in section in figure 1. This is practically the same as that used by Prof. J. Zeleny in his work on : "The Discharge of Electricity from Pointed Conductors"[1]. A hemisphere of 1.75 cm. radius was turned in a brass cylinder and divided into three sections of equal areas (A, B, C). These were separated by air spaces of .28 mm. and held in place by sealing wax. A fourth cylindrical section (D) 1 cm. in length and of the same external and internal diameter as Section C was added to the cylinder so as to make the field between the point and the hemispheres more nearly approximate that between two concentric spheres. As the discharge spreads back from the point with decrease of pressure this surface D receives most of the extra flow of current.

The discharge point (I) consisted of a platinum wire .18 mm. in diameter whose end was ground as nearly spherical as possible. This wire, 1.0 cm. long, was

---

1. Loc. cit.

soldered into one end of a brass cylinder 3 mm. in diameter and 2.5 cm. long. At the other end of this cylinder was a lock-nut which permitted the position of the point to be adjusted. The point when in position rested upon an ebonite block which was fastened to the hemisphere and carefully notched and adjusted so that when the point was placed in position its direction coincided with the axis of the hemisphere. The distance from the center of curvature to the extremity of the block was then carefully measured. After that the only adjustment of the point necessary was to make it coaxial with the cylinder, to set the lock-nut at the required distance from the point, and to put it in place on the ebonite block. This arrangement made it easy to remove the point whenever necessary.

The apparatus as finally connected up is shown in figure 2. The hemisphere was sealed into one end of a glass cylinder 5 cm. in diameter and 20 cm. long while the other end was closed by means of a ground glass stopper (E) into which was sealed the connecting rod (F). This rod was made of brass and had at its extremity a sleeve which just fitted over the cylinder carrying the point and served as a means for removing the same. Electrical connection was made with the point by means of a fine wire arm (F) soldered to the cylinder (I). This arm dipped into a small mercury cup bored into the top of the brass rod (F).

Connection could be made to the different sections of the hemisphere, A, B, C and D by means of well insulated wires leading to the switching device J. The current passing to the different sections of the spherical surface was measured by means of a Leeds and Northrop "P" type galvanometer (G), where one scale division represented 2.46×10^{-8} amperes.

Potentials above 2500 volts were measured by means of a Braun Voltmeter (E) and those lower than 2500 volts with a Kelvin Vertical Voltmeter.

A Wimshurst Machine (W) run by a small motor was used as a source of electricity. In order to obtain a constant potential from this machine, two batteries of Leyden Jars (L and L') were connected in parallel with the poles of the machine. These two batteries were separated by a high resistance of about 100 megohms, such as will be described later. This served to steady the potential of the point and also to increase the total amount of current generated by having the machine work at a higher potential.

The regulation of the potential of the point, especially for the lower pressures, caused considerable trouble. An auxiliary point and plane arrangement was at first used for this purpose and proved very satisfactory until the lower pressures and voltages were reached. Here however it was found that often a clicking of the telephone receiver (T), which was taken as an indication of an intermittent current, was really caused by a sudden dropping of the current in the whole circuit by a small spark passing from the auxiliary point to the earthed plane. Liquid resistances such as alcohol and the Cadmium Iodide resistance described by Starke[1] and Hittof[2] were tried in place of the auxiliary point but found unsatisfactory because of their comparatively low resistance.

---

1 Starke: Elect. in Gases, p. 9.

2 W. Hittof: Wied. Ann. V. 7, p. 558 (1879).

The resistance shown in figure 3 was then devised and proved itself serviceable. It consists mainly of two strips of paper, of very high resistance, the one 3 x 45 cm. (A), the other 1.5 x 45 cm. (B). In order to obtain the required range of resistance, fine lines were ruled upon these strips with Higgins' India Ink. By selecting the proper width of paper and adjusting the density of the rulings one can easily get a range of resistance from 1 to 500 megohms per centimeter of length. The two strips in series were here used in order to obtain a finer adjustment, for the one had a range of 1 to 5 megohms per centimeter, and the other had practically a constant resistance throughout of 50 megohms per centimeter.

The construction of the resistance rack is shown by figures 3 and 4. The frame is built of well seasoned wood thoroughly shellacked. The end of the paper strip where it is connected to the binding posts C and D by means of a mercury cup E is thoroughly blackened with the India Ink so as to make it as good a conductor as possible. Each strip passes through a sliding mercury cup and is then fastened to the other extremity of the rack. The sliding mercury cup (F) is in continuous electrical contact with the mercury trough (H) by means of the point (i). The mercury trough completes the electrical circuit between the strips of paper and the binding posts. The resistance is varied by means of the sliding mercury contacts F and F'.

Various kinds of paper were tried. The hot and cold pressed drawing paper were found to have too low a resistance, and the lines ruled on them seemed to break in places and thus give an erratic resistance. A special linen bond paper was finally adopted.[1] Its resistance is much higher than that of the other papers tried and the surface is highly glazed, thus holding the ink well and still not absorbing the particles of mercury into which it is dipped. This resistance seemed fairly constant when kept well cleaned and proved very satisfactory.

The pressure within the tube (K) was measured by means of an ordinary mercury gauge. In order to

---

1 Byron Weston Company's "Linen Record".

prevent any leakage over the surface of the tube (K) it was partly covered with tinfoil connected to earth.

During all the experiments here described a glass vial (Z), figure 2, containing 1 gram of 1 percent radium bromide was placed beneath the tube (K). The effect of the radium upon the electrical discharge will be taken up later.

II. TESTS OF THE APPARATUS AND DIFFICULTIES ENCOUNTERED.

Before proceeding with the experiment it seemed important to ascertain the effect of the continuous discharge on the enclosed gas.

In order to do this a set of readings was taken for the minimum potential of each section and the current passing to the same at different pressures, the air being renewed for each change of pressure. Then a continuous set of readings was taken with a given mass of gas, without renewing the same. A third set was now taken the same as the first set but having the discharge first pass through the gas for a period of ten or fifteen minutes before any readings were taken. With the point charged positively it was found that the second and third set of readings were nearly identical but differed from the first set considerably; the current values being about 1.5 percent lower in case of the latter. This test was repeated after the point had been used for some time, On the supposition that the change might be due to changes in the condition of the point itself.[1]

[1] Precht: Wied. Ann. 49:150 (1893); J. Zeleny, Phys. Rev. 24:137 (1908).

But the readings were found to be practically the same as before. With the negative discharge these effects if present were masked by irregularities in the current.

When oxygen was used this deterioration of the gas with use was very marked, especially with the starting potentials. Sometimes the starting potential would drop 5 or 10 percent of the average value obtained when a new gas was used. This deteriorated gas when left to stand for a few hours would however usually recover. On the whole, the results obtained with the prolonged use of a gas were found unsatisfactory both for the starting potentials and the lower current values, and so all of the readings in this investigation were taken in as short an interval of time as possible and in each case after the current had been passing for a short time only.

