The Effect of Different Compositions and Radiation on Electret Properties

A Thesis

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by

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Chapter 1 Problem

Electrets were only investigated a few years ago, therefore the procedures, the effect and the causes are not definitely established. Most of the investigation has been concerned with the materials and methods which made electrets. But some studies have been made to determine how other phenomena affect electrets. Because this is a new field a further study would be of value.

This investigation was concerned with the effects of different composition and radiation on the electret. The project was divided into; (1) Obtaining charge versus time curves for electrets of different composition; (2) comparing the type of charge obtained with time for various mixtures; and (3) determining the effect of gamma-rays on the charge of an electret.

CHAPTER 11

Review of The Literature

The discovery of Electrets is of twentieth century vintage with the first investigation occuring in 1925. Electrets are essentially permanent electrified dielectrics. Electret properties are found in certain chemical compounds when they are subjected to an electric field while undergoing transition from liquid to solid state. The investigators have been chiefly concerned with the production of electrets and the measurement of charge density, although some correlation between the electret and other phenomena has been considered. In general the research pertaining to the field is limited and the theories involved vary between investigators, therefore the fruits of literature search are lean in nature.

In 1925, a Japanese named Eguchi,[1] at the University of Tokyo, while studying dielectrics observed a definite type of phenomenon occuring. Certain waxes in the molten state were subjected to an electric field of 10 KV/cm and allowed to remain under the influence of the electric field until the waxes were in the solid state. A charge was found induced in the wax. The upper surface of the wax had an opposite sign of charge than the lower surface of the wax. Eguchi observed the value of the charge on each surface over a period of time, and found that with time the sign of the surface charge for each face reversed. This

1 J.V. Eguchi, "Electrets", Phil. Mag. 49,181 (1925)

reversal of charge with time was the phenomenon that classified whether or not an electret was formed. He defined an electret as a waxed dielectric which had the above property. A mixture of 50% carnauba wax and 50% rosin gave Eguchi a reversal of charge effect. The following details show how he obtained the product called the electret. The 50-50 mixutre was heated to a molten state and poured into a pie shaped tin pan. This pan served as a bottom electrode. The object was to place the molten wax between two electrodes and apply an electric field of sufficient strength until the wax had become solid and cooled to room temperature. The upper electrode was a circular tin disc. To measure the charge introduced upon the surface of the electret Eguchi used a electrometer arrangement where the electret was placed between two condenser plates; and by lowering the upper condenser plate onto the surface of the electret then raising it rapidly a deflection was noted on the electrometer, hence the surface charge could be determined. His observation was that a charge of one to ten e.s.u. per cm^2 would be obtained. The initial charge placed upon the electret decayed with time but a charge of opposite sign appeared and grew to a maximum value within the range referred to above which showed no sign of decay as time went on. The decaying charge was the heterocharge and the permanent charge was

the homocharge.

Eguchi studied the action of X-rays on Electrets to determine whether or not the field was destroyed. Eguchi stated that X-rays caused the free charge to disappear for a finite period of time but always the full value of the free charge was regained. The rate of recovery of the free charge was influenced by the time of exposure, the nature of the X-rays[2], and the intensity of rays. But under any condition when the free charge had recovered it was found that the surface density was at the same value as it had before exposure. Eguchi tried several means of exposing electrets to X-rays. In one case the X-rays were sent in the direction normal to the surface of the disc shaped electret. This was to allow the X-rays to go through the dielectric material. In another case a lead band of sufficient breadth was used to protect the electret from the rays at the edges, hence the X-rays would only pass along the disc surface, thus the rays were cut off and would not go through the dielectric material, which was merely grazed. But in both of the above cases the effect was the same; that being a reduction of field followed by a spontaneous recovery. The disappearance and recovery of the free charge might be explained on the view that the ions in the air produced by the X-rays were caught by charges of opposite

2 Note that Eguchi doesn't explain what is meant by "nature of the X-rays" other than saying "soft" X-rays.

sign on the electret's surface, and when the X-ray source was discontinued ions fly off, hence the charge reappears. This flying off effect was considered to be caused by the kinetic energy of agitation opposing the electrostatic attraction. The recovery curves very nearly obey the exponential law. A small difference in the final surface density of the two surfaces was probably caused by non-uniformity of the electrification near the rim of the electret. Eguchi also noted that scraping with a knife or putting a bunsen burner flame to the surface of an electret produced temporary disappearance of charge.

Adams[3] made the first attempt to explain how electrets were formed. He stated the electrification was not truly permanent but decays slowly to give rise to a free charge. This was based on the pyroelectric effect where a crystallizing substance, such as quartz, appeared charged on a temperature change but was no longer charged as the original temperature was reached. According to Lord Kelvin the charge was only permanent if the conductivity of the crystal was zero. But the value of the polarization entire field would not be great enough to furnish the desired effect even if all the dipoles were completely in alignment, therefore a piezoelectric effect must exist.

3 E.P. Adams "On Electrets" J. Franklin Inst. 204, 469 (1927).

Andrew Gemant[4] set out to disprove Eguchi but found the following conditions to exist. Electrets were the electrical analogue of permanent magnets. The field had been maintained and the free surface charge maintained constant value after the aging effect only if they were kept short circuited and in a dry state. His observations were made with a set up similar to Eguchi. Gemant, in studying the aging effect of electrets, found two possible charges to exist. One had the opposite sign of the adjacent polarizing electrode and known as the heterocharge which was of short duration. The second type of charge had the same sign as the adjacent polarizing electrode and is known as the homocharge. This charge increases with age of the electret, whereas the first charge decays with age. He considered the homocharge final value as probably a valuable method for exploring the structure of organic molecules. Acidic materials produce heterocharge, while non-dissociating dipoles materials, chiefly esters, lead to the steady homocharge. The heterocharge was considered an ionic effect where the ions were captured by the solidification of the melt and remain for a certain period of time because of the very low conductivity of solid wax.

[4] Andrew Gemant "Electrets" Phil. Mag. 20, 929 (1935)

This was believed true for the positive ions only in the space confronting the cathode, whereas the space charge confronting the anode disappears.[4,6] The homocharge was considered to be caused by the non-dissociable component of finite dipole moments. This was supported by the fact that mainly compounds of esters and alchols showed homocharge properties. Further data to support the theory of Gemant were that, amorphous media had crystalline nuclei; and normally disordered crystallites attained orientation in the presence of an electric field.[17,21] To obtain the oriented dipoles a very hard wax is required, (such as Carnauba Wax.) Thus Gemant concluded that a piezoelectric effect must exist. (Gutmann states that this demands quadrupoles to be formed in the electret, but soft waxes produced electrets, hence the theory doesn't seem to hold. Also Gemant's theory can't explain discharge currents observed by other investigators.[8,36,32])[9]

4 P. Jaeger, "Spacecharge measurements in beeswax during solidification and in the solid state" D. Physik 5-21-481 (1934-35)

6 P.A. Thiessen, A. Winkel, and K. Herrmann "Electric After Effect in Solidified Dielectrics" Physik Zeits 37,511 (1936)

9 Gutmann "The Electret" Rev. Mod. Phy. 20 457 (1948)

17 M. Ewing "X-ray Diffraction of Electrets" Phys. Rev. 36 378, (1930)

21 A. Tupain and M. Durepaire "On Electric Charge Developed in certain Amorphous Dielectrics under Application of Pressure" Chem. Rev. 189,739 (1929)

Gemant further stated that the degree to which the mixture had been strained while cooling, or the cooling rate would affect the value of the homocharge but Stranathan[22] reported only a small decrease in charge density with longer cooling times.

M. Ewing[10] studied the X-ray diffraction pattern of electrets. He found four concentric rings which pointed out that there was crystalline structure.

