The Effect of Temperature on the Natural Ionization of Gases in an Iron Chamber.

By

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Head of Department

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Abstract

This problem is an investigation of the effect of temperature on the rate at which ions are formed in a gas contained in an iron chamber, with all controllable sources of radiation removed. The ionization was carried out with air and with carbon dioxide at a pressure of 255 pounds per square inch. The ionization was found to increase with temperature in each case. The ionization increased more rapidly for carbon dioxide than for air.

The ionization was found to be greater for carbon dioxide than for air. The variation of ionization with pressure was found not to be a linear function for air and carbon dioxide. The curves are concave toward the pressure axis.

THE EFFECT OF TEMPERATURE ON THE IONIZATION OF GASES.

INTRODUCTION.

The conduction of electricity through gases is now generally attributed to the presence of free ions. Since there is a continual recombination of the ions present, it follows that some agent must be at work splitting up the atoms in order that the supply of ions may be kept constant. This ionization which exists in gases is known as natural or spontaneous ionization. It was at first thought that this was an inherent property of the gas itself. Later, however, the theory of a penetrating radiation was advanced and has received so much experimental support that it is now generally accepted.

The natural ionization was first investigated by Elster and Geitel[1] and by C.T.R.Wilson[2]. The experiments of Elster and Geitel showed that, with air in a closed vessel, the rate of leak was proportional to the pressure, that the leak was independent of the voltage above a certain saturation potential, and that the rate of leak was the same for positive as for negative electricity.

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1. Elster and Geitel, Phys. Zeits. 2, 560: 2, 116.
2. Wilson, Roy. Soc. Proc. 68, 151 : 69, 277.

It had been shown that ions. produced by X-rays in air saturated with water vapor. would act as nuclei for water droplets. Wilson tried to get a continuous formation of water droplets in air by natural ionization but failed. The ions formed by X-rays can be drawn out of a gas by a strong field. Attempts to free the air of the ions formed by natural ionization failed. The electroscope would discharge after the field had been applied as well as before. Wilson[3] attributed this failure to the smallness of the number of ions present but stated also that it would be incorrect to assume that these ions are identical with freshly formed ions. He further investigated the discharge of an electroscope in dust free air. From the latter investigation he concluded that continual leakage of electricity takes place through the air when a conductor is suspended in dust free air. He also found that the conductor lost the charge at the same rate in the dark as in diffuse daylight. No difference was found between the rate of leak of positive electricity and the rate of discharge of negative electricity. The discharge was found to be independent of the potential above 120 volts. The same quantity of electricity was lost in unit time at 120 volts as at 240. The rate of leak was, however, found to be dependent on the pressure of the gas under investigation.

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3. Wilson, Roy. Soc. Proc. 68, 151.

The quantity of electricity lost per second was approximately proportional to the pressure. He found about 20 ions of either sign to be produced in one c.c in one second. These results are in agreement with the observations of Elster and Geitel except that the number of ions per c.c. per sec. found by them differed from the number found by Wilson.

The origin of the radiation which brings about the ionization in closed vessels is of great interest. Four sources have been pointed out by various investigators:
Radioactive materials in the soil.
Radioactive emanation in the air.
Impurities in the walls of the vessel.
Penetrating radiation. Probably coming into the earth's atmosphere from all directions.

Rutherford and Cook[4] investigated the effect of screens on natural ionization. The apparatus used by them was similar to that used by Wilson. The rate at which ions were formed was obtained by allowing an electroscope to discharge without a protecting screen. The electroscope was then surrounded by a lead screen 2 mm. thick. The effect of this was too small to be noticeable. By increasing the thickness of the lead screen to 5 cm., however, a noticeable effect was produced, a decrease of about 30 per cent being observed. An addition of five tons of lead piled about the electroscope was not

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4. Rutherford and Cook, Phys. Rev. 16, 183.

observed to produce an additional effect. A screen 5 cm. thick of iron produced about the same effect as 5 cm. of lead. The same decrease in ionization could be obtained by a screen of water 70 cm. thick. While Wilson found 20 ions per c.c. per sec. Rutherford and Cook found but 10 in an unscreened brass vessel thoroughly cleaned.

To make use of the screening effect of water, Simpson and Wright[5] carried on their investigations on a ship over the Atlantic Ocean. They report an ionization of from 4 to 6 ions per c.c. per sec. Similar investigations were carried on with the yacht Carnegie[6] over the Pacific Ocean. The mean of the values found on the yacht Carnegie is given as 3,8 ions per c.c per second. The values obtained over the Atlantic and Pacific are thus in good agreement when one considers that the observations were carried on with different ionization chambers.

McLennan[7] and his students carried their ionization chambers of ice over Lake Ontario and found the ionization reduced to 2.6 ions per c.c per second. McLennan seems to be inclined to attribute even this remaining ionization to impurities in the ice.

Miss Downey[8] had a raft built on the Mississippi River on which she placed her ionization chamber. She could detect

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5. Simpson and Wright, Roy. Proc. 85, 175.
6. Publication #175 Vol. 3 of the Carnegie Inst. Washington.
7. McLennan, Phil. Mag. 30, 428: 30, 415.
8. Downey, Phys. Rev. 16, 420: 20, 186.

no decrease in ionization on account of the screening of the water in the river. Neither did Wilson find the ionization much changed by taking his electroscope into a tunnel. Steinke[9], on the other hand, by taking his apparatus into a tunnel 1000 meters below the surface has recently noted a marked effect because of the shielding of rocks and the soil.

Strutt[10] found that the ionization in a closed vessel depends on the material of which the ionization chamber is constructed. Of the materials studied, lead produced the highest and zinc the lowest ionization. A considerable difference was found, however, between different samples of the same material. These results were confirmed by Wood[11] and by Campbell[12]. McLennan gives as the result of similar experiments, that lead produces an ionization twice as great as that produced by zinc while tin lies between the two.

Cook[13] found that some materials, particularly brick when used for a screen, would increase rather than decrease the ionization. This increase in ionization can be entirely cut off by a very thin sheet of lead. J.J.Thomson suggested that every material emits and absorbs penetrating radiation capable of producing ions in a closed vessel, and that the screening effect depends on the ratio of the emission and the

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9. Steinke, Zeits. f. Phys. 48, 647.
10. Strutt, Phil. Mag. 5, 680.
11. Wood, Phil. Mag. 9, 550.
12. Campbell, Phil. Mag. 11, 206.
13. Cook, Phil. Mag. 6, 403.

absorption for the material and on the thickness of the screen. Cook found further that no matter how thick the lead screen the ionization could not be reduced more than 30%. This led to the conclusion that there must be a very penetrating radiation from an external source. An unsuccessful attempt was made by Cook to gain some evidence as to its direction by placing a lead screen in various positions with respect to his ionization chamber. He concluded that the radiation came equally from all directions. Millikan's[14] experiments on Pikes Peak led him to the same conclusion.

In 1910 A.C. Eve[15] worked out a relationship between altitude and radiation, assuming that the radio-active material was distributed over the surface of the earth. This led to a series of experiments at different altitudes. Wulf[16] carried his electroscope to the top of Eifel tower and found that the ionization decreased from 6 to 3.5 ions per c.c. per second. Gockel[17] made the first observations in a balloon. In the first two trips he found no variation, in the third trip, however, he found an actual decrease but not as much as would be expected if the ionization were all of a terrestial origin. Gockel concluded that there must be another source of penetrating radiation besides the γ rays

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14. Millikan and Bowen, Phys. Rev. 27, 353.
15. Eve, Phil. Mag. 21, 26.
16. Wulf, Phys. Zeits. 10, 997.
17. Gockel, Phys. Zeits. 16, 345.

which are due to the radio-active elements in the earth's surface. Hess[18] made ten balloon trips to test the ionization above the earth's surface. Some of his observations were made during the night because of the fact that Pacini[19] had noticed fluctuations in the ionization. One of his trips was made during the sun eclipse of 1912. He found no dependence of ionization on the time of day, neither did the sun eclipse have any effect on the ionization. Hess concluded from these observations that even if part of the radiation were cosmic it could hardly come from the sun. On one of his flights which carried him to a height of 5350 meters he noticed a slight decrease in ionization up to 2500 meters but from there on the ionization increased. The ionization varied from 17.3 at the surface to 40.7 ions per c.c. per sec. at 5350 meters. Hess explained these results by assuming a very penetrating radiation to come from above into our atmosphere penetrating to the surface of the earth and causing part of the ionization in closed vessels. This penetrating radiation seemed to undergo fluctuations. The increase in cosmic radiation in the first 1000 meters was exceeded by the decrease in radiation caused by the radio-active substances in the earth's surface. He assumed the penetrating radiation to be very complex and predicted that the absorption curve for the incoming radiation would be exponential.

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18. Hess, Phys. Zeits. 12, 998: 13, 1084; 14, 610.
19. Pacini, Accad. Lincei. Atti. 18, 123.

Hess divided the radiation into three parts; radiation from the earth's surface, radio-active substances of the atmosphere, principally radium C, and a radiation which increases with height and exerts a marked influence even at the earth's surface.

Kolhoerster[20] made observations up to 9000 meters. His work confirms the results of Hess. At 9000 meters he found an ionization of 80.4 ions per c.c. per second.

Gockel and Oberguggenberger detected irregular fluctuations in the radiation. Hertz and Kofler found nothing positive as to fluctuations. Hess, DeBrogle, Kolhoerster, and Devik found no effect because of the sun eclipse. Kolhoerster claims to have observed a relation between the radiation and the position of the Milky-way. At first this effect was found only on top of a high mountain but recently he found this relationship also in Berlin. Buttner confirmed the observations of Kolhoerster by noting the same relationship in Goettingen. Millikan and Cameron[21], on the other hand, find no effect of the Milky-way on the ionization.

Millikan and Bowen[22] sent recording balloons to an altitude of 15 kilometers. Their results show values only 25% of that expected from Kolhoerster's curves. Millikan and Otis[23] found the ionization greater on Mt. Whitney than at sea level. On Pikes Peak they found that a heavy blanket of snow on the ground

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20. Kolhoerster, Deutch. Phys. Gesell. Verb. 16, 719.
21. Millikan and Cameron, Phys. Rev. 28, 851: 31, 163: 31, 921.
22. Millikan and Bowen, Phys. Rev. 27, 353.
23. Millikan and Otis, Phys. Rev. 27, 645.

decreased the ionization. While Millikan and Otis found 5.9 ions per c.c. per sec. on Pikes Peak, Swann[24] found but 0.75 at the same place.

Millikan and Cameron[25] sank an electroscope to a depth of 50 ft. below the surface of the water in Muir Lake(Alt. 11800 ft.) and found that the ionization decreased from 13.3 at the surface to 3.6 ions per c.c. per second. Readings taken in Arrowhead Lake (Alt. 5100ft.) correspond to readings taken at a depth of 6 ft. deeper in Muir Lake. From a curve drawn for ionization under water μ varies from 0.25 to 0.15 per meter of water. This corresponds to wavelengths from o.000525 to 0.00032 A. They concluded that the rays are of cosmic origin, very hard, and that they enter the earth uniformly from all directions. Millikan and Cameron also carried on a series of experiments during thunder storms to test the theory advanced by Wilson that the rays might be due to high potential discharges. Their results showed no difference in ionization during a heavy storm. These same experimenters went to a lake in the high Andes Mountains which was fed by snow water and surrounded by peaks. They built a raft and carried on experiments over the middle of the lake. The object of these experiments was twofold. The first was to test the theory that the cosmic rays might come from the sun and be deflected toward the poles. In this event the ionization

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24. Swann, Phys. Rev. 29, 372.
25. Millikan and Cameron, Phys. Rev. 31, 163: 31, 921: 28, 851.

in the Andes should be less than at Pasadena. This was not borne out by the results obtained as the ionization was found to be the same as at Pasadena. In the second place they hoped to make a convincing test as to the relationship between the cosmic radiation and the Galaxy. The results in this case were also negative.

Patterson[26] found that the ionization is proportional to pressure for low pressures but not for pressures above 30 cm. when the vessel is large. Miss Downey[27] found the ionization nearly proportional to the pressure up to 20 atmospheres. The curves given by Fruth[28] are practically straight up to 50 atmospheres and then bend toward the pressure axis. Broxon[29] carried the pressures up to 100 atmospheres and found no saturation pressure. His curves are smooth and at all points concave toward the pressure axis.

A. Wood[30] heated the walls of the vessel and found an increase in ionization. Air drawn over tin discharged an electroscope more rapidly when the tin was heated than when the tin was cold. This increased conductivity could be removed from the air by passing it through metal tubes, proving that it consisted of ions and not of an emanation.

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26. Patterson, Phil. Mag. 6, 231.
27. Downey, Phys. Rev. 16, 420.
28. Fruth, Phys. Rev. 22, 109.
29. Broxon, Phys. Rev. 27, 542.
30. Wood, Phil. Mag. 9, 550.

Kunsman[31] investigated the effect of temperature on the ionization of gases by making an electroscope air tight and immersing it in a cooling bath. The data obtained shows an increase in ionization with decrease in temperature. He concluded, however, that the apparent increase in ionization was due to an increase in conductivity over the surface of the insulation, and that the electrical conductivity of residual ionization is not caused by the molecular impact which is due to thermal agitation.