With the point charged negatively the usual difficulties encountered in this line of investigationwere met,[1] intthat all of the smaller currents were very

---

1 Groton and Warburg, Ann. d. Phys. 18:129 (1905). J. Zeleny, loc. cit.

irregular. The presence of radium[1] had very little effect upon the negative discharge but in the case of the positive discharge the presence of radium had a marked effect in steadying the starting potential and also the currents for the low voltages. The starting and stopping potentials were also the same when the radium was present.[2]

It also seemed important to ascertain what effect, if any, a slight displacement of the point from the determined center of curvature had upon the current values and minimum potentials of the different sections. First a slight displacement to one side of the center was tried, but no appreciable change in the minimum potential or lower current values could be detected when the displacement did not exceed one millimeter. Readings for the same potential were then taken with the point at different positions along the axis of section D.

---

1 Gorton and Warburg, loc. cit.

2 J. Zeleny, loc. cit.

The results of which are given in table I.

It is seen that a small displacement produces but a slight effect so that no appreciable error can arise from lack of perfect centering of the point. An unexpected effect is noticed however in that the minimum potential increases with diminution of the distance from the surface of the hemisphere.

III. PROCEDURE IN THE INVESTIGATION.

When starting, the point was carefully adjusted and the apparatus thoroughly freed from moisture by exhausting it several times and in each case allowing the dried air to remain in the apparatus for some time. The current was now allowed to pass to the hemisphere for several minutes and then the starting potential was carefully determined. In taking the current readings each of the sections, A, B, C and D was connected in turn to the galvanometer while the rest were joined to earth. The currents were carefully determined for regularly increasing voltages, the readings of the voltmeter being adjusted so as to come exactly on one of its subdivisions, as this permitted a more exact determination. Then a few points were usually taken on decreasing the voltage as a check upon the results. These observations were repeated for different pressures varying from atmospheric to that of about 2 mm. of mercury. For the lower pressures the maximum voltage used was limited by the nature of the discharge, a spark finally passing from the point to the sphere; but for the higher pressures the voltage was limited by the maximum capacity of the machine.

Numerous sets of observations were taken both for the negative and positive discharges in air and oxygen.

IV. RESULTS OF THE EXPERIMENTS CONDUCTED WITH AIR.

The manner in which the current distributes itself over the spherical surface is best shown by a typical set of observations given in Table II, and the potential-current curves obtained from these readings. See Fig. 4 and 5.

These readings were taken with the point placed at the determined center of curvature. The gas used was air and the temperature remained constant at 22° C. for a complete set of positive and negative currents. The negative currents were always more or less irregular and therefore the positive currents only are shown in the plots.

The curves indicate how the current flowing to each section, A, B and C, at a definite pressure, varies with the voltage, while the curve A + B + C indicates how the <u>total current</u> flowing to the hemisphere at a given pressure varies with the voltage. The various groups of curves show the distribution of the current at the different pressures indicated.

From the results we see that the current density is quite uniform over the sections A and B at all of the pressures used and that even for section C the current does not deviate greatly from that over A and B, although the effect of a higher starting potential and the proximity of the current flowing from the side of the point at the higher voltage is quite marked.

The total current passing to the hemisphere at any pressure can be expressed by the equation

$$C = \alpha V(V-M)$$

where M is the minimum potential and α a constant for the particular pressure. The values of these constants are given on each curve shown. The currents passing to sections A and B can also be expressed by an equation of this form but any error in the value of M would be much more marked in the case of the smaller current values, therefore the value of α in this case would hold only for the higher voltages.

The results for the relation between the voltage and current to the central section of the hemisphere (A) for the positive discharge in air are shown by the curves in figure 6 for the various pressures used.

From these curves those of figure 7 are directly obtained. These show the relation between the pressure and the potential required to produce a given current.

From these "potential-pressure curves" we see that the voltage required to maintain a certain current changes quite slowly for pressures between 40 and 75 cm. and varies nearly directly as the pressure. But as we approach the lower values this does not hold and the voltage changes rapidly for small changes in pressure.

The dotted curve is obtained by subtracting the potentials for the curve C = 0 from one of those above, e.g., C = I.O. This also shows that the values of (V-M) are linear for the higher pressures and then also diminish more rapidly as we approach zero.

V. EXPERIMENTS WITH OXYGEN.

Since air is a composite of several gases it seemed advisable to investigate the discharge in a simple gas. Oxygen was chosen because its minimum potential for the positive discharge does not differ greatly from that for air,[1] and the two might thus be more readily compared.

In figure 8 are given the "potential-current" curves for oxygen. These correspond to those of figure 6 for air and also show the relative voltage and current to section A only.

In figure 9 are given the corresponding "potential-pressure" curves. From these it is seen that the general behavior in oxygen is quite similar to that in air.

---

1 Precht, loc. cit.

VI. MINIMUM POTENTIALS IN OXYGEN AND AIR AND HOW THEY ARE AFFECTED BY THE PRESENCE OF RADIUM.

The minimum potentials in oxygen and air can best be compared by referring to the zero current curve in figures 7 and 9. Here we see that the minimum potential for the positive discharge in oxygen is somewhat higher than that in air.

In the investigation of the minimum potential it was found that the radium had a very marked tendency to decrease the minimum potential in oxygen while in air the only effect noticed was that it steadied the starting of the current and rendered the starting and stopping voltages the same. In figure 9 the dotted line gives the zero current curve for oxygen without radium near the discharge while the heavy zero current curve represents the minimum potential when radium is present to ionize the gas. The current values above $.5 \times 10^{-7}$ ampere are not appreciably affected by the presence of radium either in the case of oxygen or of air.

VII. THE LUMINOUS APPEARANCE OF THE DISCHARGE IN AIR AND OXYGEN.

When the electrical discharge was passing in air, there appeared at the point, simultaneously with the rush of current to the "A" section, a very small speck of white light, and as the voltage was increased the light spot became larger. When the pressure was decreased the luminosity spread back over the entire surface of the point, sometimes covering the entire wire as far back as the brass cylinder (I) (see fig. 1). At the lower pressures, when a sufficiently high potential was reached, for a spark to pass to the hemisphere, the light became very intense at the point and a spark passed to the different sections of the hemisphere.

But with oxygen the luminosity was somewhat different. The light was more of a reddish color and at the lower pressures, when the spark passed, there seemed to be a marked tendency for the spark to pass only to the "B" section. Sometimes there would be only a spot of light on the surface to which the spark passed and then again there would be a continuous band from the point to the section "B". Sometimes the current was observed to flow when no spot of light was visible at the point but this may have been due to the fact that the spot was so small it could not be seen because of the curvature of the surface.