Thiessen, Winkel, and Herrmann[6] proposed the idea that the difference in conductivity in dielectrics in the solid and liquid states was partly responsible for the effect. The electret which exhibits the heterocharge possesses high conductivity, whereas it was found that the homocharge type of electret exhibits a lesser degree of conductivity. Thiessen used the Mikola table (see page 12) to form his theory. Thiessen assumed that in liquid state the wax exhibits internal polarization building up the space charge. As the wax changes to solid state the sign of the surface charge would reverse, due to a difference in the conductivity time constants. When the wax solidifies and is still under

6 P.A. Thiessen, A. Winkel, and K. Herrmann "Electric After Effect in Solidified Dielectrics" Physik Zeits 37,511 (1936)

10 M. Ewing "X-ray Diffraction of Electrets" Phys. Rev. 36,378 (1930)

9 Gutmann "The Electret" Rev. Mod. Phy. 20,457 (1948)

the influence of a high electric field the following process should occur: A dielectric charge arises from either the interfaces between the wax and electrodes or comes from the electrodes. This process was defined as external polarization. No homocharge would be produced when the solidification field was below 10 K.V./cm. because that would be the threshold value for dielectrics charges to be formed. (But this theory did not explain the need for the short circuit to preserve charge, according to Gutmann[9].)

Groetzinger[8] stated that shorting leads to an accumulation of charge on the electrodes and when these were removed the volume charge reappears. If the electrets were allowed to remain unshorted it was found that on the surface there will be an accumulation of compensating charges, which form a screen around the electret. Electrification in the electret is probably due to a shifting of charges until compensating charges have accumulated on the electret surfaces. Under this condition the value of the accumulated charge was sufficient to cancel the field causing the volume polarization.

8 H.Fri and Groetzinger "On the Liberation of Energy in the Remelting of the Electret" Physik Zeits 37,720 (1936)

9 Gutmann "The Electret" Rev. Mod. Phy. 20,457 (1948)

Gross[7] proposed an absorption concept. He stated that with a rise in temperature the time rate of charging and discharging enormously increases in a dielectric. Waxes were found to be absorptive dielectrics. It was impossible to charge completely a dielectric at room temperature, hence an elevated temperature was needed. The decay of electrification was probably caused by external and internal conduction within the dielectric itself. If the noted discharge current reversed, then the internal conduction direction had changed. He considered that conduction current in the interfaces between electrodes and dielectrics produced the homocharge which later spray into the electret. Carnauba wax, having a long life dielectric constant, gave the appearance of having a constant charge.

W.M. Good and J.D. Stranathan[3] made a study on the method to improve the making of electrets. The following methods and conclusions were reached by them. The behavior of permanent electrets has been shown to depend upon the kinds and relative amounts of

7 B. Gross and L.F. Denard, "Dielectric and Temperature Effects in Carnauba Wax" Phy. Rev. 67,253 (1945)

3 W.M. Good and J.D. Stranathan "Improved Method of Making Permanent Electrets and Factors which Affect their Behaviour" Phys. Rev. 56 pp 810-813 Oct. 15, 1939.

materials in their composition. Also the strength of the electric field was a factor. Tin seems to be the most suitable element to form electrodes from because it showed less evidence of electro-chemical activity than other metal tried. The two electrodes and wax combination was placed inside of a sealed container which was immersed in an oil bath (temperature controlled). The temperature was maintained at 90°C for the first twenty-four hours, and then the bath was allowed to cool. The electric field was applied when the bath had cooled to 75°C. At 24°C the field was removed and the electret taken out and measured by an electrometer. The field was not turned on at 90°C because the resulting electrets would eventually crack. Stranathan noted that the time of cross over of the sign of the charge increased as the temperature to which the wax was heated initially was increased.

Gutmann[9] made an extension on the Mikola table for the classification of electrets. The table as presented follows; (see next page)

9 Gutmann "The Electret" Rev. of Mod. Phy. 20,457 (1948)

Substances capable of permanent volume Polarization

Yielding Heterocharge Only	Yielding also Homocharge
(1) Acidic Groups	(1) Carnauba Wax
(2) Glass	(2) Beeswax
(3) Resin	(3) Polar Hydrocarbons
(4) Sulfur	(4) Esters
	(5) Alcohols
	(6) Asphaltes

Substance Giving

Surface Charge Only	No Permanent Charge
(1) Cetyl Alcohol	(1) Paraffin Wax
(2) Cetyl Palmitate	(2) Palmitic Acid
(3) Non-Polar Hydrocarbons	(3) Stearic Acid
(4) Stearanilide	(4) 1-8 Dinitro-naphthalene
(5) Seekay wax	

Note that some substances yielding heterocharges only are capable of permanent volume charge as stated by the table, but Gemant says heterocharges are of short duration, hence a difference of opinion on the word "permanent".

A simpler type of oven to make electrets in was proposed by Edward Padgett[13] (The details of his method are discussed because a modification of his method was used in the present investigation.) His oven consisted of a transite box with wire heating coils on all four

13 Edward Padgett "Improved Electrets" Radio Electronics April 1949 pp 20-23

walls and shielded with an outer jacket of transite having the two separated by a layer of rock wool insulation. A small transite support was placed in the oven cavity which serves as an electrode holder. The lower electrode was a circular rimmed brass cup of 40 mm. in diameter, and the upper electrode was a flat brass disc of 25 mm. in diameter. Both electrodes were covered with tinfoil to produce a common pair of electrodes. The heating coils on the oven walls were connected to a Variac to control the rate of heating. The high voltage terminals were placed on the inside of the oven so that they may be connected across the electrode pair by use of clip leads. The high voltage source was a 3000 volt D.C. power supply. The oven was heated to 110°C. and then the wax mixture in the molten state was poured into the lower electrode. When the oven had cooled to 90°C the field was applied. At room temperature the field was removed, and the electret taken from the oven. For a keeper the electret was wrapped in tinfoil. Padgett used a gold leaf Lindemann electrometer to measure the charge. He used a mixture of 45% Carnauba wax, 45% Resin, and 10% Ethyl Cellulose which he claimed gave a higher surface charge, but his maximum value was 4 e.s.u./cm.^{2} as compared to 6 e.s.u./cm.^{2} obtained by other investigators.

Chapter III Discussion of Equipment Used

A. Oven for Making Electrets

The oven was made from sheets of 3/8 inch-thick Transite. The inside dimensions of the oven were 4 inches by 4 inches, and 6 inches high. The walls of the oven were held together with 3/4 inch right angle brackets using two brackets at each corner. A zig-zag set of holes were drilled in each of the four oven walls, and two binding posts were placed in one of the oven walls 3/4 of an inch from the bottom. This served as a framework for the heating element. For the heating element No. 28 Nichrome wire (4.25 ohms per foot) was used. The two high voltage terminals were in opposite oven walls. These were the right and left walls with respect to the wall containing the heater binding post. The oven was placed inside an outer jacket of transite dimension of 11 inches by 11 inches and 6 3/4 inches high. Between the jacket walls and the oven walls the space was packed with rockwool insulation. A radio neutralizing condenser was adapted for use as the electrode support since it formed a chair for the electrodes. The upper plate of the neutralizing condenser was cut to 2 cm. in diameter so as to be used for an upper electrode. The lower electrode was a circular tin pan of 2.7 cm. in diameter and 3 mm.

in depth. In operation the lower electrode was placed on the lower plate of the neutralizing condenser. Aluminum foil was used to wrap the electrodes thus producing a common metal. The lower electrode made direct contact with the negative high voltage terminal and the upper electrode was connected to the positive high voltage terminal. For the high voltage source a high voltage transformer with one stage rectifier was used. The source furnished was pulsating D.C. The voltage output of the transformer was controlled by lowering the input of the transformer. A Voltmeter was placed across the electrodes. An oven top of transite was made. To indicate the temperature of the oven, a thermometer was inserted through the oven top.

B. Vacumm Tube Electrometer.

A special vacumm tube electrometer and circuit was constructed, the details of which (including operations), are reported by J.S. Pappas in his masters' thesis to the University of Houston 1952. This instrument appears to be more satisfactory than the "old fashioned" electrometer.