Campbell[32] found a slight increase in ionization while the temperature of the ionization chamber was being raised and a decrease while the temperature was being lowered. He suggested that this might be due to electricity induced on the electrode by very massive charged particles carried about by convection currents.

Patterson[33] heated the ionization chamber while the pressure was kept constant. He found that the ionization current increased but very little if at all. Patterson, however, allowed the gas to expand and this brings about a decrease in density. A decrease in density causes a decrease in ionization which is due to penetrating radiation, as has been shown by a number of observers; an increase in ionization on account thermal effect would thus be offset by a decrease in

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31. Kunsman, Phys. Rev. 16, 349.
32. Campbell, Phil. Mag. 13, 614.
33. Patterson, Phil. Mag. 6, 231.

ionization because of penetrating radiation.

Devik[34] heated the gas by adiabatic compression and measured the ionization at the moment of greatest compression. Antimony hydride was the only gas studied which showed any marked increase in ionization at the highest temperature obtained, which he estimated to be 900 degrees Centigrade.

Kingdon[35] made an air tight ionization chamber about which he wound a resistance wire for changing the temperature. The temperature was changed from 30 to 100 degrees Centigrade at constant volume. The observed changes in ionization were very small from 30 to 80 degrees and much larger from 80 to 100 degrees.

Langevin[36] deduced a formula for the ionization that might be produced by thermal impact. This expression, however, demands that the ionizationincrease very rapidly with temperature which is contrary to experimental evidence. Kingdon[37] revised the formula so as to give results which are in fair agreement with observed values.

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34. Devik, Sitz. d. Heid. Akad. Wiss. 24, (1914)
35. Kingdon, Phil. Mag. 32, 398.
36. Langevin and Rey, Le Radium, 10, 142. (1913)
37. Kingdon, Loc. Cit.

APPARATUS.

The apparatus was set up as shown in Fig. 1. The essential parts are: an ionization chamber (A), a gold leaf electroscope (B), a cooling system for the amber insulation (C), a device for maintaining a constant water pressure (D), an electrical furnace (E), a thermostatic control (F), and two thermocouples, one(G) for measuring the temperature of the furnace and the other (H) for measuring the temperature of the insulation.

The ionization chamber (Fig.2) consists of a cylindrical steel tank, fifteen cm. in diameter, having a capacity of 10.06 liters. To this was fitted the cooling system, turned out of steel. A detailed drawing of this is shown in (Fig. 3). The neck of the cooling system was about five inches long, with a small hole (1.3 cm.) through the center of it. The neck was made long in comparison with the diameter in order to cut down the conduction of heat. Convection currents were kept low by the small hole through the neck and further reduced by a glass plate at the upper end of the neck. The hole through the glass plate was made 5 mm. in diameter. In order to allow room for the end of the amber plug and an annular tray of drying material, the hole was enlarged to 5 cm. at the upper end. Water was allowed to circulate freely through a cavity about the upper part of the neck. The lower

General Set-up of Apparatus.

Fig. 1

A - Ionization chamber
B - Gold leaf electroscope
C - Cooling system
D - Overflow can for adjusting water pressure
E - Electrical furnace
F - Bimetal thermostat for regulating temperature of furnace
G - Thermocouple junction for measuring temperature of ionization chamber
H - Thermocouple junction for measuring temperature of amber
I - Temperature adjustment screw and platinum contacts
J - Constant temperature bath
K - Double pole double throw switch to throw galvanometer to upper thermocouple or to potentiometer
L - Galvanometer
M - Potentiometer
N - Battery for potentiometer
O - Double throw double pole switch to throw thermocouple or standard cell to potentiometer
P - Standard cell
Q - Water outlet - to sink
R - Pressure gauge for measuring pressure in ionization chamber
S - Hot plate
T - Battery to operate relay
U - Relay to operate switch in main circuit
V - Shunt resistance across switch in main circuit
W - Series resistance
X - Outlet from overflow can - to sink
Y - Resistance to control current in hot plate
Z - Boiler to warm water when ionization chamber is below room temperature

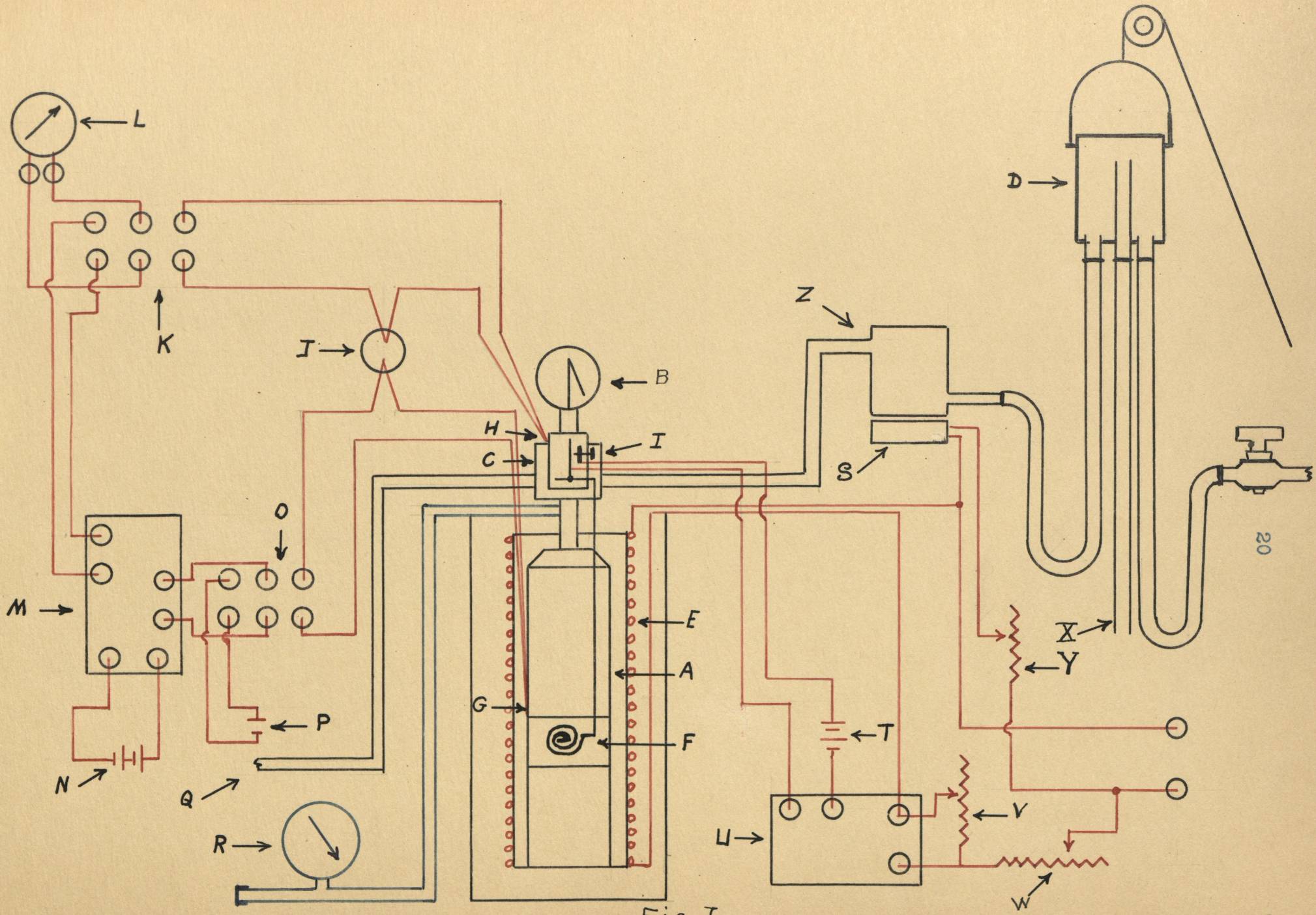


Fig. I

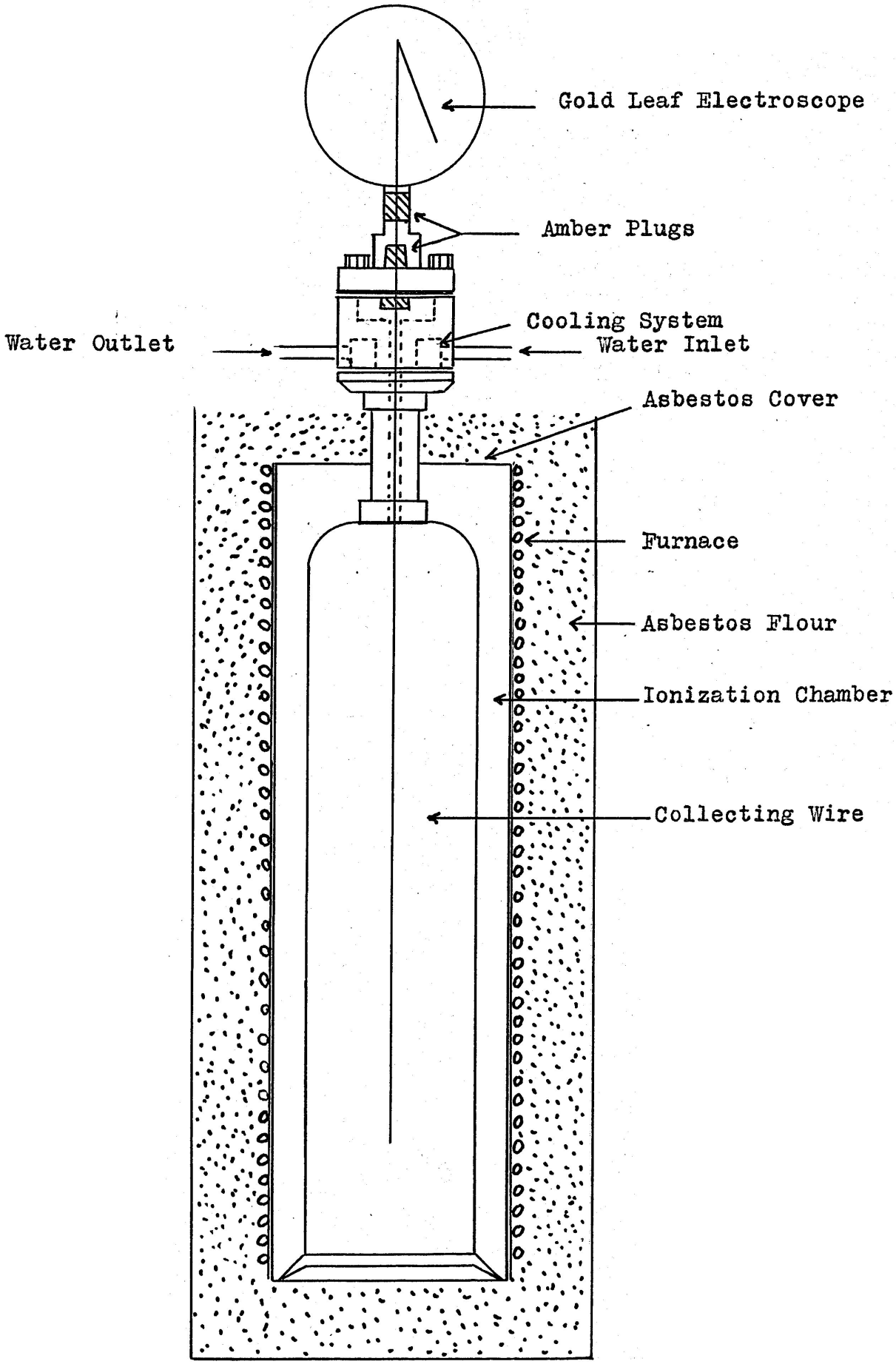

Gold Leaf Electroscope
Amber Plugs
Cooling System
Water Outlet
Water Inlet
Asbestos Cover
Furnace
Asbestos Flour
Ionization Chamber
Collecting Wire