VIII. SUMMARY.

1. A high resistance (1-100 megohms) was devised by which the potentials of a static machine may be regulated without encountering any of the difficulties usually met in regulating such a machine by means of an auxiliary point and plane or an electrolytic resistance.

2. It has been found that an electrical discharge passing from a pointed conductor to a hemispherical surface distributes itself quite uniformly over the surface for all pressures between 2 and 750 mm.

3. The negative discharge from a point to a hemispherical surface is quite irregular, especially for all voltages between the starting potential and the minimum potential for the positive discharge.

4. The relation existing between the current and potential at the various pressures for oxygen does not differ greatly from that for air.

5. In comparing the potential-pressure curves

obtained under the above conditions with those similarly obtained[1] with the discharge passing to a plane we see that in the case of the former, especially for the higher currents and voltages, they more nearly approach the linear form.

---

1 Compare J. Zeleny, loc. cit.

Table 1.

Distance of Point from Center of Curvature		Positive Discharge				Negative Discharge			
		Minimum Potential of Section							
		A	B	C	D	A	B	C	D
-1.3	mm.	2870	2940	3080	3475	2630	2675	2830	3100
-1.0	" "	2870	2940	3100	3500	2620	2670	2820	3130
-0.5	" "	2860	2930	3125	3540	2630	2660	2840	3160
-0.2	" "	2870	2930	3150	3560	2640	2660	2830	3180
-0.0	" "	2870	2950	3150	3550	2625	2675	2850	3175
+0.5	" "	2890	2990	3210	3700	2640	2700	2900	3200
+1.0	" "	2900	3050	3275	3850	2650	2740	2960	3480
+1.5	" "	2915	3090	3325	3960	2670	2800	3000	3540

+ Indicates within the hemisphere.
- " without "

Table II

Pressure in cm Hg	Voltage of Point	Current in 10^{-6} amp. flowing to A	B	C	D	A+B +C
[illegible]	2900	.03	—	—	—	.03
	3000	.05	.03	—	—	.08
	3100	.08	.05	—	—	.13
	3200	.10	.07	.01	—	.18
	3500	.22	.17	.08	—	.51
	3700	.29	.25	.15	—	.65
	4000	.40	.36	.27	.03	1.04
	4250	.50	.45	.35	.06	1.03
	4500	.60	.56	.48	.08	1.66
	5000	.83	.82	.80	.34	2.45
	5600	1.16	1.11	1.12	.59	3.30
	6000	1.40	1.37	1.48	.90	4.25
	6500	1.78	1.70	1.88	1.20	5.30
	7000	2.20	2.06	2.32	1.60	6.60
	7500	2.70	2.55	2.77	2.15	7.98
	Min.	2870	2950	3150	3550	
40.0	2200	.05	.01	—	—	.06
	2300	.10	.04	.01	—	.16
	2400	.14	.10	.05	—	.32
	2500	.18	.15	.10	—	.47
	2750	.31	.27	.22	.02	.85
	3000	.43	.45	.38	.03	1.25
	3500	.74	.73	.76	.32	2.30
	3750	.94	.92	1.00	.50	2.85
	4000	1.15	1.13	1.28	.79	3.53
	4500	1.60	1.58	1.80	1.30	5.04
	5000	2.15	2.15	2.35	1.90	5.85
	Min.	2100	2150	2260	2600	
15.0	1400	.03	—	—	—	.03
	1500	.05	.05	.01	—	.11
	1600	.10	.14	.07	—	.36
	1750	.30	.30	.10	.05	.60
	2000	.55	.55	.60	.33	1.65
	2500	.82	.82	.83	.82	2.50
	2300	1.22	1.21	1.50	1.08	3.38
	2750	1.70	1.69	1.82	1.50	5.10
	3000	2.15	2.13	2.40	2.10	6.50
	3250	2.80	2.75	2.90	2.50	8.50
	Min.	1350	1370	1590	1640	
10.0	1300	.10	.09	—	—	.35
	1400	.26	.18	.16	.05	.65
	1500	.32	.32	.30	.20	1.04
	1600	.39	.50	.40	.35	1.24
	1750	.70	.71	.70	.55	2.10
	2000	1.20	1.19	1.19	1.10	3.66
	2250	1.78	1.75	1.97	1.50	5.59
	2750	2.50	2.65	2.95	2.20	9.90
	Min.	1225	1250	1340	1425	

Positive Discharge — temperature 22°C.