Chapter IV Procedure

A. Making Electrets

The oven was heated (see page 14) to 110°C by means of a Variac to control the heating rate. The material was prepared to make electrets by crushing and melting a wax mixture to 180°C. The molten mixture was poured into the dish shaped lower electrode and the upper electrode was lowered until contact was made with the liquid surface. The electrode combination was then placed into the oven and the system reheated to 100°C. and then allowed to cool. An electric potential of 2500 volts was applied across the electrode pair when the oven temperature had reached 90°C. At 50°C. the potential was removed. The electrets were removed and wrapped in aluminum foil keepers and stored in a desiccator for future measurement. The following mixtures were used: 50% ratio of Carnauba wax and Resin; 75% Carnauba wax and 25% Resin; 25% Carnauba wax and 75% Resin; 100% Carnauba wax; 100% Sulfur; and 50% Sulfur and 50% Carnauba wax.

B. Measuring Electrets

Electrets were measured by the use of the vacuum tube electrometer. The electrometer was set up as follows:

(1) the filament current was turned on and adjusted to 10 Ma., (2) after the filament current had been applied for 30 minutes the plate current was turned on and adjusted to 100 μa. by use of R_4. So that a deflection in either direction can be determined, a balancing circuit was used, hence the zero position of the plate meter was changed to enable one to measure both signs of charge. See J.S. Pappas' thesis for details concerning the electrometer. Before the electrometer was used the plate current meter was calibrated in terms of volts. The calibration was accomplished by the standard Leeds and Northrup potentiometer method.

The electret was placed between the condenser plates of the electrometer. [illegible] The upper electrode was lowered on to the electret's surface. The electrodes were short circuited and then opened. With a rapid motion the upper electrode was raised. Both positions of the upper electrode and the maximum value in the plate current was recorded. By fixing the distance the electrode moved, and the diameter of the condenser plates, the capacity of the condenser combination was constant. Then by reading the voltage from the calibration curve, the proportional charge on the electret was calculated. The effective charge on the electret was measured

over a period of time in order to determine the changes with respect to time.

C. Procedure for Gamma-ray Study

A source of 1.03 mg. of radium was used for the gamma-ray source. The following types of exposures were used: (1) electret directly over the opening in the shield of the radium source, hence making the radium 6 cm. from the electret; (2) with the radium source unshielded suspended vertically above the electret at a distance of 7 mm.; (3) with the radium source unshielded suspended horizontally above the electret at a distance of 2 cm.; (4) with the radium source unshielded and directly on the electret's surface; (5) with the radium source unshielded directly on the electret but with the electret wrapped in a foil keeper. The time of exposure was 30 minutes, except in case (1) where the study was from one minute to 48 hours, and in case (3) where one hour was used also. At the end of each radiation period the value of the effective charge was measured and at intervals thereafter to determine the effect of gamma-rays on the electret. The electrets used were a 50% ratio between Carnauba wax and Resin.

TABLE 1

50% Carnauba Wax and 50% Resin

Electret No. 1

Molten Temp.	Polarizing potential	Distance Between Electrodes	Polarizing Field
0°C.	volts	cm.	e.s.u.
180	2500	2.94	9.18

For Bottom Surface

Date	Range	Distance the Upper Condenser Plate Moved	Deflections	No. of Days	Q/k
		cm.			e.s.u.
4/15/52	C	0.13	31.5	0	-1.20 x 10^{-2}
4/16/52	C	0.18	22.0	1	-0.99 "
4/17/52	C	0.17	23.5	2	-0.85 "
4/18/52	C	0.14	4.0	3	-0.11 "
4/23/52	C	0.17	8.0	8	0.48 "
4/24/52	C	0.19	16.0	9	0.87 "
4/25/52	C	0.14	20.0	10	1.50 "
4/26/52	C	0.15	19.0	11	1.33 "
4/27/52	C	0.13	25.0	12	2.03 "
4/28/52	C	0.17	20.0	13	1.24 "

For Top Surface

4/15/52	C	0.15	22.0	0	1.20 "
4/16/52	C	0.15	23.0	1	1.24 "
4/17/52	C	0.17	23.0	2	1.10 "
4/18/52	C	0.15	20.0	3	1.09 "
4/23/52	C	0.16	6.0	8	-0.50 "
4/24/52	C	0.15	16.0	9	-0.94 "
4/25/52	C	0.24	20.0	10	-1.08 "
4/26/52	C	0.13	15.0	11	-1.22 "
4/27/52	C	0.16	23.0	12	-1.52 "
4/28/52	C	0.14	17.0	13	-1.28 "

TABLE 11

75% Carnauba Wax and 25% Resin

Electret No. 5

Molten Temp.	Polarizing Potential	Distance between Electrodes	Polarizing Field
0°C.	volts	cm.	e.s.u.
100	3300	3.15	10.05

For Bottom Surface

Date	T	Range	Distance the upper Condenser Plate Moved cm.	Deflections	No. of Days	Q/k e.s.u.
4/26/52		C	0.15	30.0	0	2.11 $\times 10^{-2}$
4/27/52		C	0.13	27.0	1	2.85 "
4/28/52		C	0.17	25.0	2	1.55 "
4/29/52		C	0.15	16.5	3	1.16 "
4/30/52		C	0.17	16.0	4	1.55 "
5/ 1/52		C	0.18	13.0	5	0.76 "
5/ 2/52		C	0.19	8.5	6	0.47 "
5/ 3/52		C	0.18	4.0	7	0.23 "
5/ 5/52		C	0.22	16.0	8	0.76 "
5/ 6/52		C	0.13	13.0	10	0.80 "
5/ 7/52		C	0.20	10.0	11	1.06 "
5/ 9/52		C	0.16	5.0	13	0.33 "
5/10/52		C	0.18	21.5	14	0.58 "
5/11/52		C	0.17	20.0	15	1.24 "
5/12/52		C	0.18	17.0	16	0.99 "
5/14/52		C	0.24	7.0	18	0.33 "
5/15/52		C	0.19	4.0	19	0.22 "
5/17/52		C	0.17	20.0	20	0.12 "
5/19/52		C	0.18	5.0	22	0.24 "
5/21/52		C	0.18	4.0	24	0.21 "
5/23/52		C	0.18	4.0	26	0.21 "

(Top surface for Table 11 on next page)

TABLE 11 (cont.)

For Top Surface

Date	Range	Distance the Upper Condenser Plate Moved cm.	Deflections	No. of Days	Q/k e.s.u.
4/26/52	C	0.13	9.0	0	-0.73 x10^{-2}
4/27/52	C	0.17	31.0	1	-1.92 "
4/28/52	C	0.16	34.0	2	-2.24 "
4/29/52	C	0.19	16.0	3	-0.89 "
4/30/52	C	0.20	22.0	4	-0.63 "
5/ 1/52	C	0.13	9.0	5	-0.73 "
5/ 2/52	C	0.18	4.0	6	-0.23 "
5/ 3/52	C	0.16	4.0	7	-0.26 "
5/ 5/52	C	0.20	12.0	8	-0.74 "
5/ 6/52	C	0.19	10.0	10	-0.72 "
5/ 7/52	C	0.21	5.0	11	-0.25 "
5/ 9/52	C	0.14	5.0	13	-0.37 "
5/10/52	C	0.16	22.0	14	-1.72 "
5/11/52	C	0.20	26.0	15	-1.42 "
5/12/52	C	0.19	15.0	16	-0.84 "
5/14/52	C	0.25	4.0	18	-0.17 "
5/15/52	C	0.19	4.0	19	-0.56 "
5/17/52	C	0.18	15.0	20	-0.88 "
5/19/52	C	0.18	3.0	22	-0.18 "
5/21/52	C	0.17	4.0	24	-0.24 "
5/23/52	C	0.17	4.0	26	-0.24 "