Fig. 2

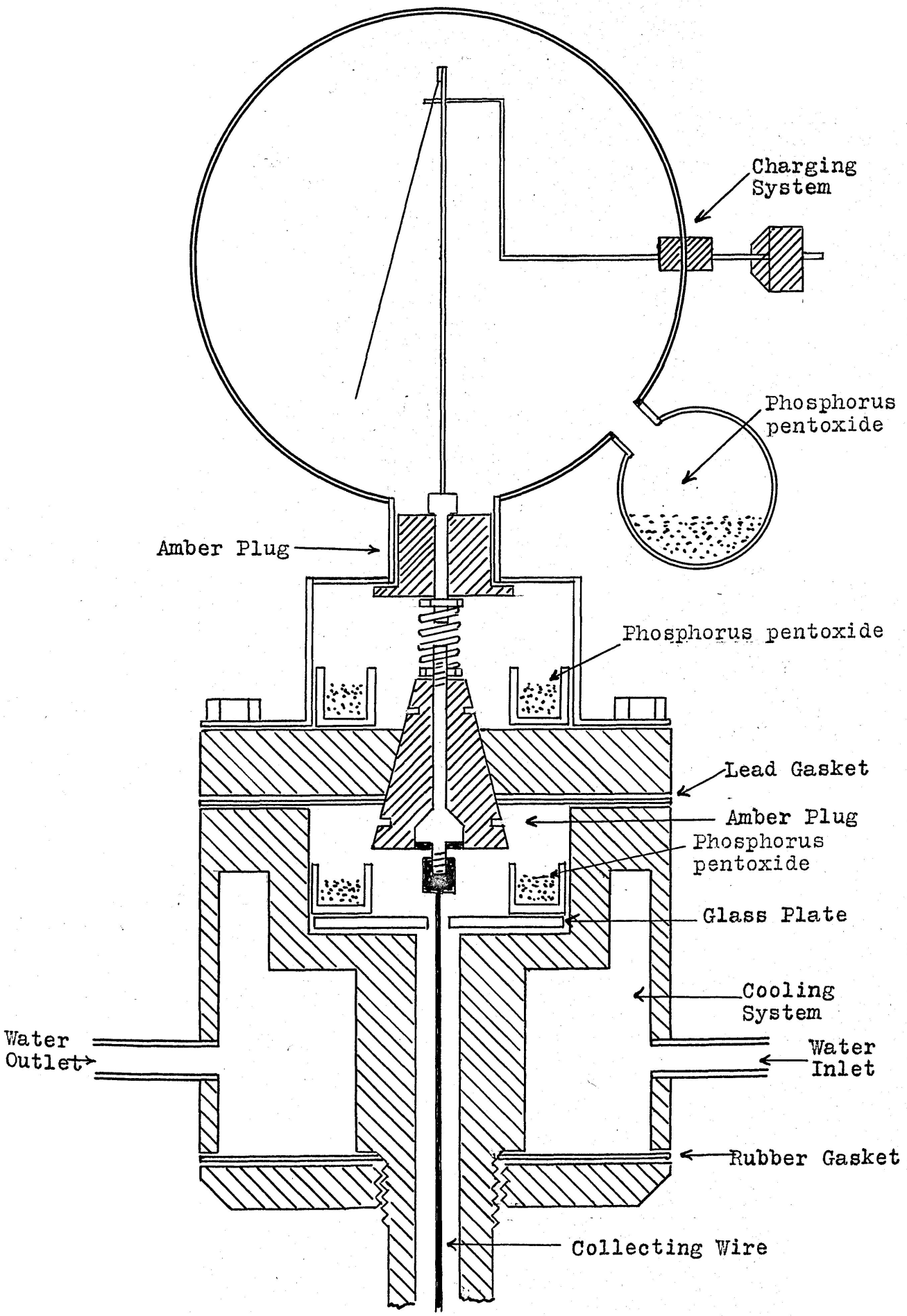

Charging System
Phosphorus pentoxide
Amber Plug
Phosphorus pentoxide
Lead Gasket
Amber Plug
Phosphorus pentoxide
Glass Plate
Cooling System
Water Outlet
Water Inlet
Rubber Gasket
Collecting Wire

Fig. 3

part of this cavity was closed by a steel plate threaded onto the neck and fitted with a rubber gasket. A steel plate, 1.5 cm. thick, closed the upper end of the neck. Into this plate was fitted an amber cone which carried the central system for collecting the charges. The metal part was made of brass, cone shaped at one end. Both ends of this brass were turned to the same size and threaded in order that the collecting wire might be attached to either end. The steel plate is also reversible so that the plate may be used in the position shown when the tank is filled with gas. When it was desired to exhaust the tank the plate was turned over. In this way the brass cone, the amber cone, and the steel plate will always be forced together by the existing pressure, thus making an air tight joint. The steel plate was held in place by nine machine bolts. A lead gasket made the joint between the plate and the main body air tight.

The gold leaf electroscope was supported by a separate housing held in place by three machine bolts. In order to avoid convection currents in the electroscope as much as possible, an amber plug was fitted into the neck of the electroscope. Contact between the electroscope and the collecting system was made by means of a coiled spring of brass wire. On the inside of the housing supporting the electroscope was placed an annular tray of phosphorus pentoxide. The electroscope was also provided with a flask

containing phosphorus pentoxide. A thin piece of brass was soldered onto the upper end of the leaf support. The leaf was stuck onto this piece of brass thus causing the leaf to free itself from the support up to the edge of this piece of brass. All joints of the electroscope were coated with sealing wax and paraffin, thus making it practically air tight. The electroscope was provided with a reading microscope and to facilitate the reading a fine quartz fiber was fastened to the end of the gold leaf.

To keep the temperature of the amber constant the outlet of the cooling system was provided with a stop cock and the intake with an overflow can the height of which could be adjusted. A boiler was also provided so that the water could be warmed when the temperature of the ionization chamber was below room temperature.

The collecting system consisted of a brass rod, 3 mm. in diameter, supported by a thin Chromel wire. Chromel wire was used for the support since it has a very low coefficient of thermal conductivity.

The furnace was made of two tanks, one eight inches in diameter and thirty-four inches high, the other fourteen inches in diameter and forty inches high. (Fig.2). The smaller tank was made of heavy sheet iron so as to make it rigid. It was covered with asbestos paper and then wound with number ten Chromel A wire so as to have a resistance

of about seven ohms. The wire was held in place by American Seal furnace cement which was found to work admirably. The cement was applied only in narrow vertical strips thus leaving most of the wire exposed. Four such strips were found to be ample to hold the wires in place. After the cement had dried this tank was placed into the larger one, leaving three inches at the bottom, and the space between the two tanks filled with asbestos flour. The ionization chamber was then placed into the furnace, an asbestos cover fitted around the neck of the cooling system, and asbestos flour added to fill the outer can. The furnace was placed on a concrete pier and firmly anchored to it. The ionization chamber was anchored to a rigid ring about the upper part of the outer can which was in turn anchored to the pier. This was done in order to avoid any change of capacity which might be caused by a tilting of the cylindrical chamber.

The temperature was controlled by means of a bi-metal thermostat and a system of levers.(Fig.4). The platinum points opened and closed a circuit which in turn operated a switch in the main circuit. An old magnetic control from a Johnston heating system was slightly modified and found to be exceedingly sensitive as a control switch. A shunt resistance was placed across the switch terminals in addition to a series resistance in the main circuit. It was found that by proper adjustment of the series and shunt

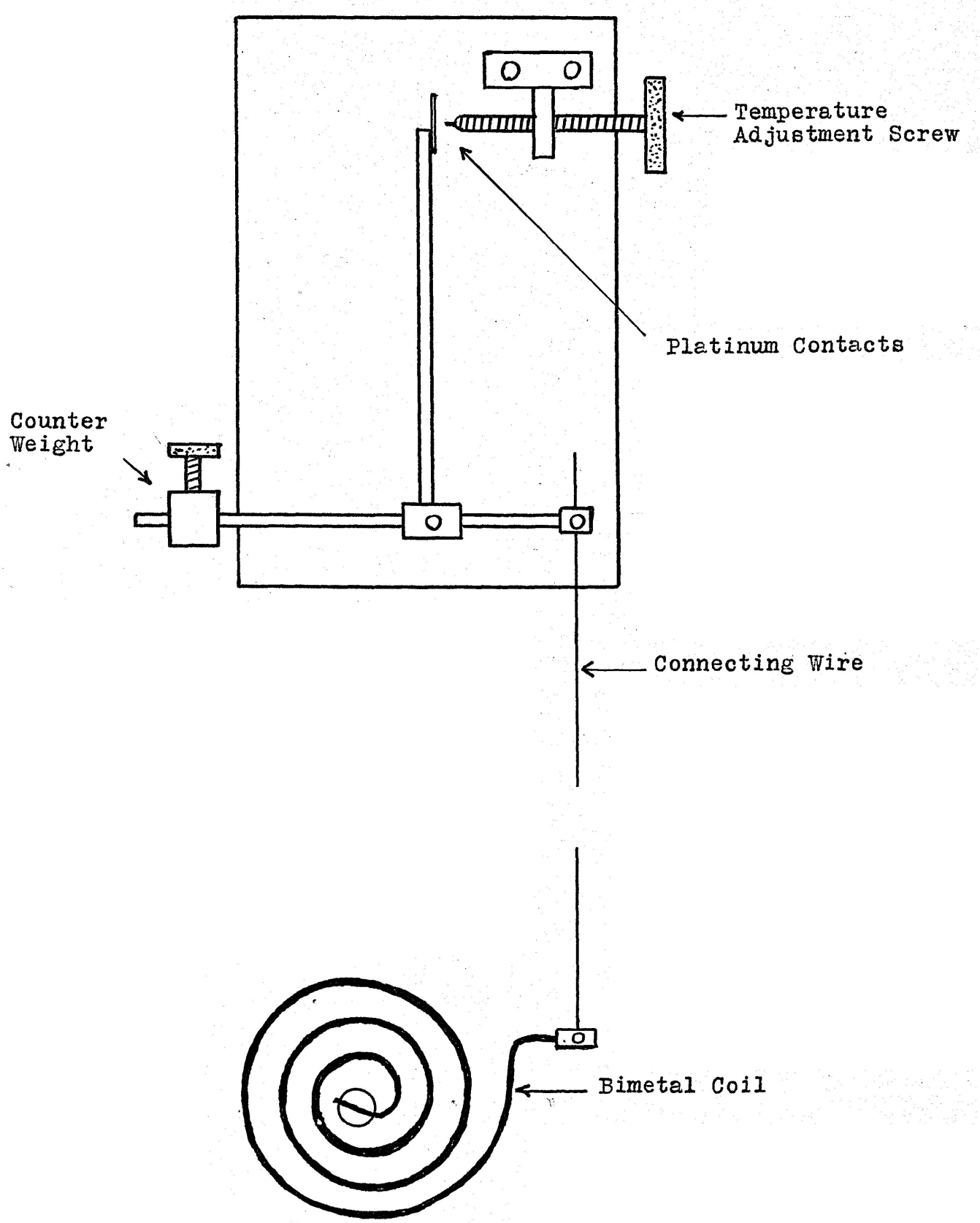

Temperature
Adjustment Screw
Platinum Contacts
Counter
Weight
Connecting Wire
Bimetal Coil

Fig. 4

resistances the temperature could be kept from over shooting. With a little patience the adjustment could be made to hold the temperature constant to one degree and left without attention for days.

The temperature was obtained with a Chromel-Alumel thermocouple in connection with a potentiometer. One junction was fastened to the middle of the ionization chamber while the other end was kept in a constant temperature bath. For comparison a mercury thermometer was also placed on the inside of the furnace. A second thermocouple had one junction fastened onto the cooling system close to the amber while the other junction was kept in a constant temperature bath.

A standard condenser of the desired range not being obtainable a parallel plate condenser was constructed.(Fig.5). The central disk and guard ring are supported by hard rubber, the central disk being mounted firmly to it by means of amber insulation. The guard ring which has an inside diameter of 5.2 cm. and an outside diameter of 7.2 cm. is mounted on a three point adjustable support so that it can be brought into the plane of the central disk. The movable plate consists of a disk 7.2 cm. in diameter, mounted on a micrometer shaft. The support holding the micrometer is bolted firmly to the iron base. The support of the guard ring and central disk is so mounted as to allow an adjustment in declination and azmuth. By these adjustments