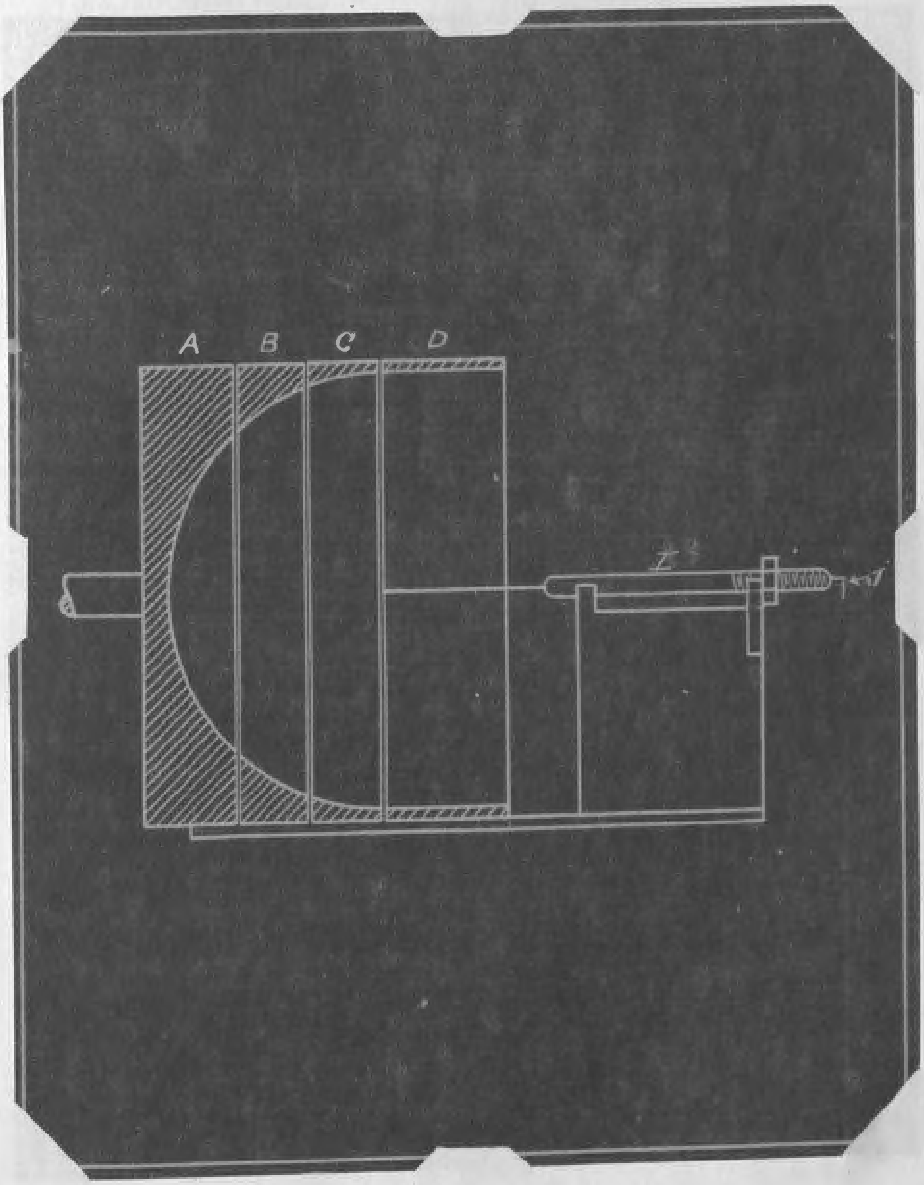


Figure 1.

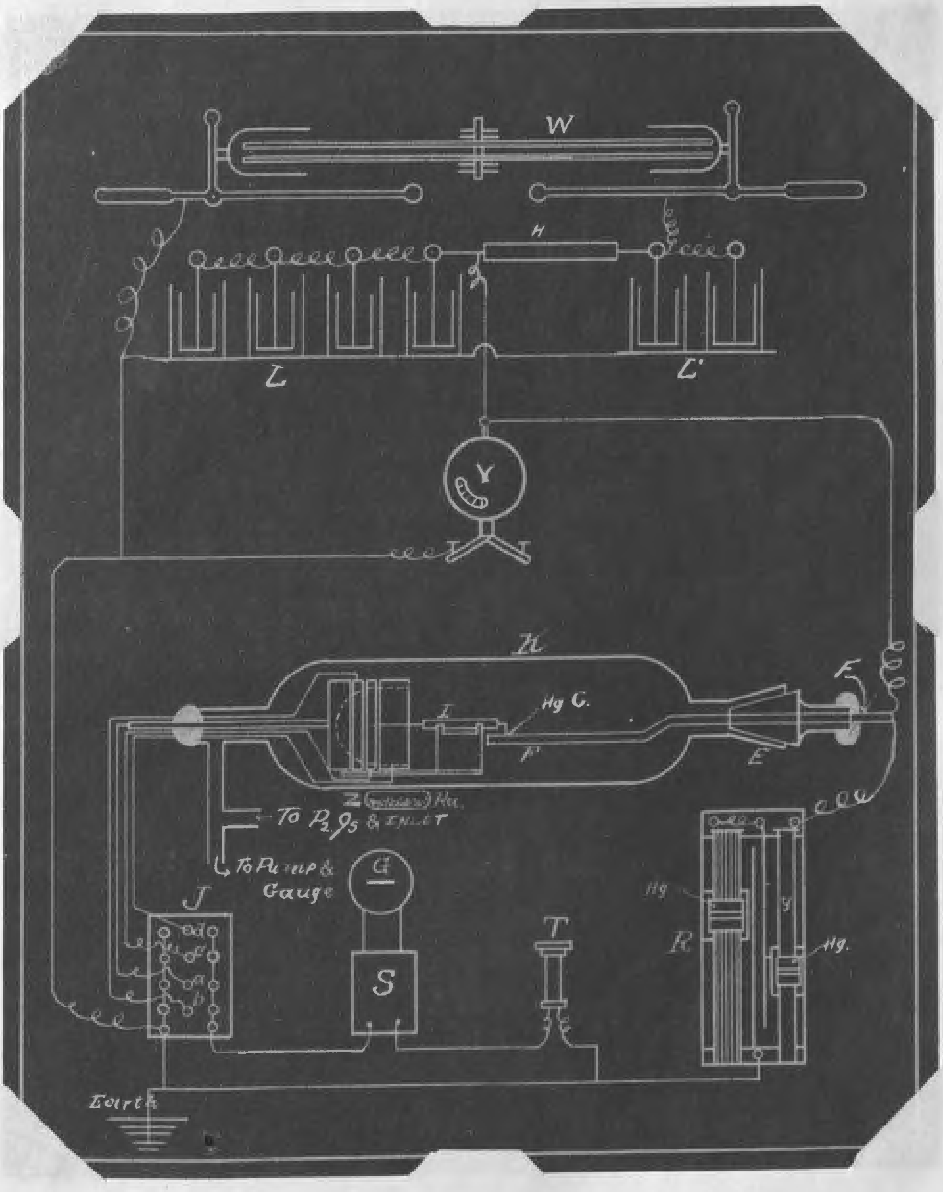


Figure 2.