TABLE 111

25% Carnauba Wax and 75% Resin

Electret No. 2

Molten Temp.	Polarizing potential	Distance Between Electrodes	Polarizing Field
0°C.	volts	cm.	e.s.u.
235	3000	3.03	9.73

For Bottom Surface

Date	Range	Distance the Upper Condenser Plate Moved cm.	Deflections	No. of Days	Q/k e.s.u.
4/28/52	C	0.16	32.0	0	-1.85 x10^{-2}
4/29/52	C	0.14	13.0	1	-0.98 "
5/ 1/52	C	0.14	8.0	3	-0.60 "
5/ 2/52	C	0.16	2.0	4	-0.19 "
5/ 3/52	C	0.18	3.0	5	-0.21 "
5/ 4/52	C	0.16	4.0	6	-0.26 "
5/ 5/52	C	0.17	2.5	7	-0.22 "
5/ 6/52	C	0.16	0.0	8	0.00
5/ 7/52	C	0.14	0.0	9	0.00
5/ 8/52	C	0.16	2.0	10	0.13 "
5/ 9/52	C	0.16	14.0	11	0.93 "
5/10/52	C	0.16	14.0	12	0.93 "
5/11/52	C	0.16	15.0	13	0.99 "
5/12/52	C	0.19	15.0	14	0.83 "

For Top Surface

4/28/52	C	0.16	24.0	0	1.58 "
4/29/52	C	0.13	20.0	1	1.62 "
5/ 1/52	C	0.15	15.0	3	1.06 "
5/ 2/52	C	0.18	5.0	4	0.36 "
5/ 3/52	C	0.15	7.0	5	0.49 "
5/ 4/52	C	0.17	13.0	6	0.81 "
5/ 5/52	C	0.16	4.0	7	0.27 "
5/ 6/52	C	0.16	2.0	8	0.27 "
5/ 7/52	C	0.15	0.0	9	0.0 "
5/ 8/52	C	0.16	2.0	10	0.03 "
5/ 9/52	C	0.18	10.0	11	0.67 "
5/10/52	C	0.16	12.0	12	0.80 "
5/11/52	C	0.18	12.0	13	0.71 "
5/12/52	C	0.16	7.0	14	0.25 "

TABLE IV

50% Carnauba Wax and 50% Sulfur

Electret No. 4

Molten Temp.	Polarising Potential	Distance Between Electrodes	Polarising Field
°C.	volts	cm.	e.s.u.
200	3000	3.04	9.85

For Bottom Surface

Date	Range	Distance the Upper Condenser Plate Moved cm.	Deflections	No. of Days	Q/k e.s.u.
5/ 1/52	C	0.23	22.0	0	1.06 x10^{-2}
5/ 3/52	C	0.18	8.0	2	0.47 "
5/ 5/52	C	0.22	20.0	4	0.96 "
5/ 6/52	C	0.16	16.0	5	1.08 "
5/ 7/52	C	0.14	8.0	6	0.52 "
5/ 8/52	C	0.20	2.0	7	0.11 "
5/10/52	C	0.19	12.0	9	0.63 "
5/11/52	C	0.18	27.0	10	1.50 "
5/12/52	C	0.16	19.0	11	1.25 "
5/13/52	C	0.20	19.0	12	1.01 "
5/14/52	C	0.17	3.0	13	0.19 "
5/15/52	C	0.22	1.5	14	0.02 "
5/16/52	C	0.16	14.0	15	0.79 "
5/17/52	C	0.12	2.0	16	0.17 "
5/18/52	C	0.17	11.0	17	0.68 "
		For Top Surface			
5/ 1/52	C	0.18	23.0	0	-0.70 "
5/ 3/52	C	0.18	2.0	2	-0.07 "
5/ 5/52	C	0.20	12.0	4	-0.67 "
5/ 6/52	C	0.20	9.0	5	-0.47 "
5/ 7/52	C	0.19	1.0	6	-0.06 "
5/ 8/52	C	0.22	0.5	7	-0.01 "
5/10/52	C	0.15	1.0	9	-0.07 "
5/11/52	C	0.19	7.0	10	-0.39 "
5/12/52	C	0.14	5.0	11	-0.38 "
5/13/52	C	0.22	2.0	12	0.01 "
5/14/52	C	0.20	0.0	13	0.0 "
5/15/52	C	0.20	0.5	14	0.03 "
5/16/52	C	0.16	3.0	15	0.20 "
5/17/52	C	0.20	0.0	16	0.0 "
5/18/52	C	0.10	0.0	17	0.0 "

TABLE V

100% Carnauba Wax

Electret No. 6

Molten Temp.	Polarizing Potential	Distance between Electrodes	Polarizing Field
0°C	volts	cm.	e.s.u.
100	1500	3.30	5.45

For Bottom Surface

Date	Range	Distance the Upper Condenser Plate Moved. cm.	Deflections	No. of Days	Q/k e.s.u
4/18/52	C	0.15	24.0	0	-1.08 x10^{-2}
4/23/52	C	0.17	5.0	5	0.31 "
4/24/52	C	0.19	12.0	6	0.67 "
4/26/52	C	0.17	20.0	8	1.24 "
4/27/52	C	0.13	23.0	9	1.87 "
4/28/52	C	0.17	20.0	10	1.24 "
4/29/52	C	0.15	7.0	11	0.49 "
4/30/52	C	0.19	18.5	12	1.08 "
5/ 3/52	C	0.20	11.0	15	0.68 "
5/ 4/52	C	0.20	12.0	16	0.63 "
5/10/52	C	0.23	18.0	21	0.83 "
5/11/52	C	0.20	20.0	22	0.99 "
5/12/52	C	0.25	19.0	23	0.80 "
5/13/52	C	0.20	6.0	24	0.31 "
5/14/52	C	0.16	5.0	25	0.33 "

For Top Surface

4/18/52	C	0.15	22.0	0	-1.02 x10^{-2}
4/23/52	C	0.17	7.0	5	-0.43 "
4/24/52	C	0.19	12.0	6	0.61 "
4/26/52	C	0.15	14.0	8	0.98 "
4/27/52	C	0.17	8.0	9	0.50 "
4/28/52	C	0.16	5.0	10	0.32 "
4/29/52	C	0.17	1.0	11	0.06 "
4/30/52	C	0.16	4.0	12	-0.26 "
5/ 3/52	C	0.18	0.5	15	-0.08 "
5/ 4/52	C	0.20	3.5	16	-0.19 "
5/10/52	C	0.20	18.0	21	0.95 "
5/11/52	C	0.18	16.0	22	0.90 "
5/12/52	C	0.19	15.0	23	0.70 "
5/13/52	C	0.21	3.0	24	0.15 "
5/14/52	C	0.16	2.0	25	0.13 "

TABLE VI

100% Sulfur

Electret No. 3

Molten Temp. °C	Polarizing Potential volts	Distance between Electrodes cm.	Polarizing Field e.s.u.
130	2800	2.00	14.0

For Bottom Surface

Date	Range	Distance the Upper Condenser Plate Moved cm.	Deflections	No. of Days	Q/k e.s.u.
4/11/52	C	0.18	16.0	0	-0.65 x10^{-2}
4/12/52	C	0.18	25.0	1	1.10 "
4/13/52	C	0.18	25.0	2	1.16 "
4/14/52	C	0.15	19.5	3	1.08 "
4/15/52	C	0.15	22.0	4	1.16 "
4/16/52	C	0.17	21.0	5	1.10 "
4/17/52	C	0.16	20.0	6	1.03 "
4/23/52	C	0.14	18.0	12	0.80 "
4/24/52	C	0.20	16.0	13	0.84 "
4/25/52	C	0.18	17.0	14	0.99 "
4/26/52	C	0.14	23.0	15	1.52 "
4/27/52	C	0.14	23.0	16	1.52 "
4/28/52	C	0.18	19.0	17	1.12 "
4/29/52	C	0.15	12.0	18	0.97 "
4/30/52	C	0.15	19.0	19	1.34 "
5/ 1/52	C	0.19	12.0	20	0.67 "
5/ 2/52	C	0.15	12.0	21	0.94 "
5/ 3/52	C	0.15	30.0	22	2.10 "
5/ 4/52	C	0.18	11.5	23	0.79 "

TABLE VI (cont.)