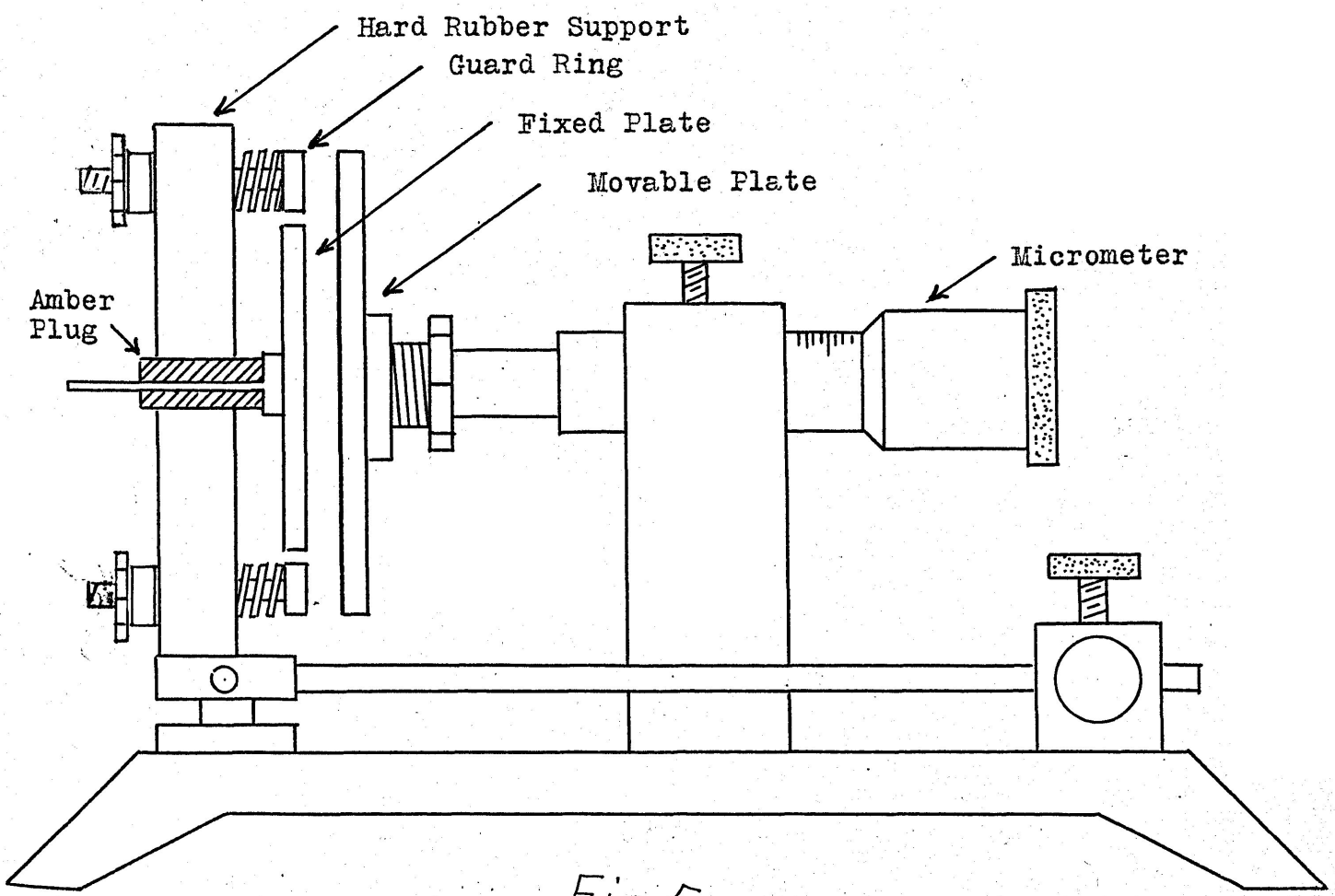
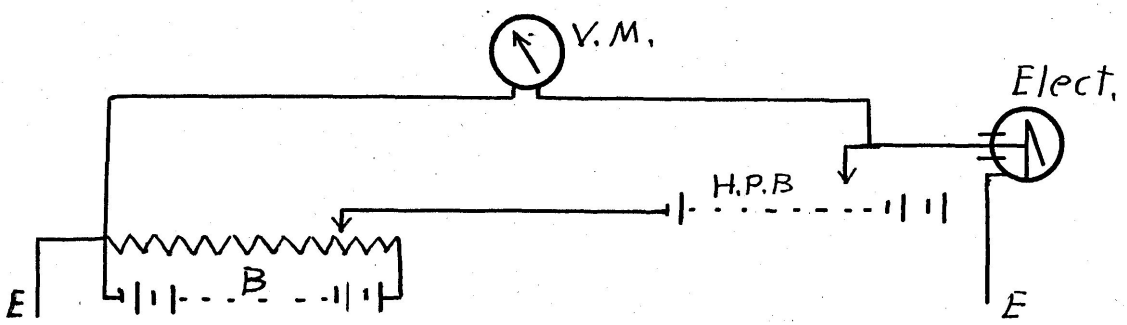

Hard Rubber Support
Guard Ring
Fixed Plate
Movable Plate
Micrometer
Amber
Plug

Fig. 5

the guard ring, central disk, and movable disk can be brought into parallelism. A contact key is fastened to the hard rubber support and by means of it the central disk may be connected to or disconnected from the guard ring.

Method and Results

The gold leaf was calibrated by means of a high potential battery in series with a 22 volt potentiometer arrangement connected as shown in the diagram. Taps on the



high potential battery allowed sections to be cut out as desired. The potential was measured with a Siemens and Halske standard voltmeter. In order to avoid any error caused by a lag between the applied potential and the deflection of the gold leaf the leaf was charged to its maximum deflection and readings taken at every ten divisions down to zero, then without allowing the leaf to discharge, the potential of the leaf was raised again by steps of ten divisions and readings taken up to the maximum. A number of observations were made in this manner and the mean used for plotting a curve. In order to obviate any error caused

by the "soaking-in effect" in the amber the leaf was never allowed to discharge completely during a run. The results are shown in table I and curve I.

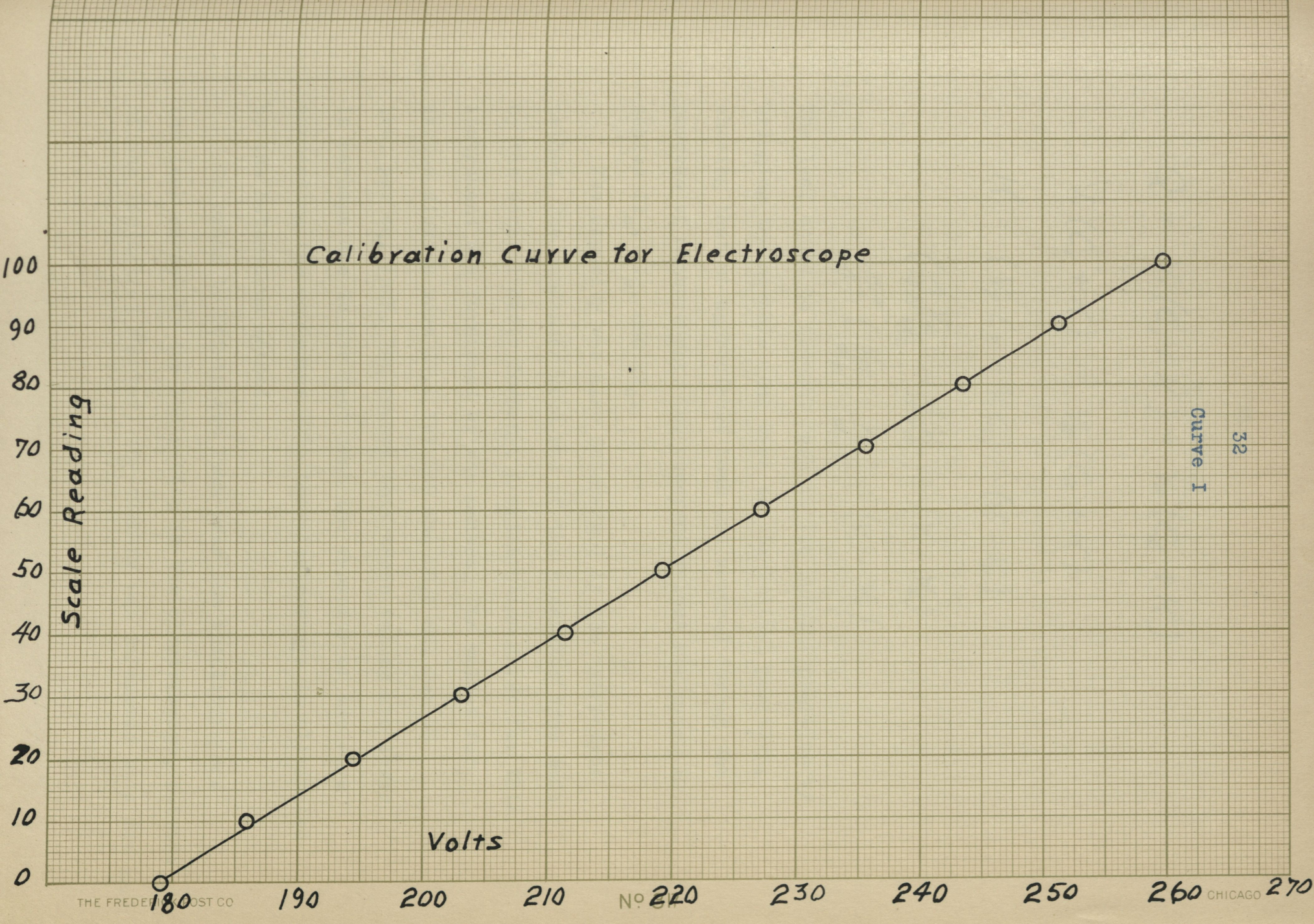
The capacity of the electroscope was obtained by means of the parellel plate condenser. The leaf system was connected to the central disk, the movable plate removed to a definite distance, and the desired voltage applied with the guard ring connected to the central disk. The central disk was then disconnected from the guard ring and the movable plate brought up to the central disk until the leaf had fallen to the desired potential. During this process the guard ring, which was always connected to the battery, was kept at the same potential as the leaf. This potential of the leaf was determined from the scale reading and the curve. When the central disk is disconnected from the guard ring the quantity of electricity, Q, on the condenser and the collecting system with the electroscope remains constant. If the capacity of the electroscope is represented by K, the capacity of the condenser in the initial position by C_1, the capacity in the final position by C_2, the initial distance between the plates by d_1, the final distance between the plates by d_2, and the radius of the central disk by r, then:

Table I

CALIBRATION OF GOLD LEAF

Data

Scale Reading	Volts	Volts	Volts	Volts	Mean
10	258	261	260	260	259.8
9	250	252	250	252.8	251.2
8	243	244	242	244.6	243.4
7	234	236.4	234	238	235.6
6	226	228	226.2	229.8	227.2
5	217.8	220	218	221	219.2
4	210	212	209.6	214	211.4
3	201.8	204	201.6	204.6	203
2	193.6	195	192.2	196.6	194.4
1	185	186	184	188	185.8
0	178	178	176	180	178


Calibration Curve for Electroscope
Scale Reading
Volts
0
10
20
30
40
50
60
70
80
90
100
180
190
200
210
220
230
240
250
260
270
Curve I
32
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CHICAGO

$$Q = V_1(C_1 + K) = V_2(C_2 + K)$$

$$V_1(C_1 + K) = V_2(C_2 + K)$$

$$K = (V_2 C_2 - V_1 C_1) \div (V_1 - V_2)$$

$$= \left(\frac{A V_2}{4\pi d_2} - \frac{A V_1}{4\pi d_1}\right) \div (V_1 - V_2)$$

$$= \frac{A^2}{4}\left(\frac{V_2}{d_2} - \frac{V_1}{d_1}\right) \div (V_1 - V_2)$$

The leaf could be brought back to its initial position by bringing the movable disk back to its initial position, showing that no appreciable leak had occured during the process of measurement. The observed values are given in tables II_a, II_b, and II_c.

The capacity was also determined by the heterodyne method. The condenser used was of the precision type made by the General Radio Company. A calibration curve for this instrument was furnished by the makers. The values for carbon dioxide were 27.1 for 255 and 26.2 cm. for 15 lbs. per sq. inch. The reason that these values are lower is perhaps due to the fact that the capacity of the wire connecting the condenser with the electroscope is eliminated by the heterodyne method.

In order to obtain the leak over the insulation and the leak caused by the ionization in the electroscope, outside of the ionization chamber, the chamber was exhausted to a few mm.

Table II_a

DETERMINATION OF CAPACITY

Temperature 34 Degrees Centigrade
Amber Cold

V_1	V_2	d_1	d_2	Capacity	
134.0	92.2	300	86.5	23.12	
134.0	92.1	300	86.0	23.25	
133.9	92.0	300	86.0	23.17	
133.5	91.7	300	85.5	23.42	23.24

Temperature 34 Degrees Centigrade
Amber Cold

133.3	91.3	400	94.5	23.51	
133.3	91.1	400	94.7	23.26	
133.1	91.2	400	93.5	23.91	
133.1	91.1	400	94.5	23.50	23.54

Temperature 220 Degrees Centigrade
Amber Cold

132.1	90.5	300	87.0	22.54	
132.1	90.5	300	84.5	23.64	
132.2	90.5	300	85.0	23.36	
132.1	90.5	300	84.5	23.64	
132.3	90.7	300	84.5	23.72	
132.2	90.5	300	85.5	23.14	23.34

Temperature 30 Degrees Centigrade
Amber Hot

129.2	87.5	300	83.5	23.12	
129.1	87.4	300	83.5	23.00	
129.1	87.6	300	83.5	23.18	
129.2	87.5	300	83.0	23.34	23.16

Air

Chromel Electrode

Pressure 255 pounds per sq. in. at 30 degrees C.

Table II_b

DETERMINATION OF CAPACITY.

Temperature 28 degrees Centigrade
Amber Cold

V_1	V_2	d_1	d_2	Capacity
133.0	91.4	300	77.5	27.65
132.9	91.3	300	77.5	27.61
132.8	91.1	300	77.5	27.26
132.2	90.8	300	77.5	27.59
131.2	90.1	400	85.0	27.82
131.2	90.1	400	85.2	27.73
130.9	89.5	400	84.5	27.62
130.9	89.5	400	84.9	27.47
130.9	89.5	400	84.7	27.53
130.5	88.9	500	90.0	27.26
130.5	88.9	500	90.2	27.20
130.5	88.9	500	90.2	27.20
130.5	88.9	500	90.0	27.26

Carbon Dioxide

Brass Electrode

Pressure 255 pounds at 30 degrees Centigrade.

131.9	90.7	300	78.0	27.42
131.9	90.7	300	78.4	27.20
131.9	90.7	300	78.0	27.42
131.8	90.5	300	78.2	27.26

Pressure 15 pounds at 30 degrees Centigrade.