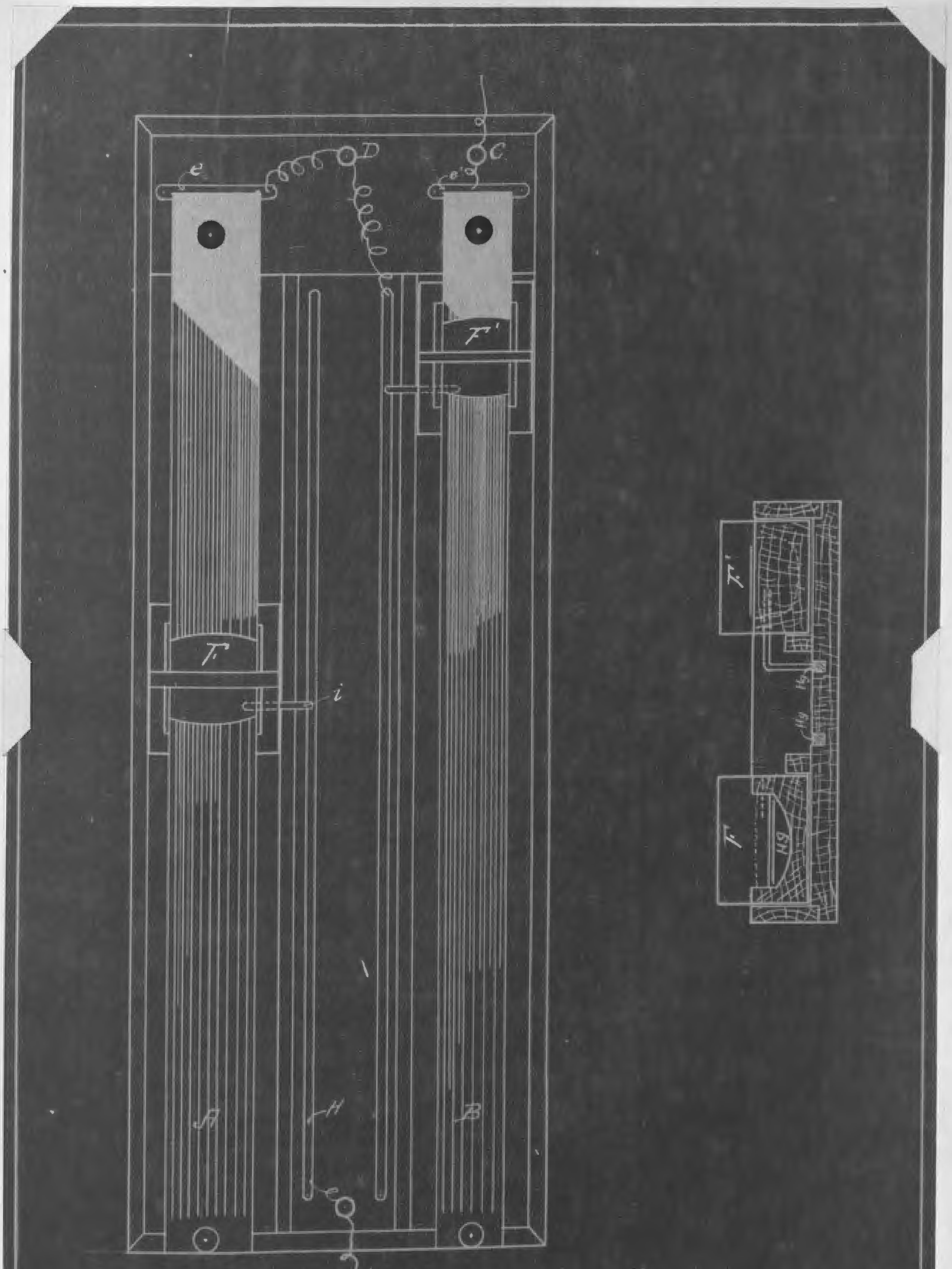


Figure #3.

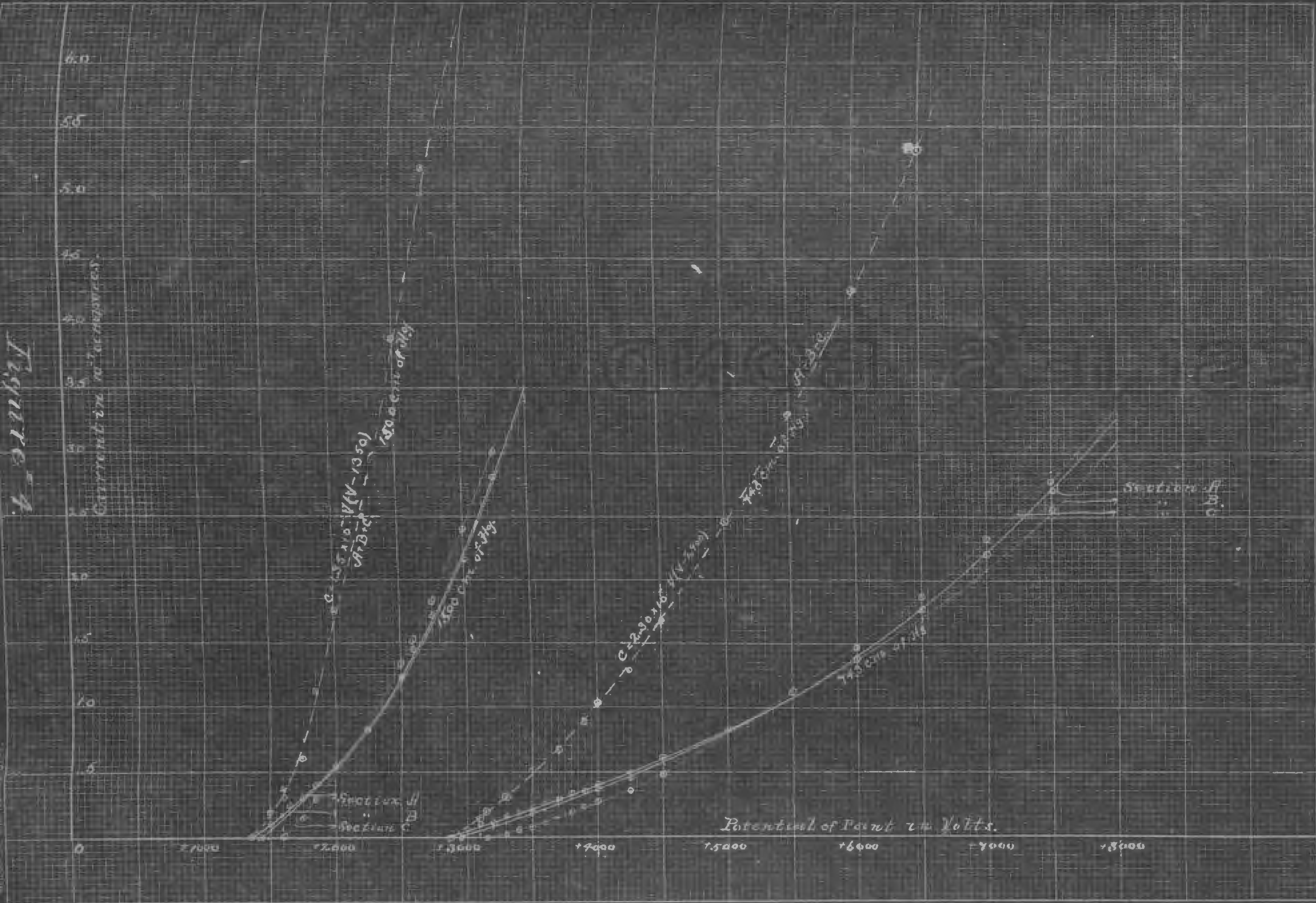

Current in Milliamperes.
Potential of Point in Volts.
0
+1000
+2000
+3000
+4000
7,5000
+6000
+7000
+8000
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
1500 cm. of Hg.
1500 cm. of Hg.
Section A
" B
Section C
Section A
" B
" C
743 cm. of Hg.
743 cm. of Hg.
A+B+C

Figure 4.