Date	Range	Distance the Upper Condenser Plate Moved cm.	Deflections	No. of Days	Q/k e.s.u.
		For Top Surface			
4/11/52	C	0.18	25.0	0	-1.30 x10^{-2}
4/12/52	C	0.18	23.5	1	1.06 "
4/13/52	C	0.16	19.0	2	1.13 "
4/14/52	C	0.15	19.5	3	1.00 "
4/15/52	C	0.15	23.0	4	1.12 "
4/16/52	C	0.14	19.0	5	1.13 "
4/17/52	C	0.13	20.0	6	0.90 "
4/23/52	C	0.18	8.0	12	0.47 "
4/24/52	C	0.19	15.0	13	0.83 "
4/25/52	C	0.15	13.0	14	0.91 "
4/26/52	C	0.18	21.0	15	1.23 "
4/27/52	C	0.17	22.0	16	1.37 "
4/28/52	C	0.20	20.0	17	1.06 "
4/29/52	C	0.18	13.0	18	0.76 "
4/30/52	C	0.20	22.0	19	1.16 "
5/ 1/52	C	0.20	12.0	20	0.63 "
5/ 2/52	C	0.15	2.0	21	0.11 "
5/3/ 52	C	0.15	30.0	22	2.00 "
5/4/ 52	C	0.20	14.0	23	0.73 "

TABLE V11

Radiation of Electrets

Radiation of a 50% ratio of Carnauba Wax and Resin with the electret being over the opening in the radium shield.

Source

1.03 mg of Radium

Time of Exposure	Effective charge on electret before exposure	Effective charge on electret after exposure	Change in Charge
minutes	e.s.u.	e.s.u.	e.s.u.
1	1.34 $x10^{-2}$	1.34 $x10^{-2}$	0.0
5	1.34 "	1.34 "	0.0
10	1.34 "	1.34 "	0.0
15	1.34 "	1.34 "	0.0
20	1.34 "	1.34 "	0.0
60	1.34 "	1.34 "	0.0
1 (day)	1.34 "	1.34 "	0.0
2 (days)	1.34 "	1.34 "	0.0

Radiation of a 50% ratio of Carnauba wax and Resin.

Source — Time of Exposure

1.03 mg. of radium — 30 minutes

2 When the Electret was 7mm. vertically from the radium.

Time	Distance the Upper Condenser Plate Moved	Deflections	Q/k
minutes	cm.		e.s.u.
0	0.20	18	9.60 $x10^{-3}$
30	0.18	15	8.70 "
35	0.20	18	9.60 "

3 When radium was 3cm. horizontally from the electret.

Time	Distance the Upper Condenser Plate moved.	Deflections	Q/k
minutes	cm.		e.s.u.
0	0.20	18.0	9.60×10^{-3}
30	0.18	15.0	8.80 "
35	0.20	18.0	9.60 "

4 When the electret is in contact with the radium.

Time	Distance the Upper Condenser Plate moved	Deflections	Q/k
minutes	cm.		e.s.u.
0	0.20	18.0	9.60×10^{-3}
30	0.19	13.0	8.10 "
35	0.20	18.0	9.60 "

5 When the electret was in contact with the radium but wrapped in foil.

Source	Time of Exposure
1.03 mg. of Radium	30 minutes

Time	Distance the Upper Condenser Plate moved	Deflections	Q/k
minutes	cm.		e.s.u.
0	0.14	13.0	9.30×10^{-3}
32	0.25	11.0	5.10 "
39	0.16	11.0	7.20 "
42	0.14	13.0	9.30 "

6 When the electret was separated from the radium by a horizontal distance of 3 cm.

Source	Time of Exposure
1.03 mg of Radium	One Hour

Time	Distance the Upper Condenser Plate Moved	Deflections	Q/k
minutes	cm.		e.s.u.
0	0.20	24.0	1.36 $\times 10^{-2}$
60	0.21	17.0	0.86 "
65	0.20	19.0	1.01 "
70	0.20	22.0	1.10 "
75	0.20	21.5	1.20 "
80	0.21	24.5	1.36 "

Comparing the cases

Case	Amount the Charge was lowered in e.s.u.
1 - - - - - - - - - - - - - -	0.0
2 - - - - - - - - - - - - - -	0.9 $\times 10^{-3}$
3 - - - - - - - - - - - - - -	0.8 "
4 - - - - - - - - - - - - - -	1.5 "
5 - - - - - - - - - - - - - -	4.2 "
6 - - - - - - - - - - - - - -	.5 "

TABLE VIII

Percentage of Relative Humidity

Month	Day	%	Month	Day	%
April	1	59	May	1	60
"	2	55	"	2	49
"	3	94	"	3	65
"	4	35	"	4	51
"	5	31	"	5	38
"	6	51	"	6	43
"	7	62	"	7	67
"	8	68	"	8	65
"	9	79	"	9	72
"	10	69	"	10	55
"	11	97	"	11	24
"	12	68	"	12	41
"	13	49	"	13	42
"	14	38	"	14	54
"	15	57	"	15	68
"	16	59	"	16	75
"	17	63	"	17	85
"	18	76	"	18	97
"	19	90	"	19	74
"	20	90	"	20	51
"	21	86	"	21	64
"	22	92	"	22	80
"	23	58			
"	24	43			
"	25	55			
"	26	27			
"	27	41			
"	28	41			
"	29	52			
"	30	51			

TABLE IX

Calibration Curves

1. Calibration of Electrometer for range A.

Deflections	Voltage
5	.049
10	.085
15	.125
20	.170
25	.205
30	.245
35	.275
40	.317
45	.357
50	.400

2. Calibration of Electrometer for range B.

5	.085
10	.120
15	.205
20	.290
25	.325
30	.395
35	.425
40	.495
45	.530
50	.610

3. Calibration of Electrometer for range C.

5	.205
10	.250
15	.550
20	.720
25	.880
30	1. 00
35	1. 10
40	1. 28
45	1. 40
50	1.60

4. Calibration of Electrometer for range C with new tube to be used after 4/28/52

5	.225
10	.450
15	.675
20	1. 00
25	1.325

TABLE IX (Cont.)

5. Calibration of Electrometer for range C by the use of a parallel condenser arrangement.

C = $\mu\mu$f.	Deflections	V. volts	Q e.s.u.
8.8 x10^5	9	6.0	1.59
	14	22.5	5.94
	20	45.0	11.90
	23.5	67.5	17.90

TABLE X

Humidity effects on the Electrometer sensitivity.

H.	D	Deflections	Q/k
%	cm.		e.s.u.
61	11	12	.930 $\times 10^2$
64	14	10	.830 "
66	16	8	.450 "
69	17	4	.250 "

TABLE XI

An Electret exposed to air only.
For 30 minutes.