Table II_c

DETERMINATION OF CAPACITY

Temperature 216 degrees Centigrade
Amber Cold

V_1	V_2	d_1	d_2	Capacity
131.8	90.3	300	77.0	27.60
131.9	90.3	300	76.5	27.82
131.8	90.3	300	76.5	27.90
131.8	90.3	300	77.0	27.60
131.6	90.3	400	85.0	27.75
131.7	90.3	400	85.5	27.40
131.7	90.3	400	85.5	27.40
131.7	90.3	400	85.5	27.40
131.7	90.3	500	92.0	27.10
131.7	90.3	500	92.0	27.10
131.7	90.3	500	92.0	27.10
131.7	90.3	500	92.0	27.10

Carbon Dioxide

Brass Electrode

Pressure 255 pounds at 30 degrees Centigrade

of pressure and the discharge obtained. This was repeated at various temperatures up to 200 degrees.C. without any noticeable difference in the rate of discharge. Values obtained for the quantity of electricity lost by this leak, expressed as an equivalent ionization, varied from 1.05 to 0.98 ions per c.c. per second. Since this is within the experimental error it was concluded that the discharge over the insulation was not effected by the temperature of the ionization chamber. This test also shed some light on the behavior of the walls of the vessel at high temperatures.

An interesting phenomena was noted when the temperature rose to the neighborhood of 265 degrees Centigrade. Above this temperature a very high ionization was produced. It was naturally expected that this was due to emission of electrons by the hot walls of the chamber. When the central electrode was charged negatively the discharge was somewhat lower than when charged positively. With a pressure of 255 pounds the temperature to produce this phenomena seemed to be higher than when the vessel was exhausted. The experiment was repeated with brass in place of the Chromel electrode with similar results.

The air used in the ionization chamber was compressed into a large tank by the liquid air machine after it had passed through the drying and purifying process. It was

further dried and cleaned by passing it to the ionization chamber through a 1½ in. pipe 3 ft. long into which had been placed a tray of phosphorus pentoxide and then through a pipe filled with glass wool. A tray of phosphorus pentoxide in the cooling jacket was expected to absorb any moisture left in after the first two processes of drying.

The pressure in the ionization chamber was read by means of an 8 in. Schaeffer and Budenberg test gauge ranging from 0 to 600 pounds per sq. inch. The vessel was filled with air to 255 lbs., a cap screwed on the valve and sealed. The same air was kept in the chamber for thirty days without any noticeable change in pressure. After the ionization chamber had stood for a number of days so as to allow for the decay of any emanation that might have been in the air the observations were begun. It was at first thought that it would not be possible to hold the pressure absolutely and for that reason the observations were begun at room temperature, carried to the maximum temperature and brought back to room temperature again. The mean should then be nearly the correct value even if a small leak had occured. It was soon found, however, that this was not necessary as no variation in pressure was detected. The method later adopted was to take a number of readings for one temperature and then go to the next. In this way more

consistent readings could be obtained as the temperature of the chamber became more uniform by holding the furnace at the same temperature for two or three days. The greatest difficulty experienced was due to convection currents in the electroscope. The plate into which the amber plug was fitted had to be kept at constant temperature during an entire run. This was done by adjusting the height of the overflow can. The electroscope was wrapped with heavy layers of cotton in order to keep it at constant temperature. Any error caused by convection currents was corrected by checking the voltage for the position of the leaf for each observation.

The quantity of electricity, Q, collected on the electrode is expressed by the relationship;

$$Q = C(E_1 - E_2) = n\ e\ t\ V,$$

$$n = C(E_1 - E_2) \div e\ t\ V,$$

where n is the number of ions formed per c.c. per sec., C the capacity in cm., $(E_1 - E_2)$ the change in the potential of the electrode in E.S.U., e the charge of the electron in E.S.U., t the time in seconds, and V the volume of the ionization chamber in c.c.

An electrode of Chromel wire, 0.5 mm. in diameter, was used. The wire was kept straight by a cylindrical brass weight attached to the lower end. Chromel wire was used on account of its low thermal conductivity. Three complete runs were

made with this electrode when the ionization chamber was filled with air to 255 pounds per sq. in. at 30 degrees Centigrade. The results are shown in tables III, IV, V, and by curves II, III, IV, and V. Curve V shows the results of the three runs combined. The values of the different runs are designated by various colors.

The low temperatures were obtained by passing liquid carbon dioxide into the tank surrounding the ionization chamber.

The Chromel electrode was replaced by one of a brass rod 3 mm. in diameter, supported by a short piece of Chromel wire. The results agree with those for the Chromel electrode within experimental error. The observations are shown in table VI and curve VI.

In order to check the ionization values with results obtained by other observers a pressure ionization test was made. Tests were made with the Chromel electrode as well as with the brass electrode in air. A similar curve was obtained with the brass electrode in air at a temperature of 125 degrees Centigrade. The values are shown in table VII and curves VII and VIII. The curve for 125 degrees C. lies above the one for room temperature.

The vessel was washed with carbon dioxide a number of times so as to drive most of the air out. It was then

Table III

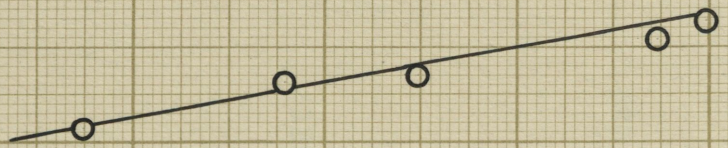
Data

First Run.

Temperature	Time	Mean	Ions per c.c. per sec.
30 degrees C.	320 min.		
	321 "		
	320 "		
	323 "	321 min.	71.4
72 degrees C.	316 "		
	316 "		
	309 "		
	309 "		
	312 "		
	312 "	312 "	73.4
100 degrees C.	310 "		
	315 "		
	315 "		
	310 "		
	310 "		
	307 "	311 "	73.7
150 degrees C.	298 "		
	303 "		
	302 "		
	305 "		
	306 "		
	303 "	303 "	75.6
160 degrees C.	298 "		
	299 "		
	300 "		
	297 "	299 "	76.6

First Run

Curve Showing Relation Between Ionization and Temperature



Air

Ions Per c.c. Per Sec.

90
80
70
60
50
40

Temperature Degrees Centigrade

-40 0 40 80 120 160 200 240 280

Curve II

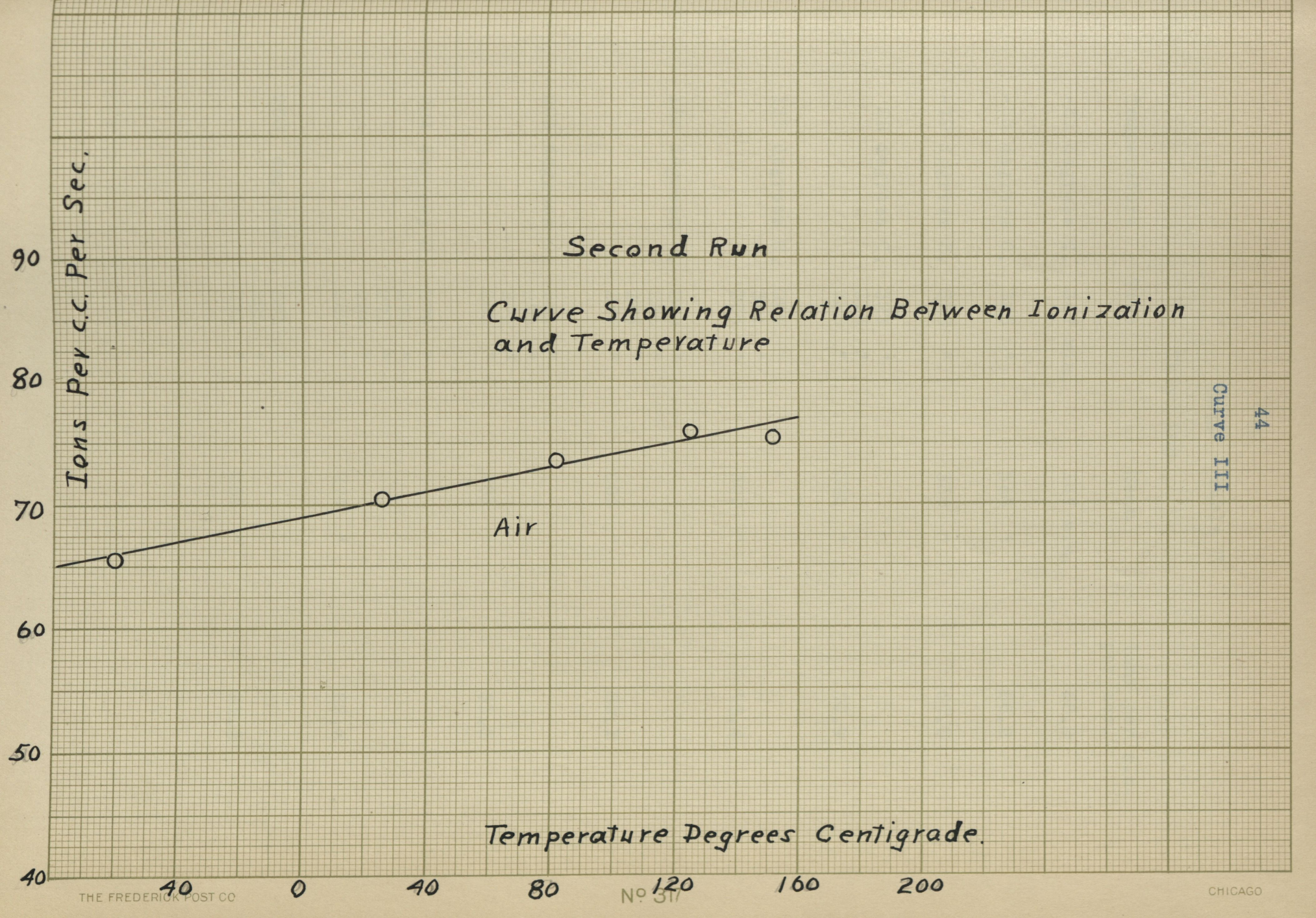
42

Table IV

Data

Second Run.

Temperature	Time	Mean	Ions per c.c. per sec.
-60 degrees C.	355 min.		
	340 "		
	456 "	350 min.	65.5
26 degrees C.	327 "		
	328 "		
	324 "		
	325 "		
	321 "		
	320 "		
	326 "		
	324 "		
	328 "	325 "	70.5
82 degrees C.	315 "		
	311 "		
	311 "		
	315 "		
	311 "		
	310 "		
	310 "	312 "	73.5
125 degrees C.	308 "		
	305 "		
	301 "		
	301 "		
	302 "		
	300 "		
	301 "		
	302 "	302 "	75.9
152 degrees C.	300 "		
	305 "		
	305 "		
	304 "		
	302 "		
	306 "		
	305 "	304 "	75.5


Second Run
Curve Showing Relation Between Ionization and Temperature
Ions Per c.c. Per Sec.
90
80
70
60
50
40
Air
Temperature Degrees Centigrade.
-40
0
40
80
120
160
200
Curve III
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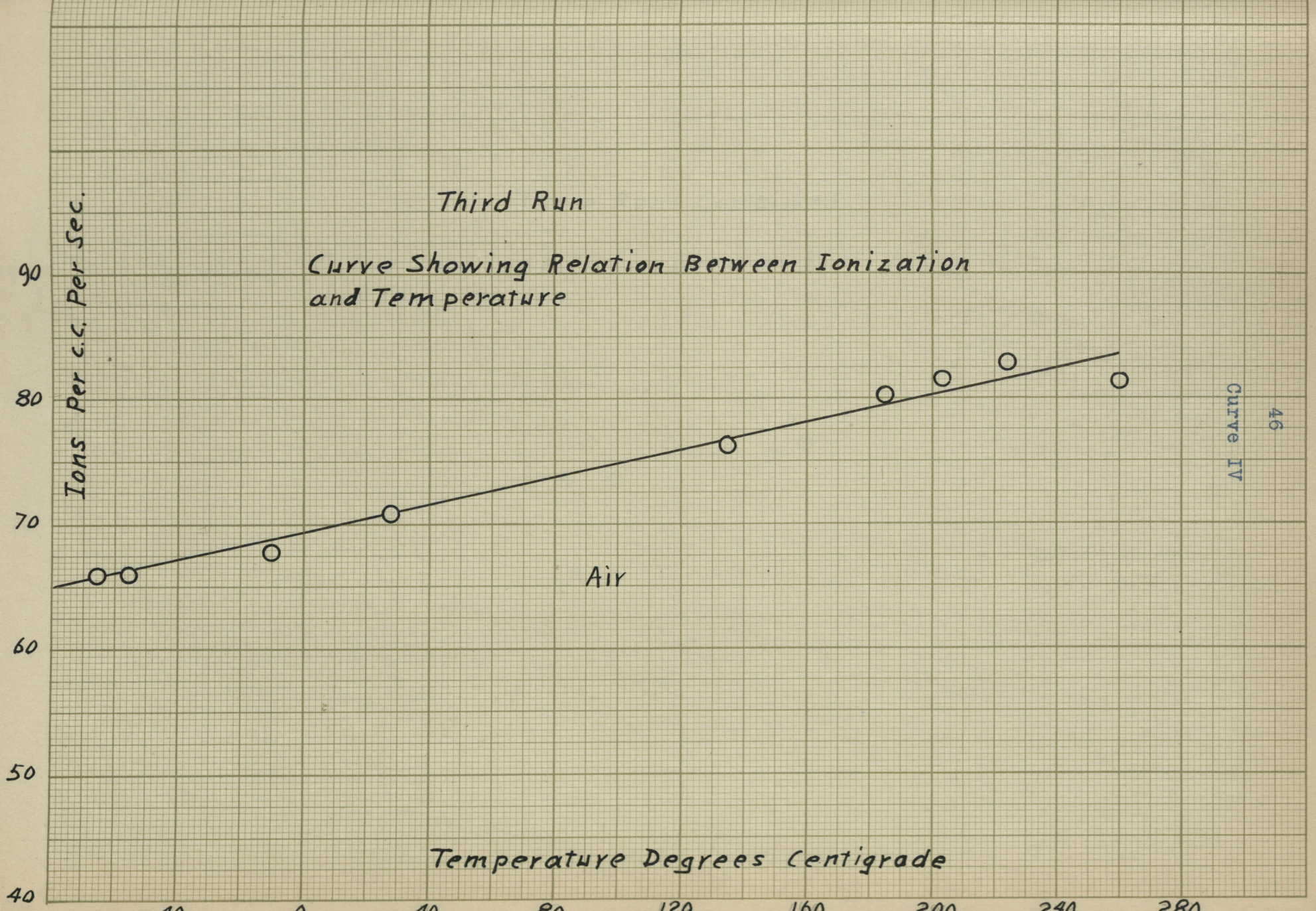
Data Table V