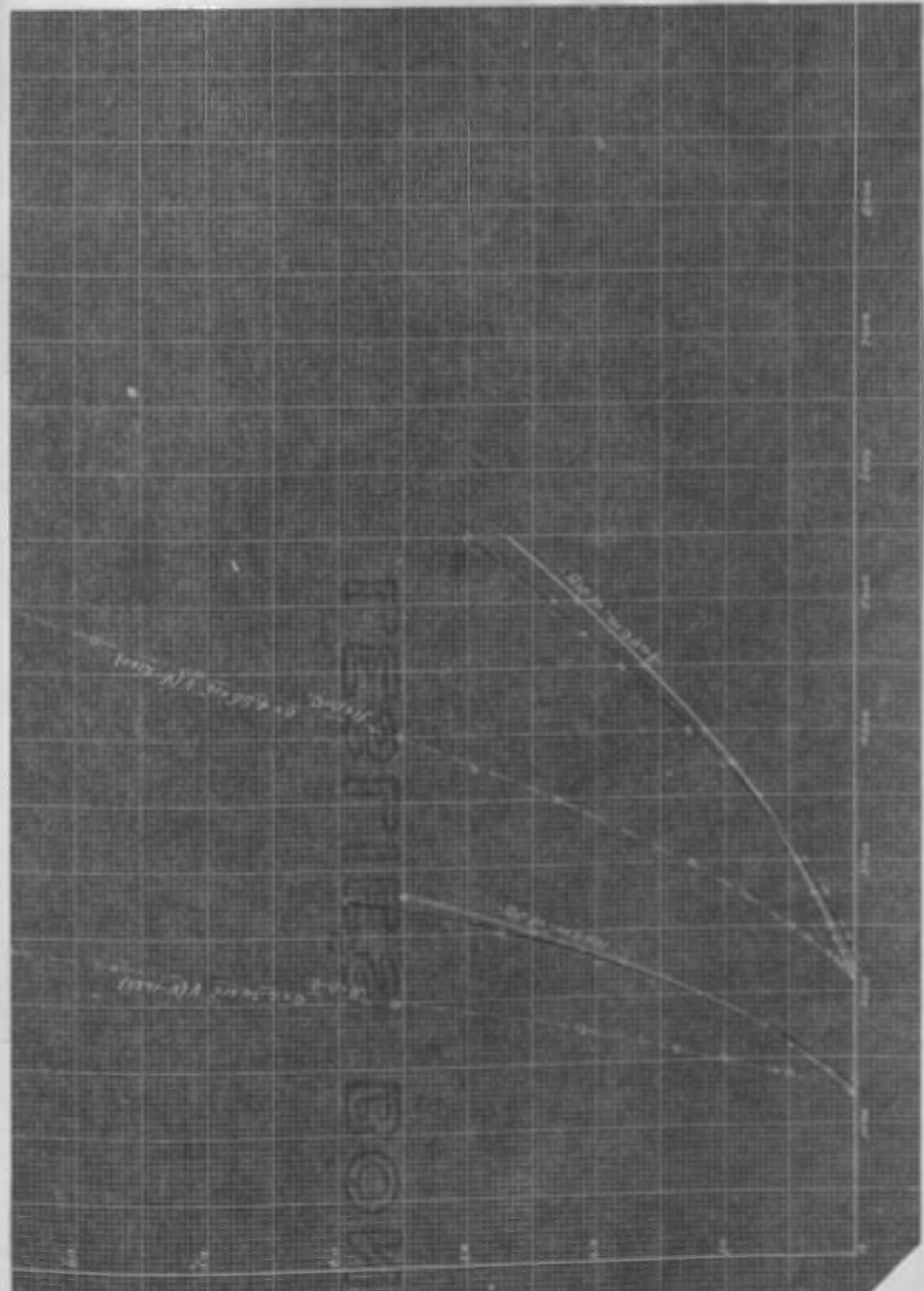
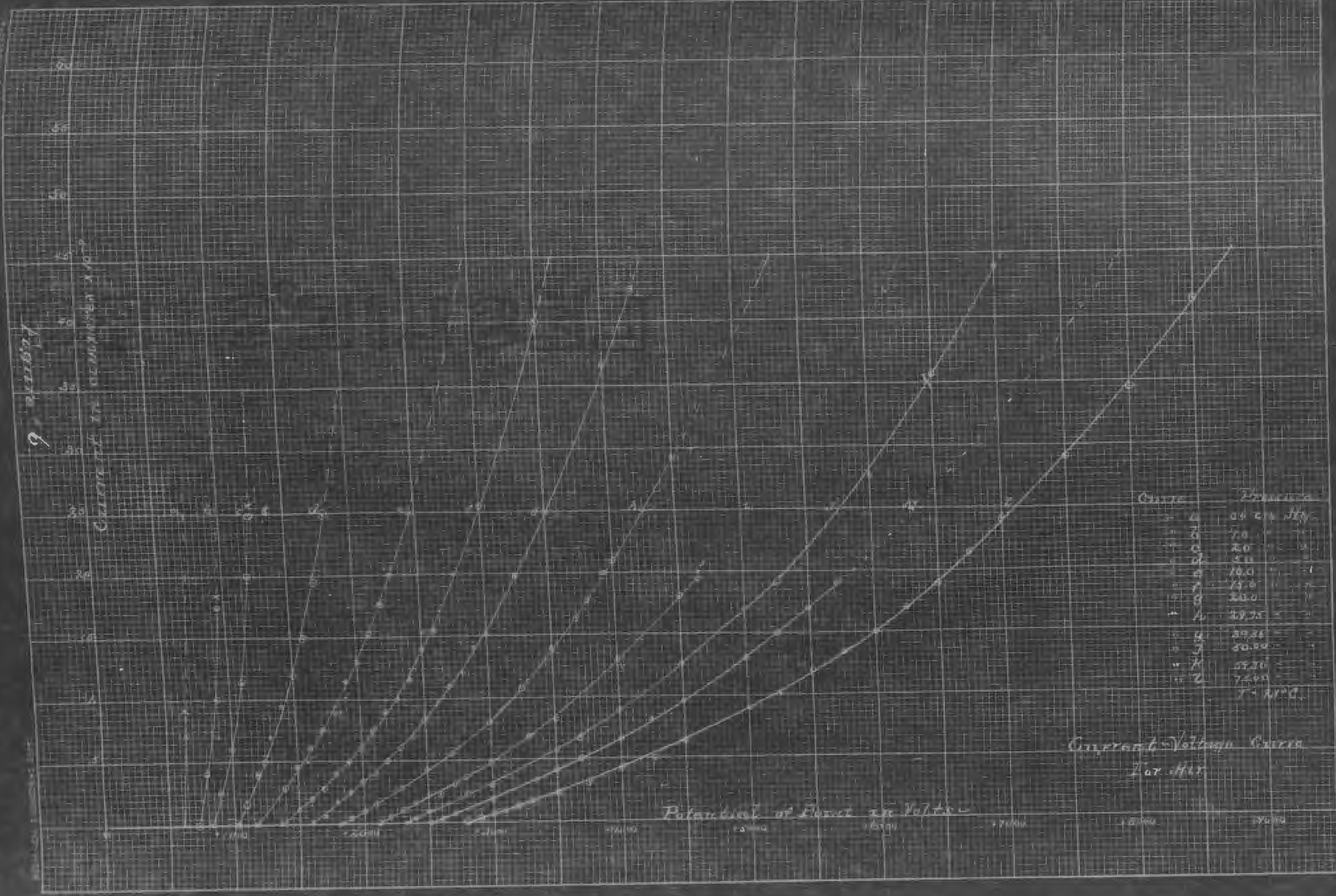
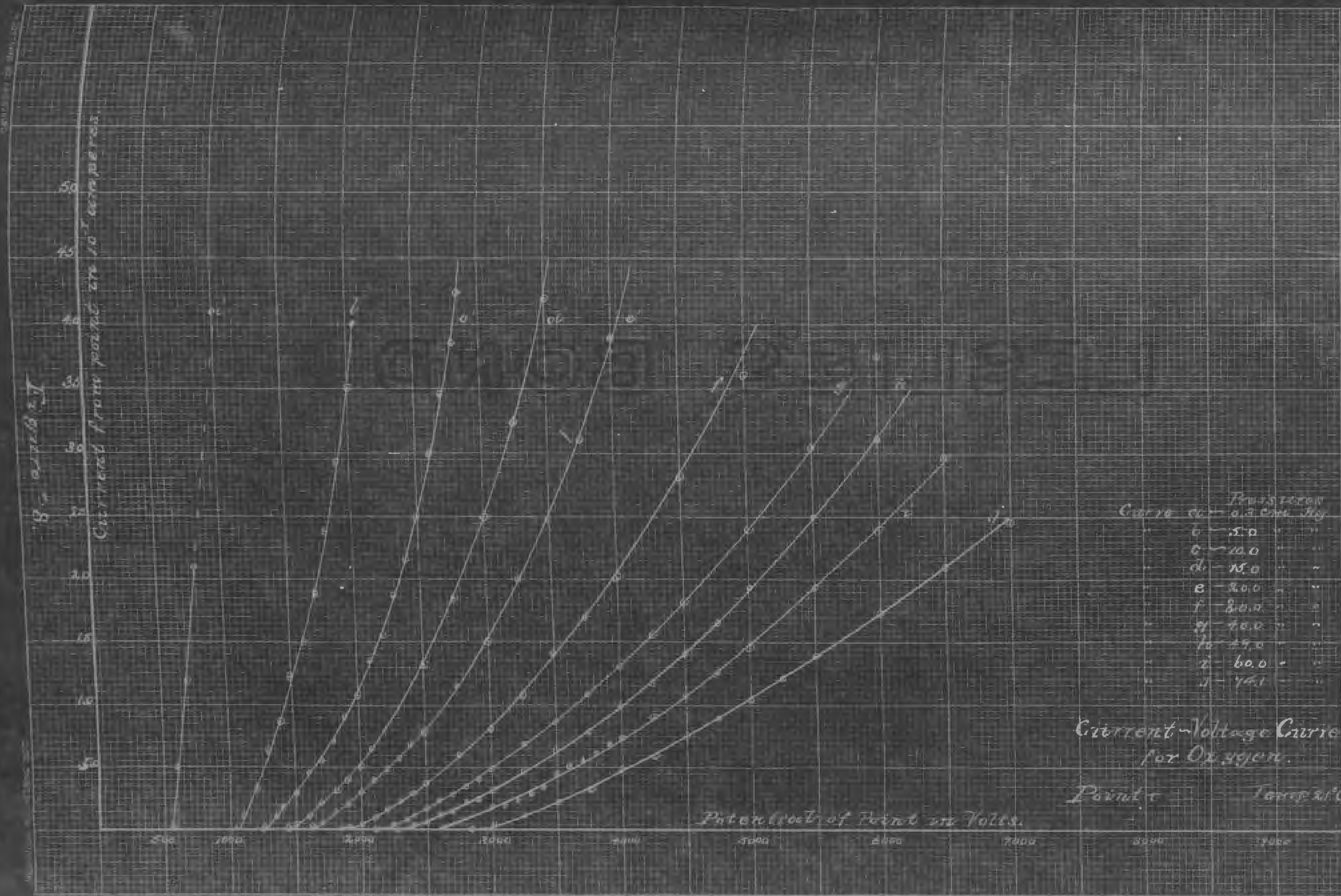