Time min.	Distance the Upper Condenser moved. cm.	Deflections	Q/k e.s.u.
0	0.17	12.0	.75 $\times 10^{-2}$
31	0.17	11.5	.73 "
36	0.17	12.0	.75 "

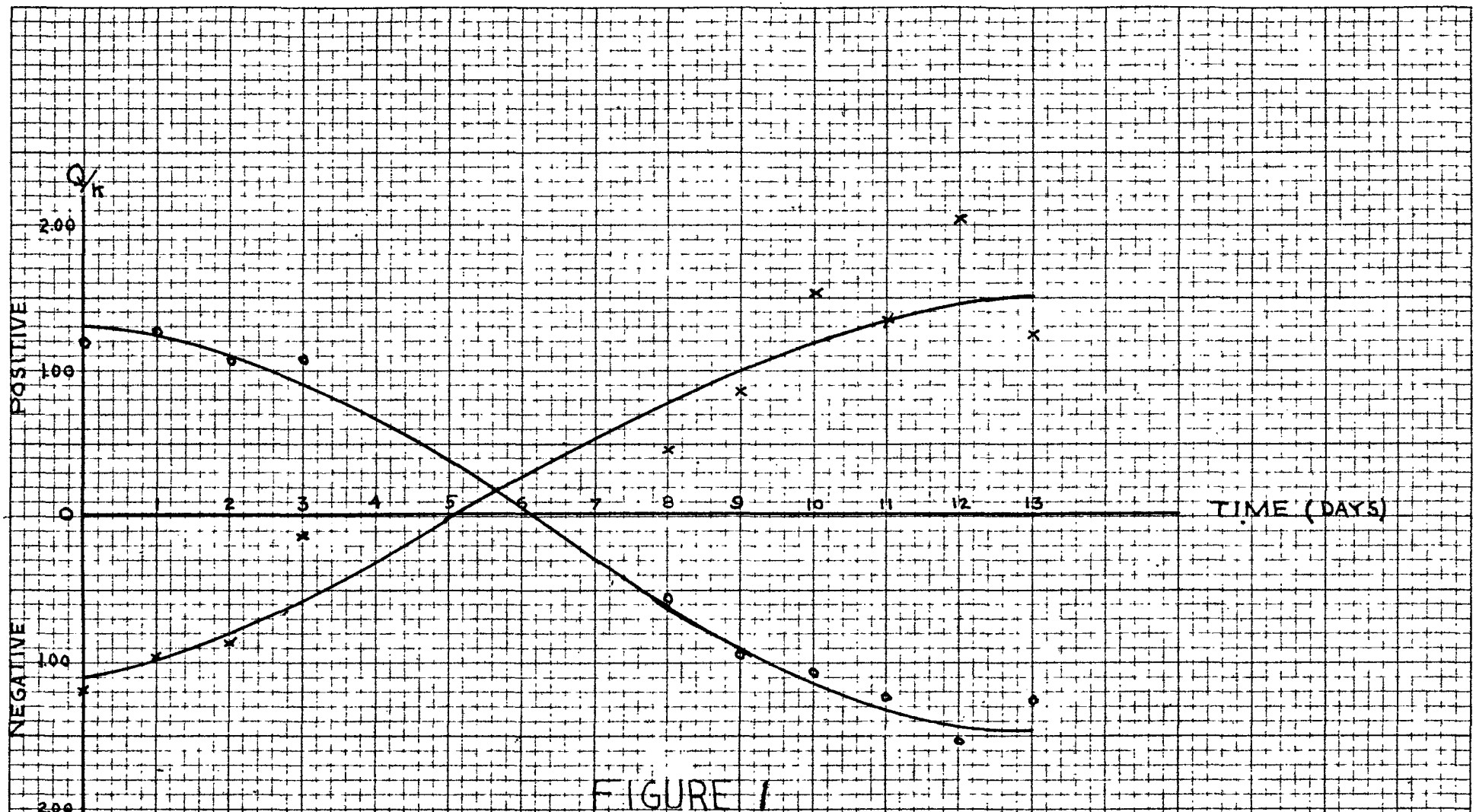


FIGURE 1

ELECTRET NO. 1 : 50% CARNAUBA WAX - 50% ROSIN
ELECTRIC FIELD 9.18 KV/cm
MOLTEN MIXTURE TEMPERATURE 180°C

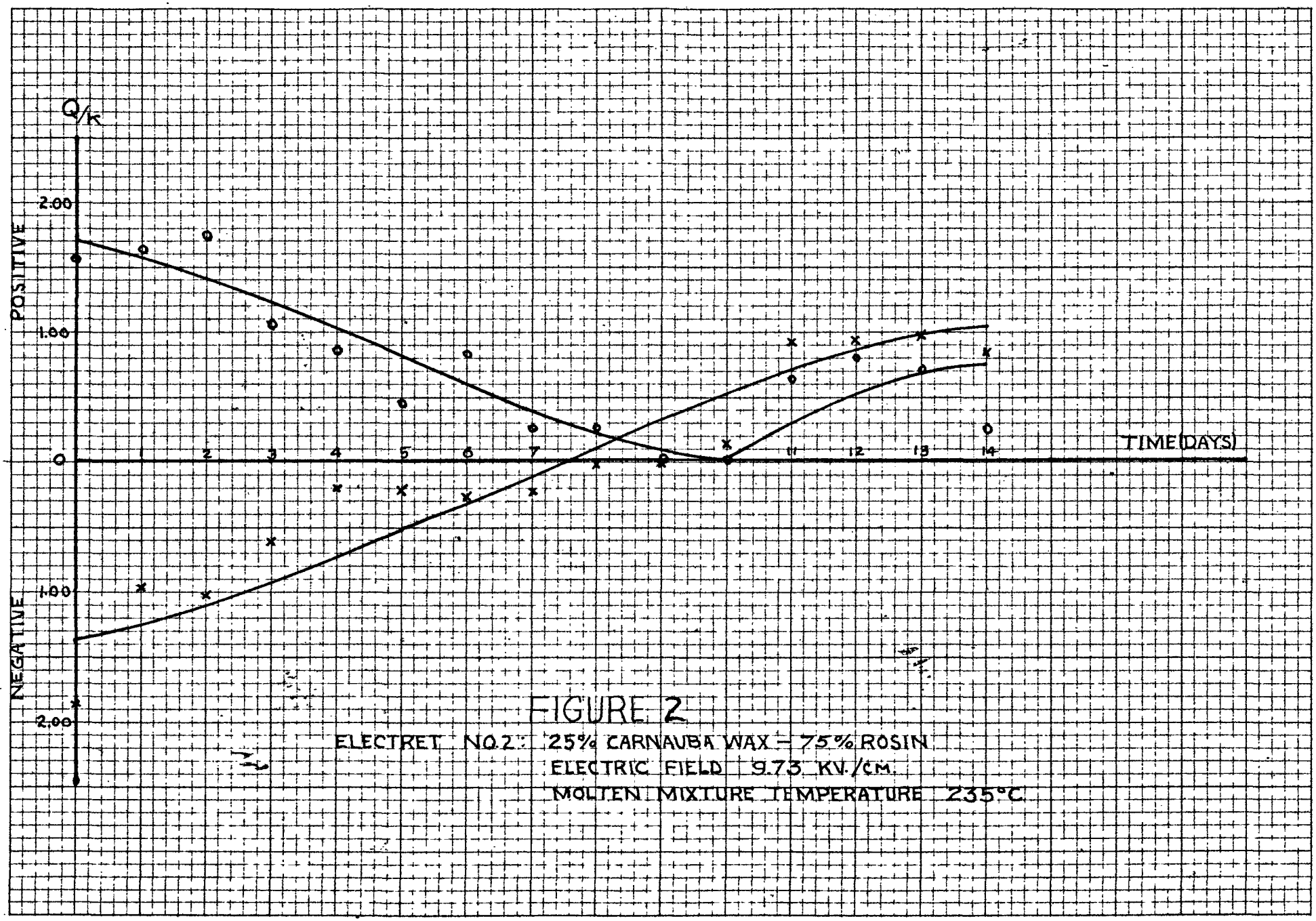


FIGURE 2

ELECTRET NO.2: 25% CARNAUBA WAX – 75% ROSIN
ELECTRIC FIELD 9.73 KV./CM.
MOLTEN MIXTURE TEMPERATURE 235°C.