Third Run

Temperature	Time	Mean	Ions per c.c. per sec.
-65 degrees C.	347 min.	347 min.	66.0
-55 degrees C.	346 "	346 "	66.2
-10 degrees C.	338 "	338 "	67.8
28 degrees C.	323 " 318 " 328 "	323 "	70.9
135 degrees C.	295 " 301 " 305 "	300 "	76.4
185 degrees C.	289 " 285 " 286 " 285 "	286 "	80.1
203 degrees C.	281 " 279 " 279 " 283 "	281 "	81.5
224 degrees C.	279 " 272 " 271 " 284 " 282 "	277 "	82.8
260 degrees C.	281 " 283 " 281 "	282 "	81.3



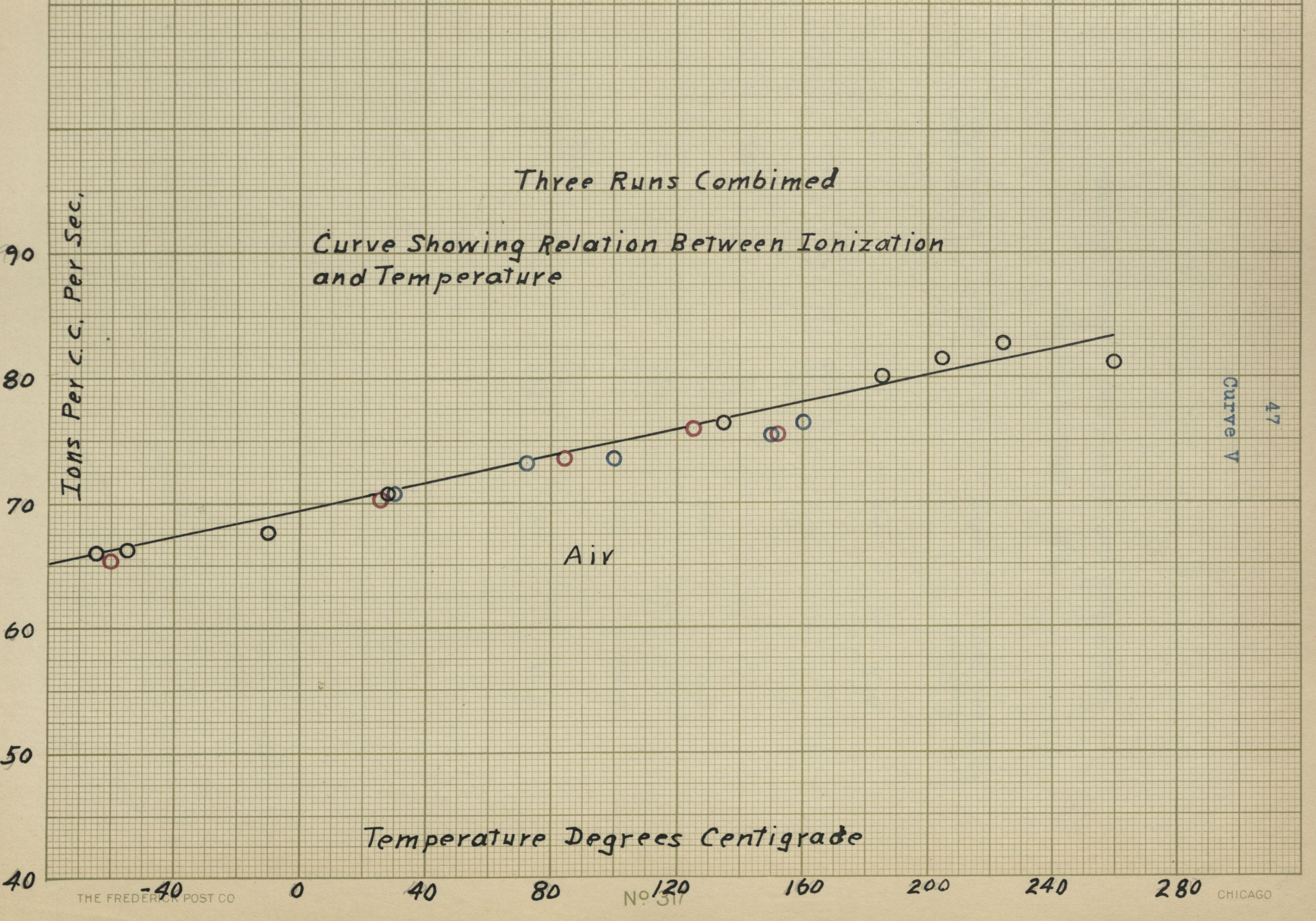

Three Runs Combimed
Curve Showing Relation Between Ionization and Temperature
Ions Per c.c. Per Sec.
90
80
70
60
50
40
Air
Temperature Degrees Centigrade
-40
0
40
80
120
160
200
240
280
Curve V
47
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Table VI

RELATION BETWEEN TEMPERATURE AND IONIZATION.

BRASS ELECTRODE. AIR.

Temperature degrees C.	Time in min.	Mean	Ions per c.c. per sec.
30	369		
	369		
	371	370	70.0
82	366		
	367		
	365	366	71.1
127	350		
	351		
	350	350	74.3
186	335		
	331		
	336	334	77.7
216	330		
	330		
	331	330	78.3

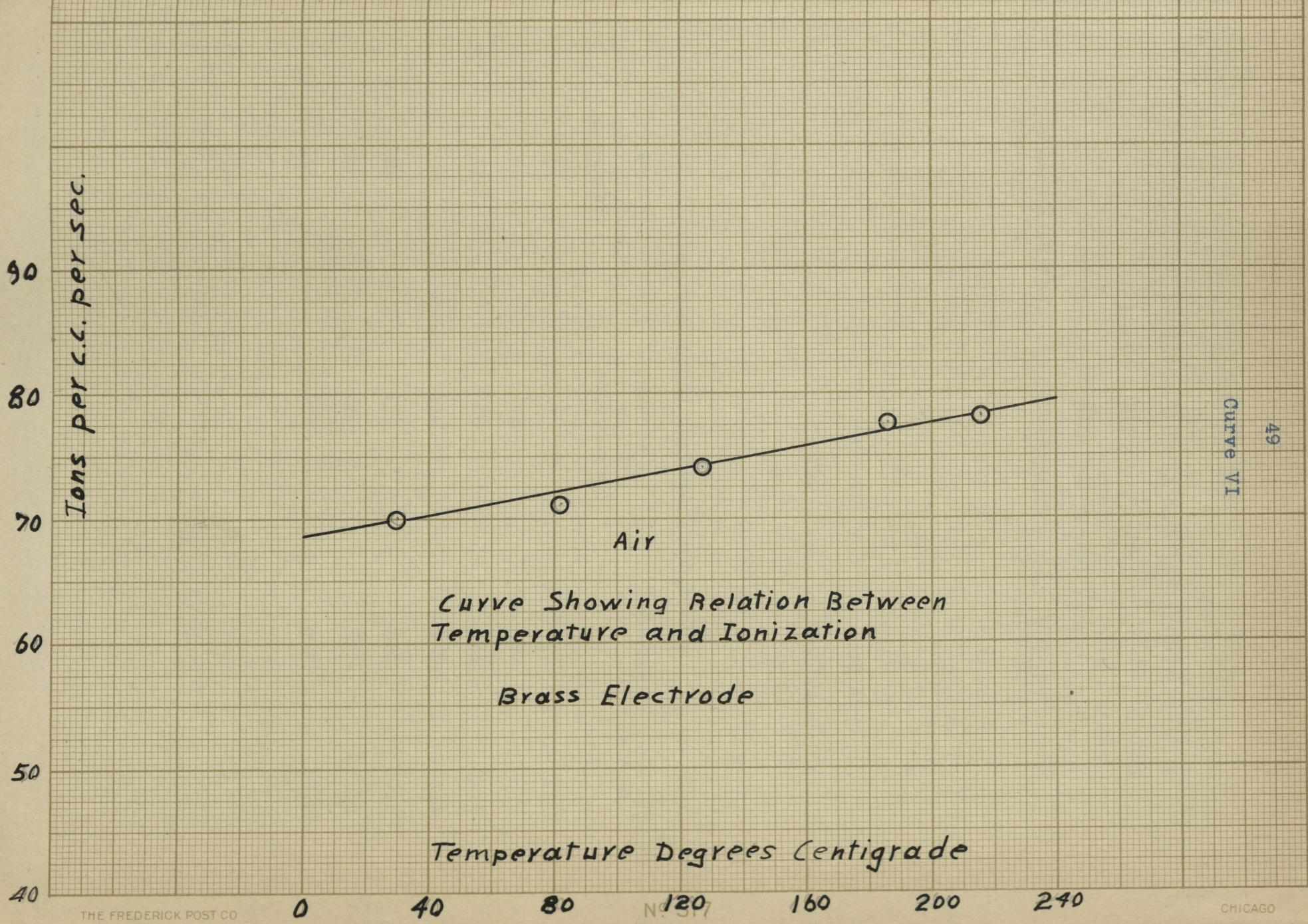
Ions per c.c. per sec.
90
80
70
60
50
40
0
40
80
120
160
200
240
Air
Curve Showing Relation Between
Temperature and Ionization
Brass Electrode
Temperature Degrees Centigrade
Curve VI
49
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Table VII

RELATION BETWEEN PRESSURE AND IONIZATION

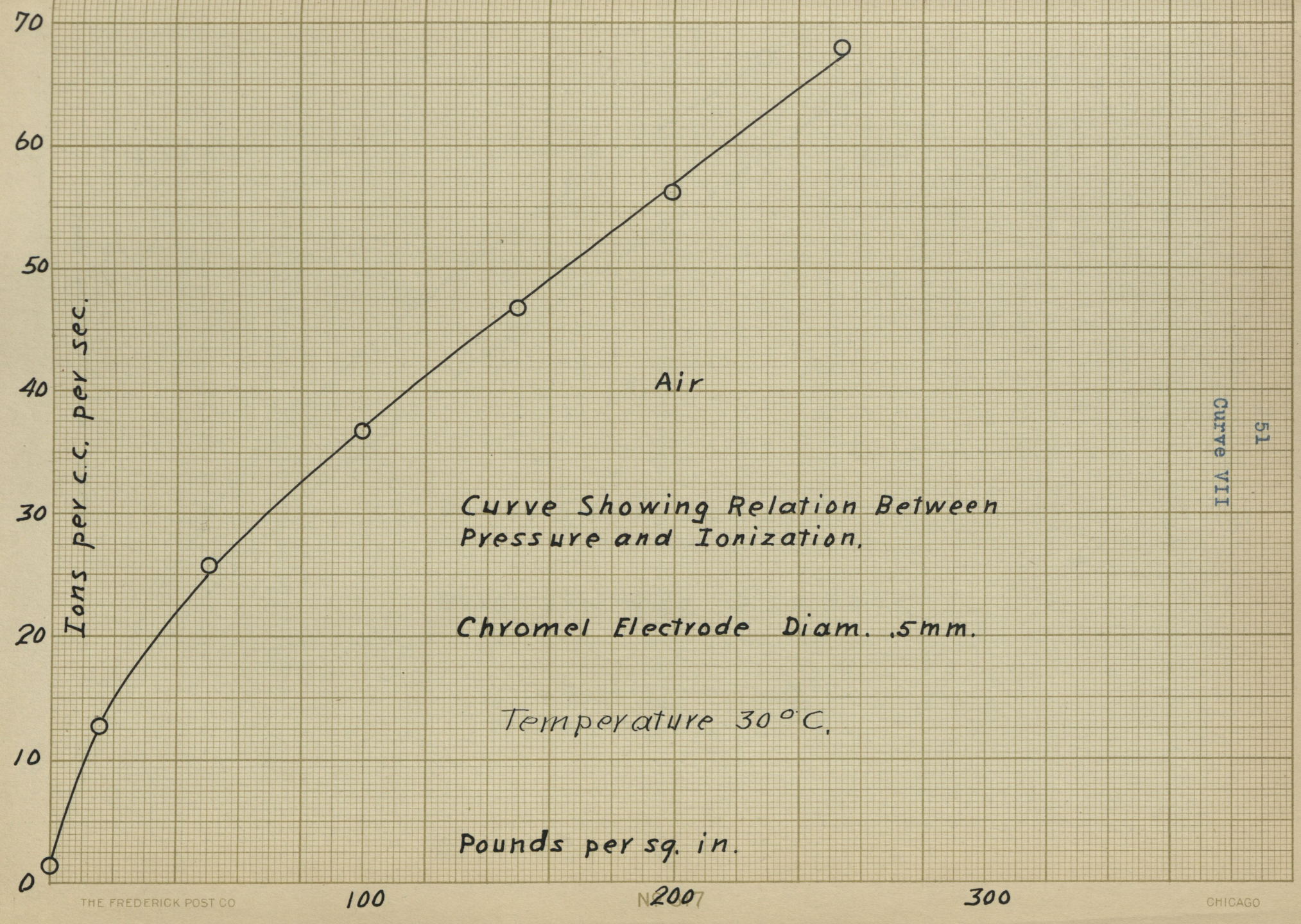
BRASS ELECTRODE. AIR.