Figure 5.



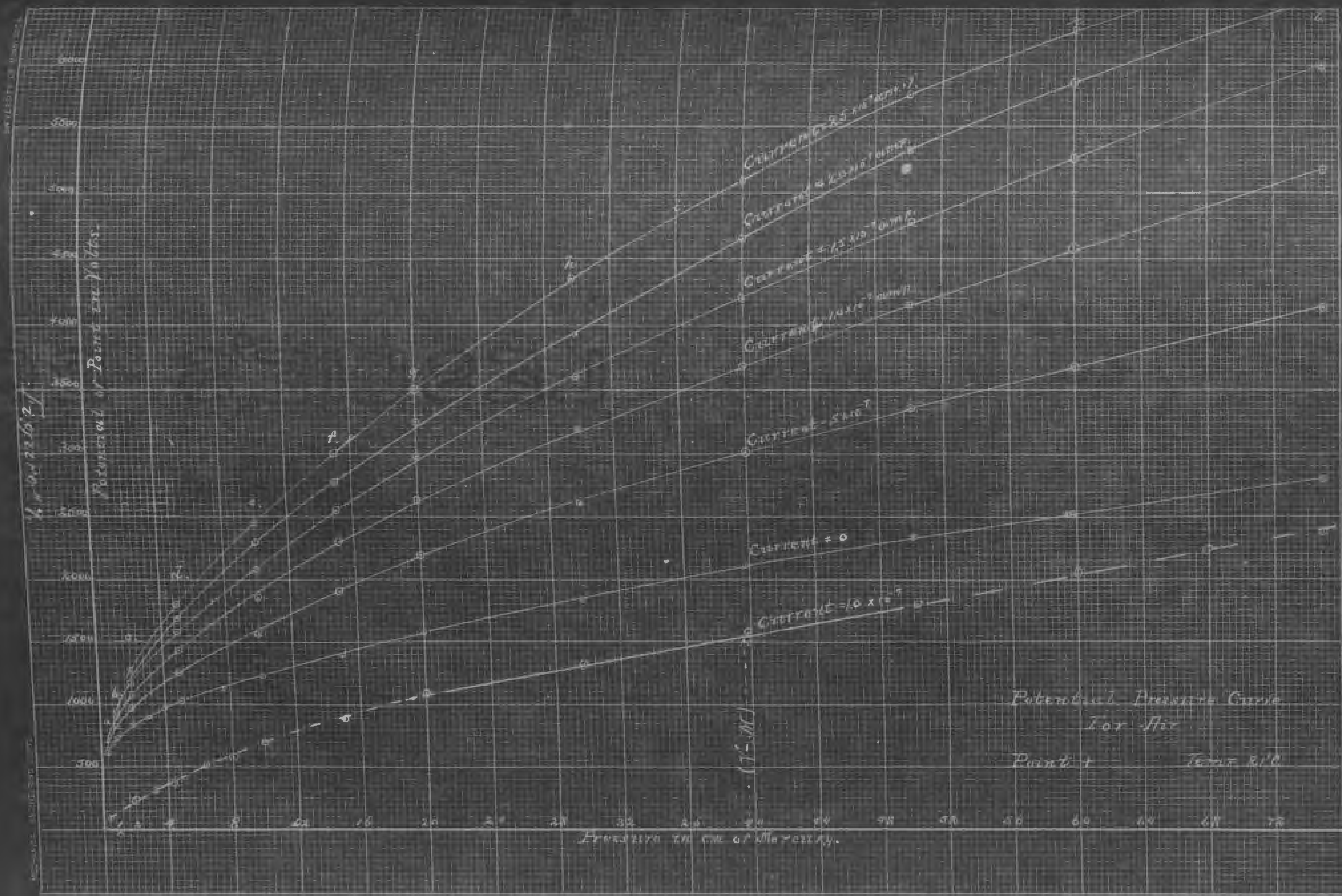
Current-Voltage Curves
For Air
Curve Pressure
a 0.4 cm Hg
b 1.0
c 2.0
d 5.0
e 10.0
f 15.0
g 20.0
h 29.75
i 39.46
j 50.00
k 57.30
l 75.00
Potential of Point in Volts