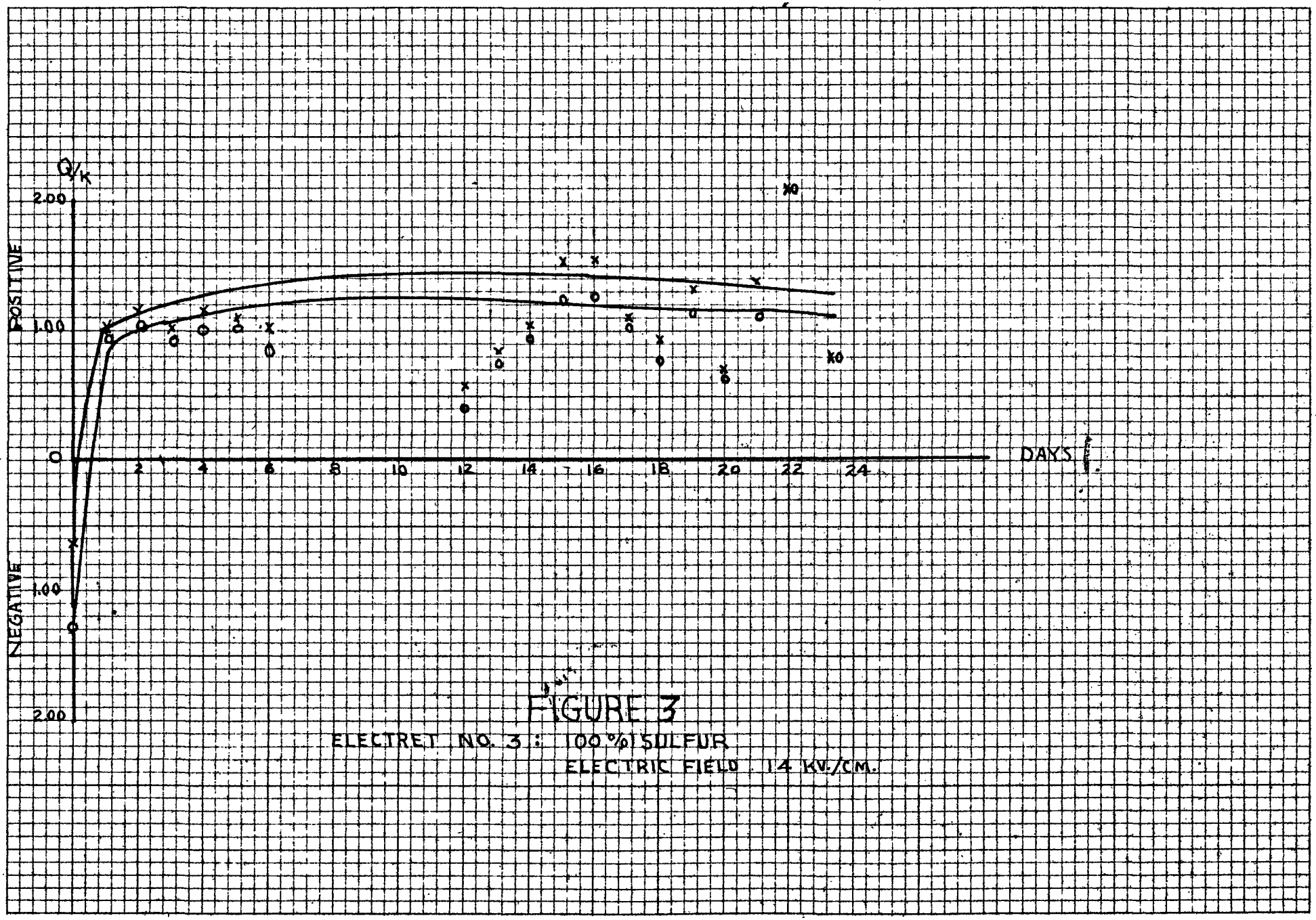


FIGURE 3

ELECTRET NO. 3 : 100% SULFUR

ELECTRIC FIELD 1.4 KV./CM.

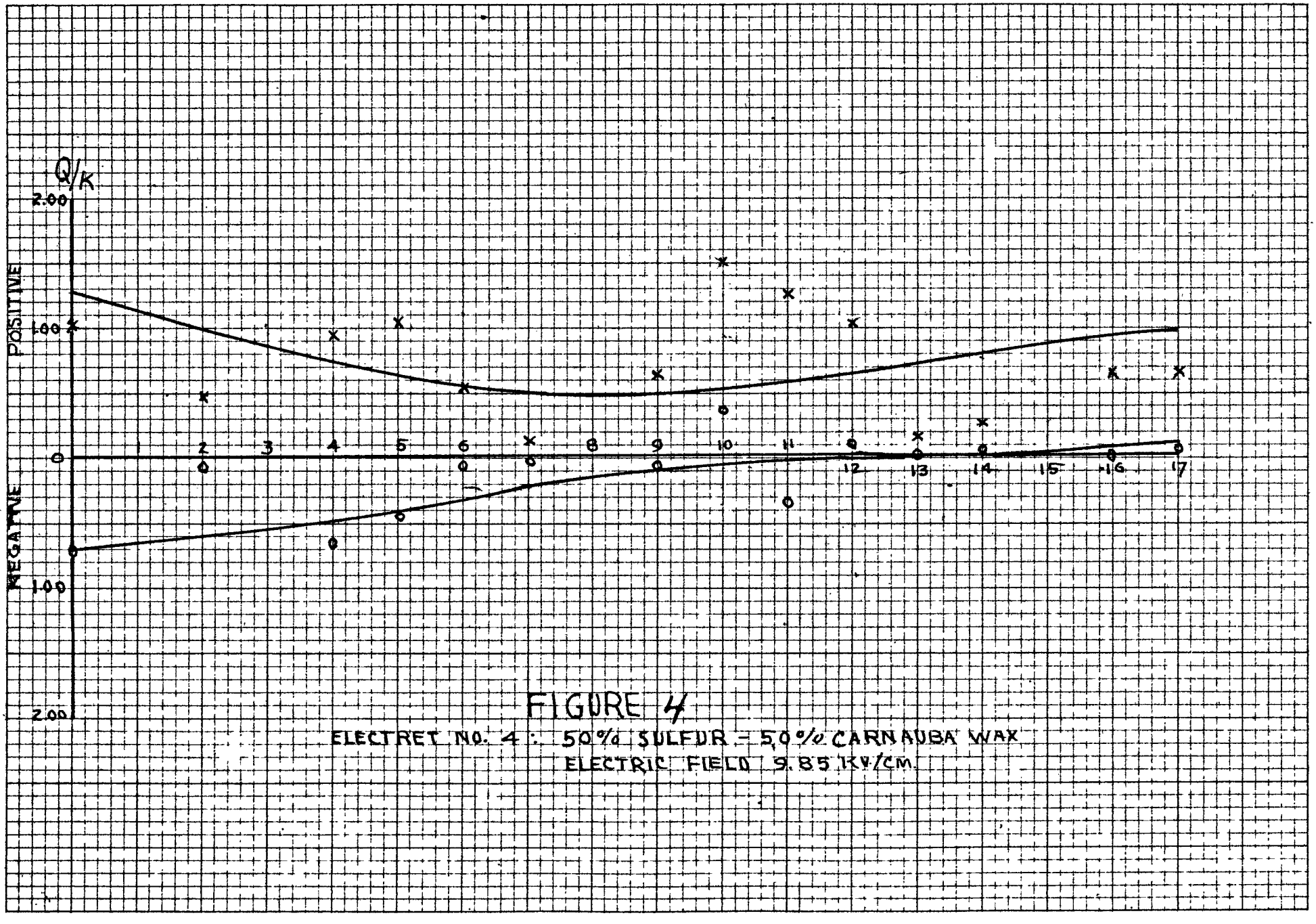


FIGURE 4

ELECTRET NO. 4 : 50% SULFUR - 50% CARNAUBA WAX

ELECTRIC FIELD 9.85 KV/CM.