Temperature 30 degrees Centigrade.

Pressure in lbs. per sq. in.	Time in min.	Ions per c.c. per sec.
15	1760	13.5
55	903	26.3
100	645	35.7
148	553	45.1
195	454	53.0
261	370	65.1

Temperature 125 degrees Centigrade.

Pressure in lbs. per sq. in. Observed	Pressure in lbs per sq. in. Reduced to 30^0	Time min.	Ions per c.c. per sec
20	15	1440	16,8
60	45	800	30.0
104	79	616	39.1
153	116	498	48.3
227	173	395	60.9
305	232	356	67.5
338	257	343	70.2


70
60
50
40
30
20
10
0
Ions per c.c. per sec.
Air
Curve Showing Relation Between
Pressure and Ionization.
Chromel Electrode Diam. .5mm.
Temperature 30° C.
Pounds per sq. in.
100
200
300
Curve VII
51
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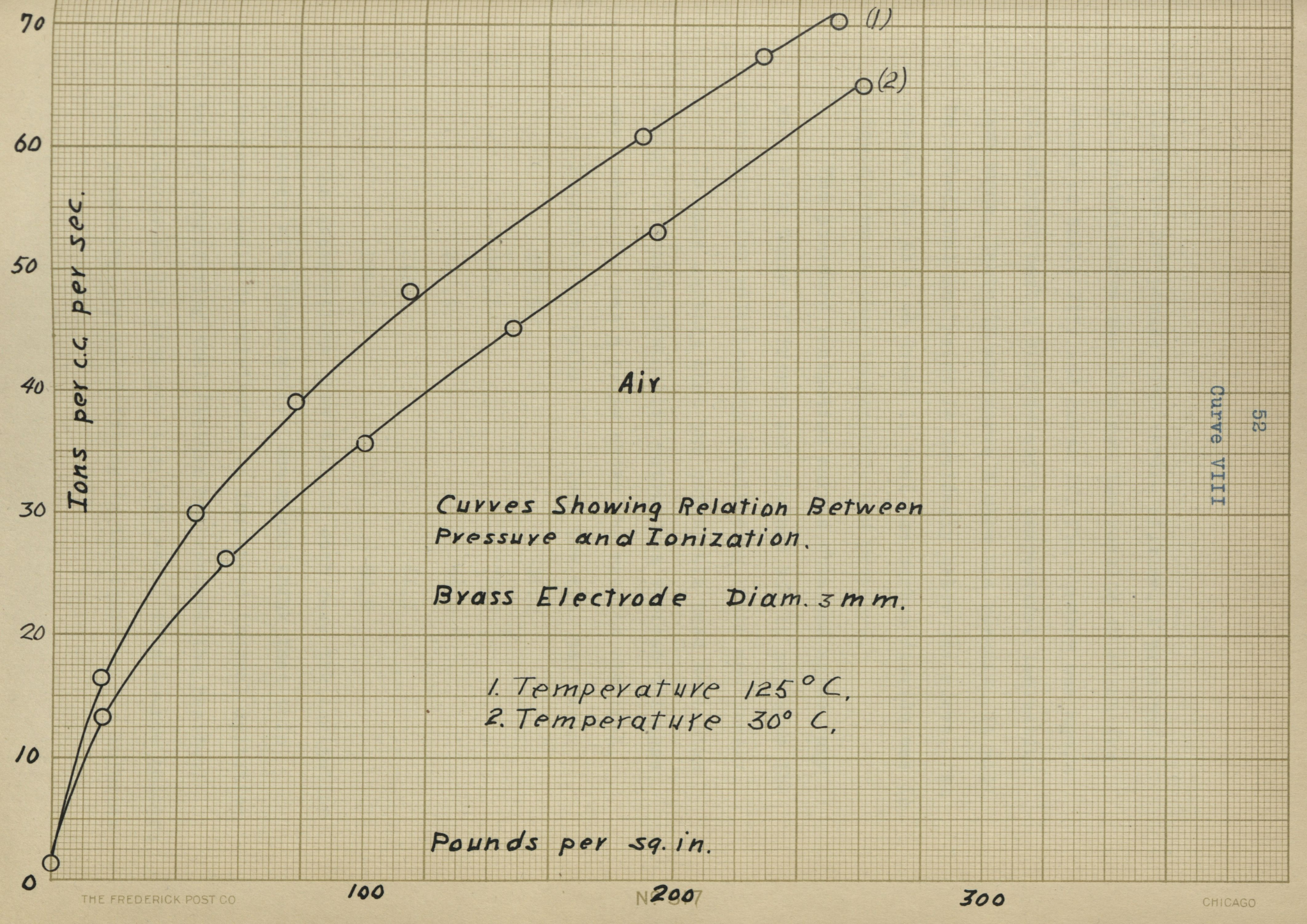
70
60
50
40
30
20
10
0
Ions per c.c. per sec.
(1)
(2)
Air
Curves Showing Relation Between
Pressure and Ionization.
Brass Electrode Diam. 3 m m.
1. Temperature 125° C.
2. Temperature 30° C.
Pounds per sq. in.
100
200
300
Curve VIII
52
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filled to 260 pounds with carbon dioxide. A pressure ionization curve was obtained the results of which are shown in table VIII and curve IX. The chamber was again filled with carbon dioxide and a temperature ionization test made. Table IX and curve X show the results. It will be noted that one point is decidedly below the curve. The reason for this no doubt is that the carbon dioxide was in liquid form at that temperature and pressure.

The pressure ionization curves obtained agree very well with those of Broxon and Steinke but do not show the straight line relationship obtained by Fruth and Downey.

To make certain that the potentials used were high enough to insure saturation potentials various voltages were used. The table below shows the results obtained.

Potential in volts	Ions per c.c. per sec.
259.0	80.0
243.5	79.5
227.0	79.5
211.5	81.1
195.0	82.0

The observations show that in each case the ionization increases with temperature. One might think that this increase could be attributed to increased thermal agitation but on considering that Steinke has reduced the residual ionization to 0.2 ions per c.c. per sec., this source becomes less promising. By substituting in the equation for emission

Table VIII

RELATION BETWEEN PRESSURE AND IONIZATION.

CHROMEL ELECTRODE. AIR.

Temperature 30 degrees Centigrade.

Pressure in lbs. per sq. in.	Time in min.	Ions per c.c. per sec.
15	1680	13.1
50	811	26.0
100	600	37.0
150	474	47.0
200	395	56.3
255	323	68.0

BRASS ELECTRODE. CARBON DIOXIDE.

Temperature 30 degrees Centigrade.

15	1406	16.3
60	668	35.7
105	525	46.0
152	440	54.7
202	391	61.5
278	334	72.0

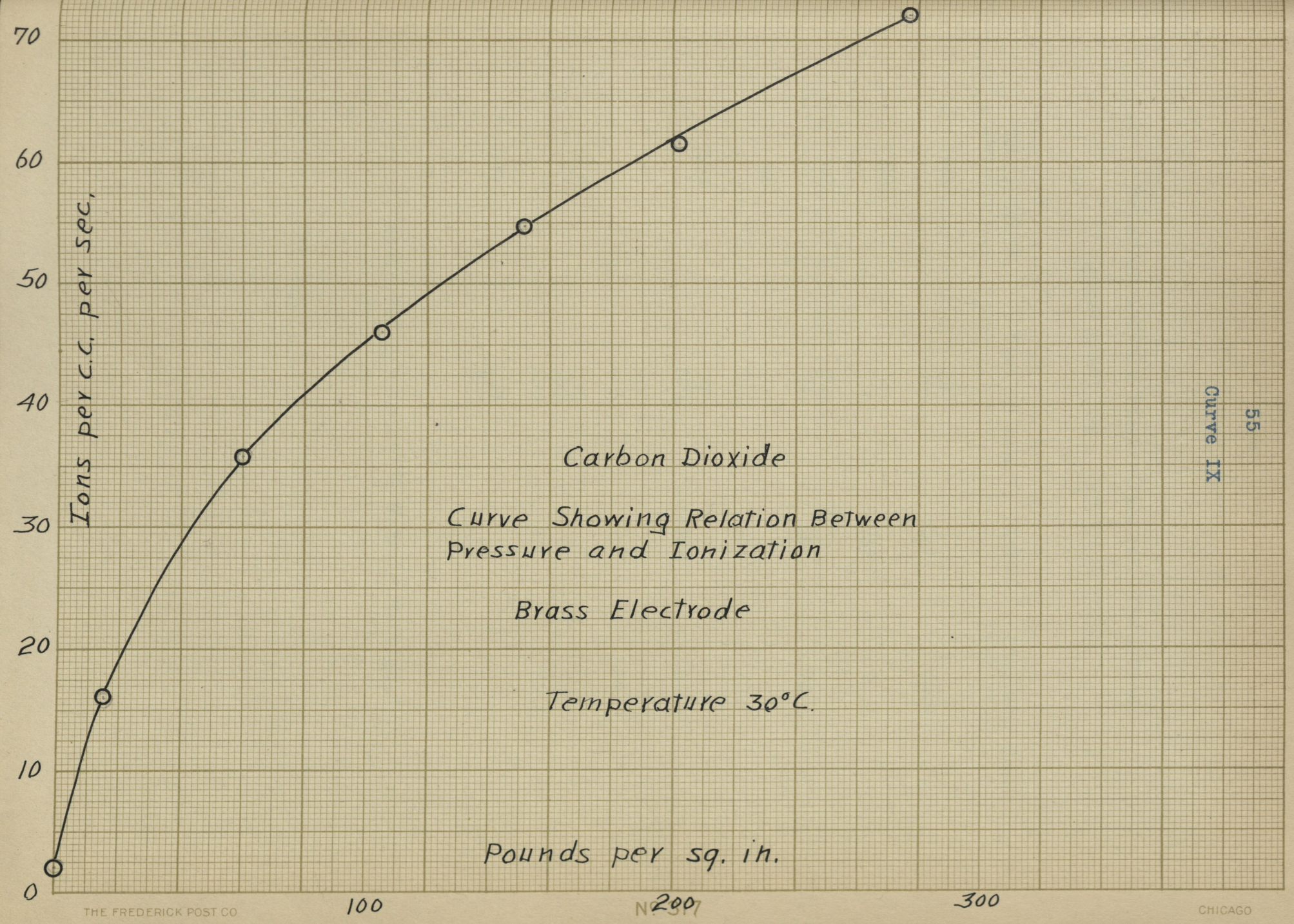
70
60
50
40
30
20
10
0
Tons per c.c. per sec.
Carbon Dioxide
Curve Showing Relation Between
Pressure and Ionization
Brass Electrode
Temperature 30°C.
Pounds per sq. in.
100
200
300
Curve IX
55
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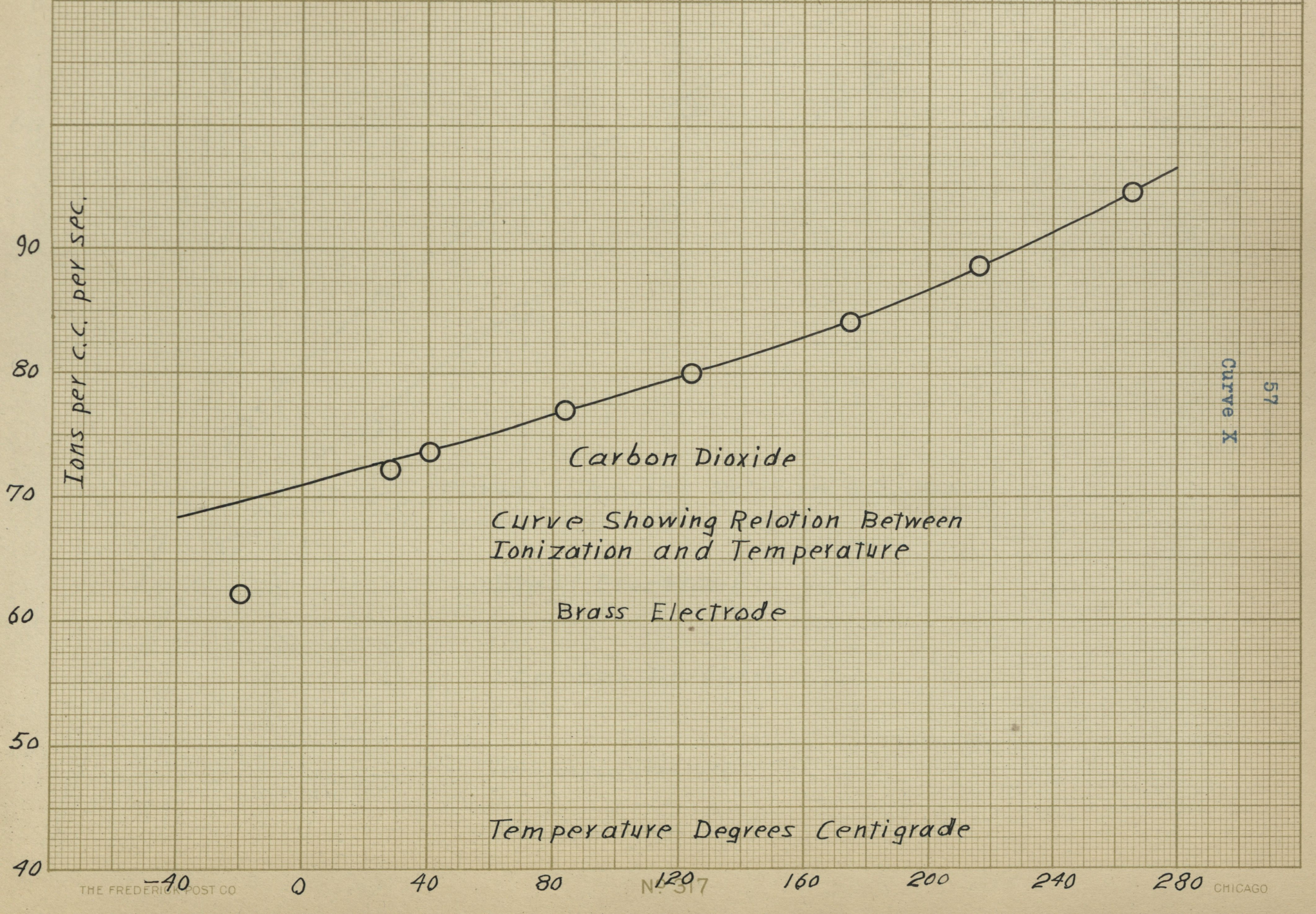
Table IX