Figure 6.

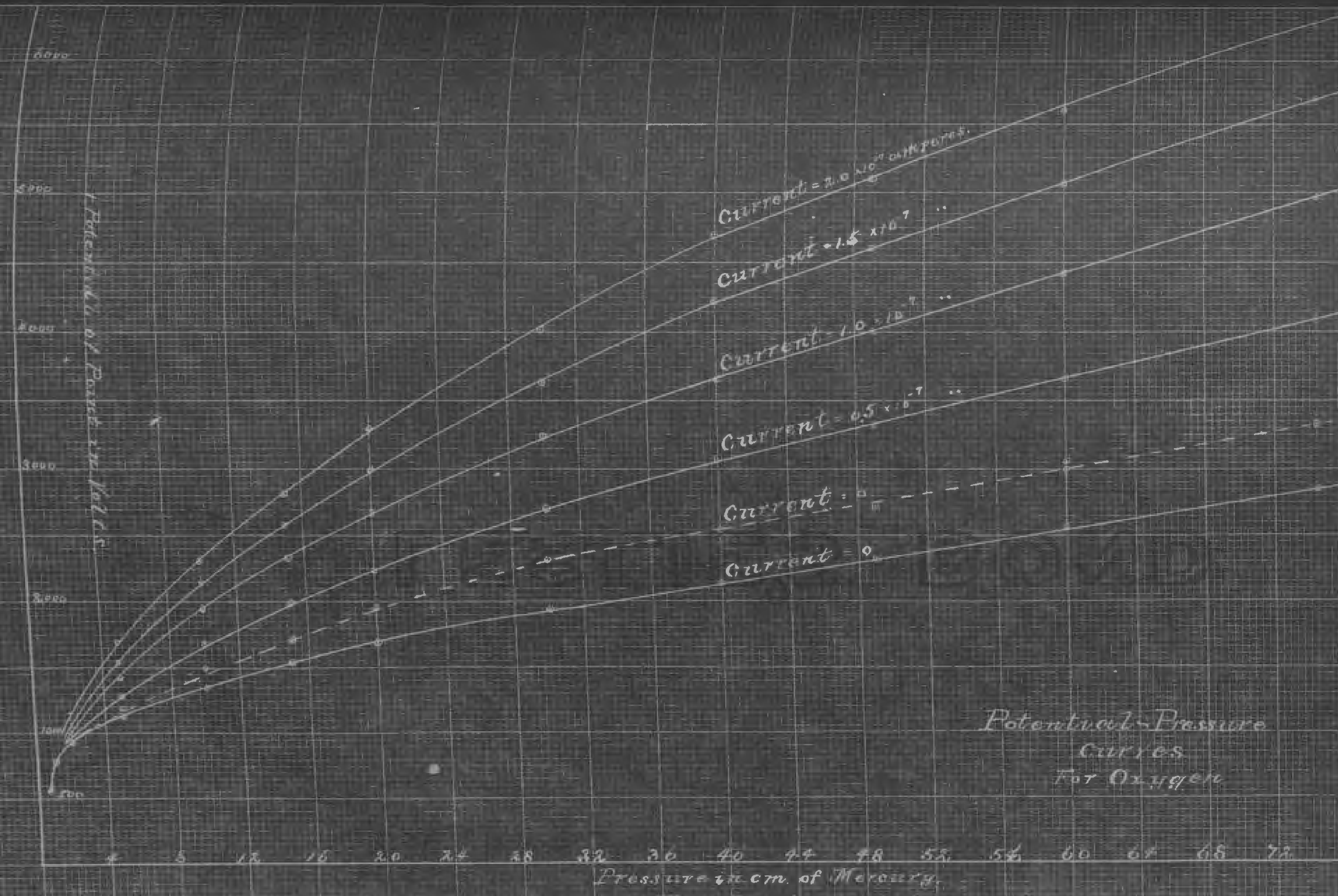


Current from point in 10⁻⁷ amperes.
5.0
10
15
20
25
30
35
40
45
50
Potential of Point in Volts.
500
1000
2000
3000
4000
5000
6000
7000
8000
9000
Pressure
Curve a — 0.2 cm. Hg
b — 5.0 " "
c — 10.0 " "
d — 15.0 " "
e — 20.0 " "
f — 30.0 " "
g — 40.0 " "
h — 45.0 " "
i — 60.0 " "
j — 74.1 " "
Current-Voltage Curve for Oxygen.
Point r
Temp 21°C

Figure 8.



Potential of Point in Volts.
Pressure in cm of Mercury.
Current = 0
Potential Pressure Curve
for Air
Point +



Potential - Pressure
Curves
for Oxygen
Current = 2.0 × 10⁻⁷ amperes.
Current = 1.5 × 10⁻⁷ "
Current = 1.0 × 10⁻⁷ "
Current = 0.5 × 10⁻⁷ "
Current = □
Current = 0
Potential of Point in Volts.
Pressure in cm. of Mercury.
500
1000
2000
3000
4000
5000
6000
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72

Figure 9.