RELATION BETWEEN TEMPERATURE AND IONIZATION.

BRASS ELECTRODE. CARBON DIOXIDE.

Temperature degrees C.	Time in min.	Mean	Ions per c.c. per sec.
-20	387		
	385	386	62.4
28	335		
	336	335	72.1
40	328		
	328	328	73.6
84	312		
	313	313	77.0
124	302		
	301	302	80.0
175	287		
	285	286	84.4
216	270		
	275		
	270	272	88.8
265	254		
	256	255	94.7

Pressure 255 pounds at 30 degrees Centigrade.


Ions per c.c. per sec.
90
80
70
60
50
40
Carbon Dioxide
Curve Showing Relation Between
Ionization and Temperature
Brass Electrode
Temperature Degrees Centigrade
-40
0
40
80
120
160
200
240
280
Curve X
57
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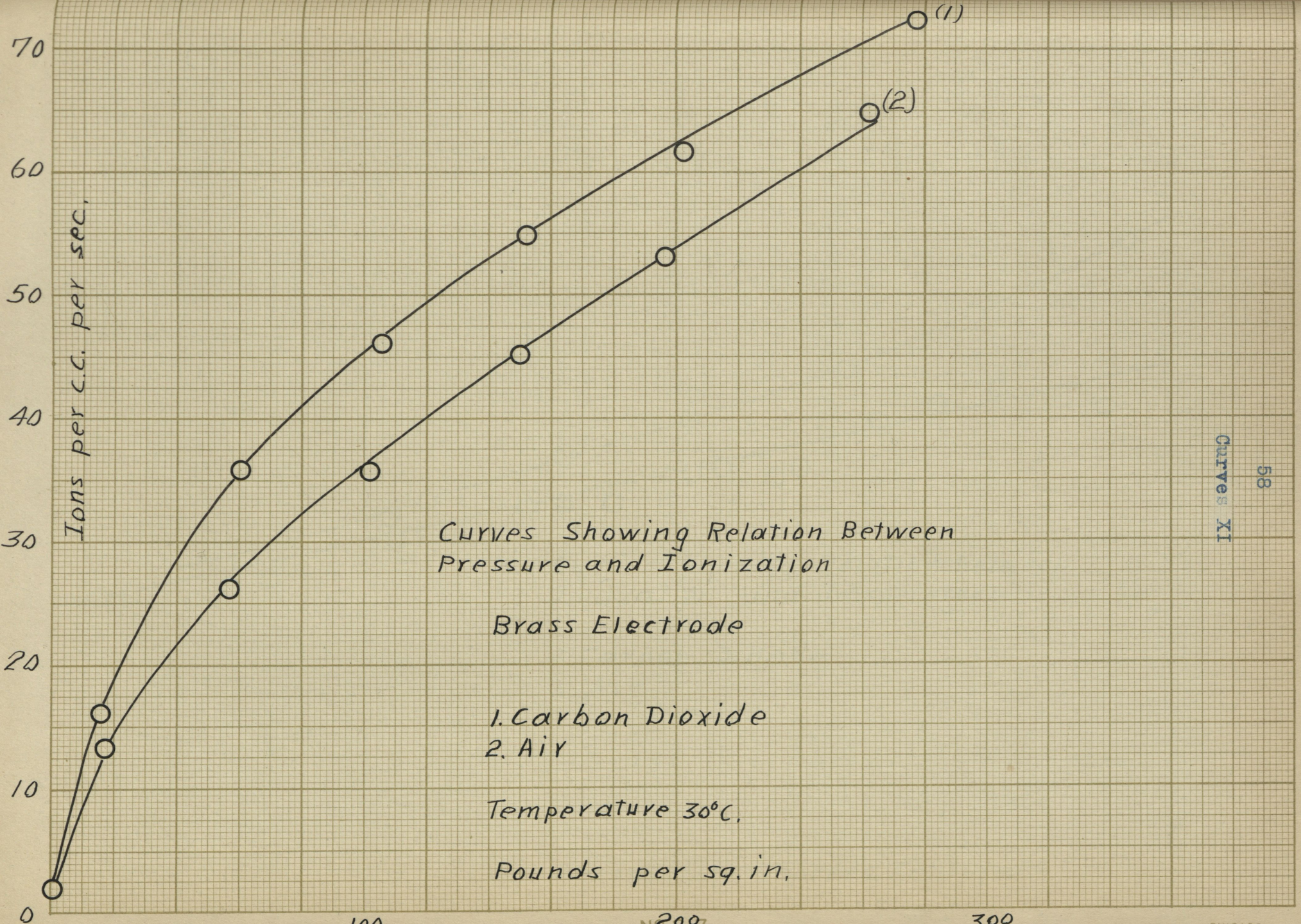
70
60
50
40
30
20
10
0
Ions per c.c. per sec.
(1)
(2)
100
200
300
Curves Showing Relation Between
Pressure and Ionization
Brass Electrode
1. Carbon Dioxide
2. Air
Temperature 30°C.
Pounds per sq. in.
Curve XI
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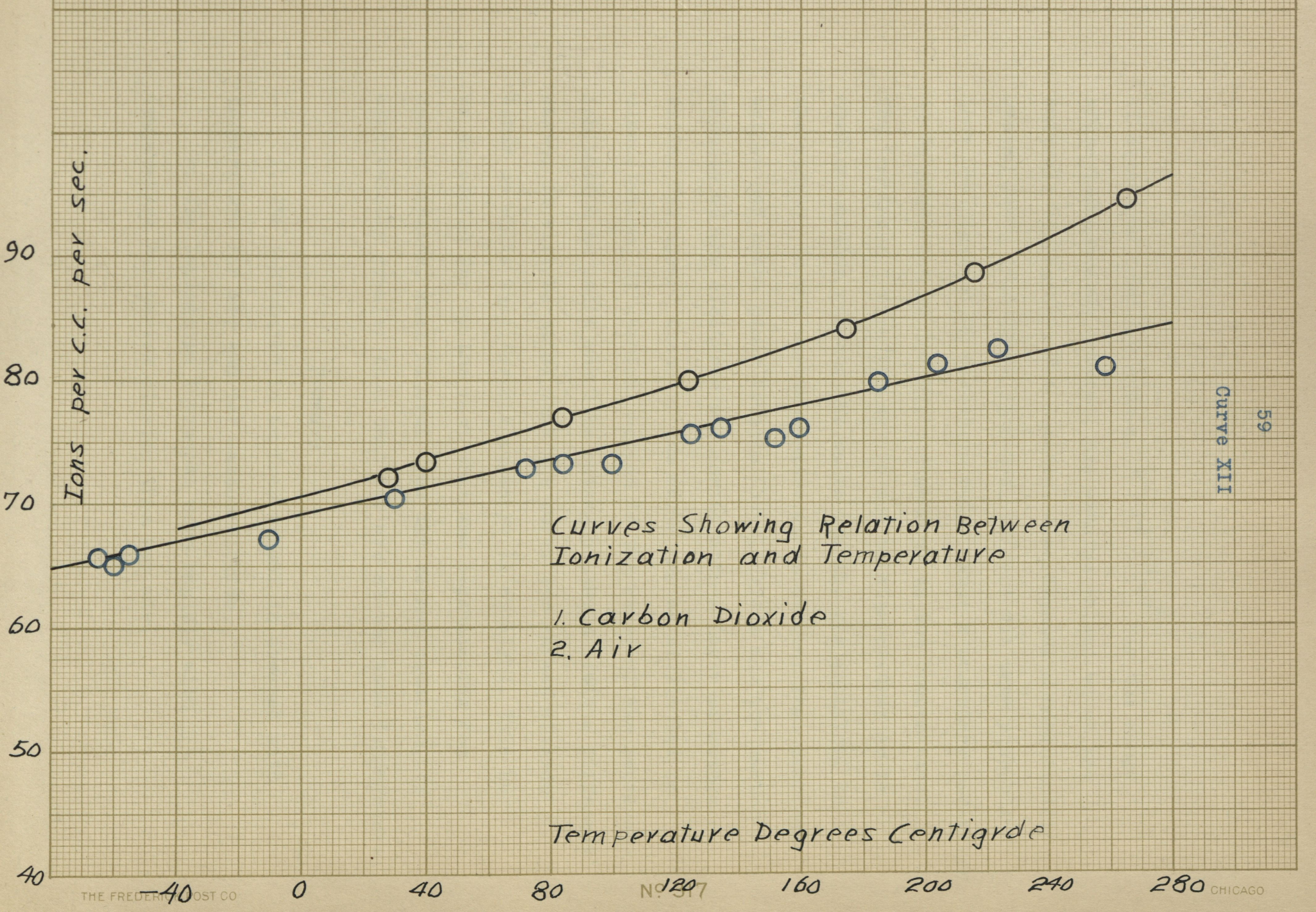

of electrons from hot bodies, $N = A T^{\frac{1}{2}} e^{-\frac{b}{T}}$, for the range ofthe temperatures covered, one obtains values which are entirely negligible. The equation also demands a more rapidly rising curve than those obtained. It does not seem probable that the penetrating radiation would cause a secondary radiation to be given out by the walls dependent on the temperature. The increased ionization may be due to dissociation or to chemical action between the walls and the gas contained in the vessel. In the carbon dioxide it is evident that chemical action had taken place between the electrode and the carbon dioxide as the electrode was coated with a layer of copper oxide. The upward trend of the curve may be attributed to dissociation. If chemical action is the cause of the increased ionization an inert gas like nitrogen should yield a different curve. It will be noted that the curve for carbon dioxide bends up while that for air seems to be straight. This can be accounted for by the fact that the dissociation for carbon dioxide, when figured from the Nernst equation, is considerably greater than that for air at the same temperature.

Summary

1. The ionization in an iron vessel in creases with temperature for air and for carbon dioxide.

2. The ionization increases more rapidly with temperature for carbon dioxide than for air.

3. When ionization is plotted against pressure the relationship is not a linear function.

4. The pressure ionization curve for air at 125 degrees Centigrade lies above that for 30 degrees Centigrade.

5. The pressure ionization curve for carbon dioxide lies above the one for air at the same temperature.

In conclusion the writer wishes to express his appreciation to the staff of the Physics Department for their kind interest, especially to Professor Kester for his aid and encouragement and to Professor Kent for many helpful suggestions. The writer is glad to acknowledge his indebtedness to Mr. Harry Snell, the mechanician, for his assistance and for solving many difficulties in the building of apparatus.