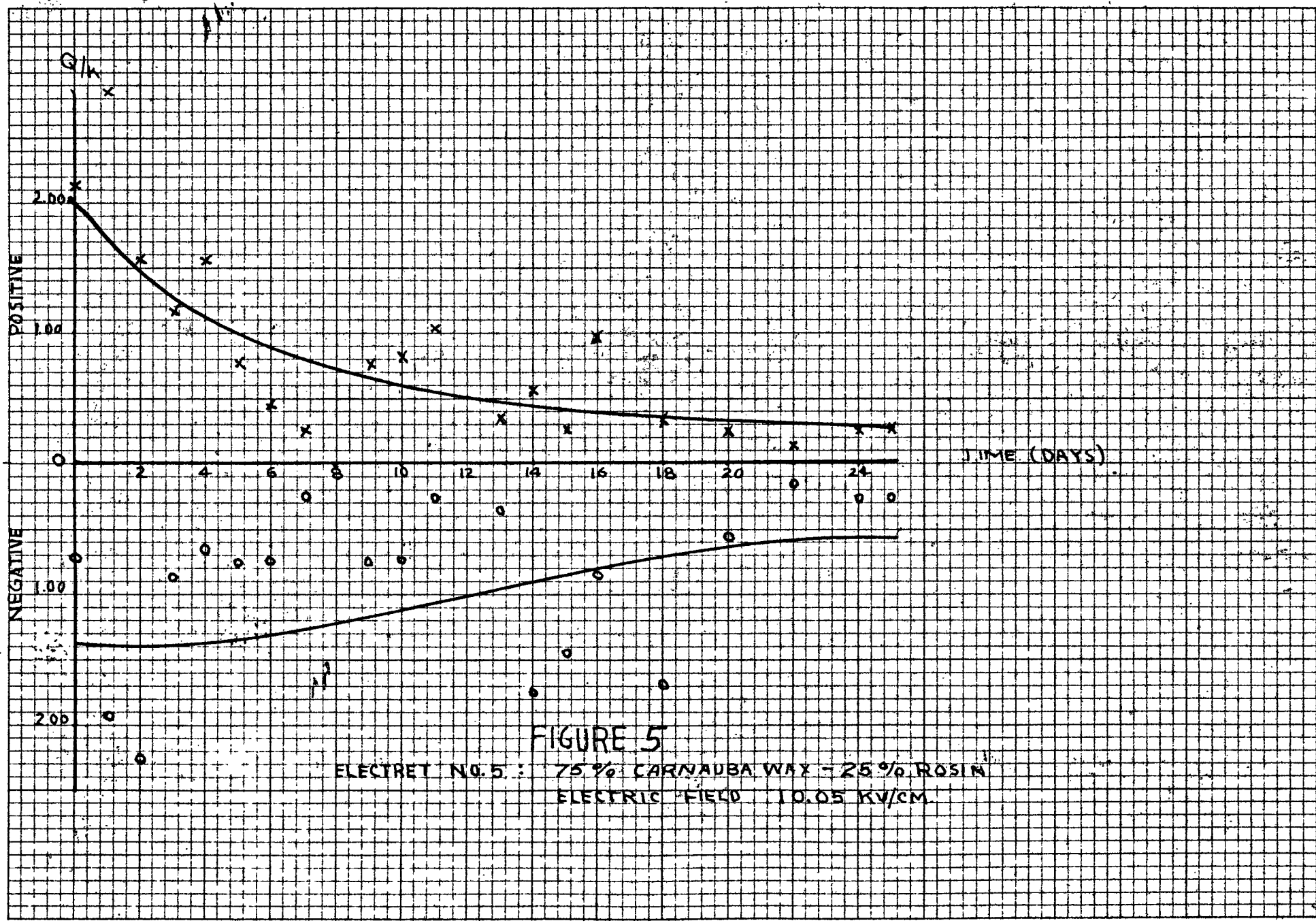


FIGURE 5

ELECTRET NO. 5 : 75% CARNAUBA WAX - 25% ROSIN

ELECTRIC FIELD 10.05 KV/CM.

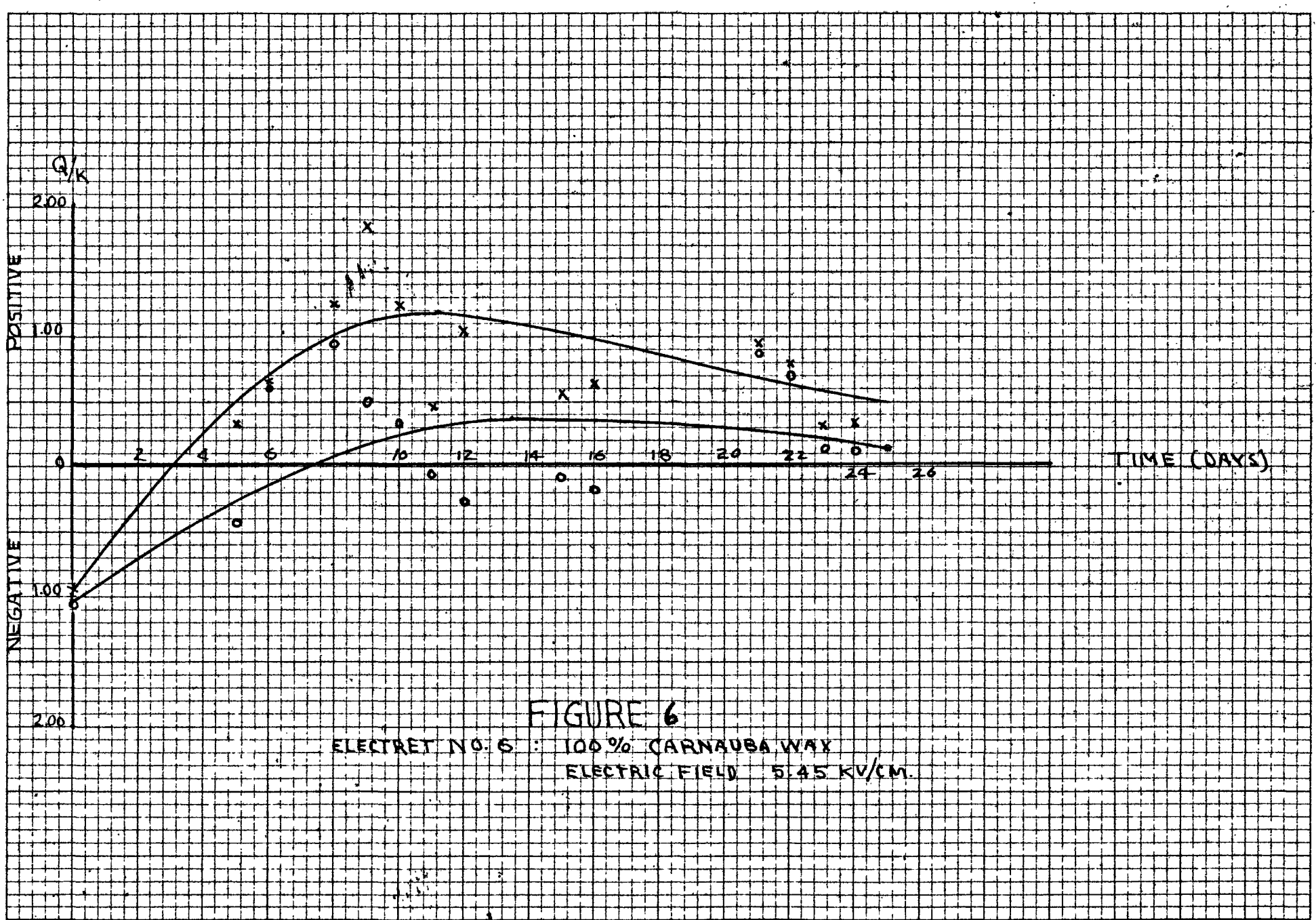


FIGURE 6

ELECTRET NO. 6 : 100% CARNAUBA WAX
ELECTRIC FIELD 5.45 KV/CM.

FIGURE 7

ELECTROMETER CALIBRATIONS
FOR RANGE A, 0-50 μA.

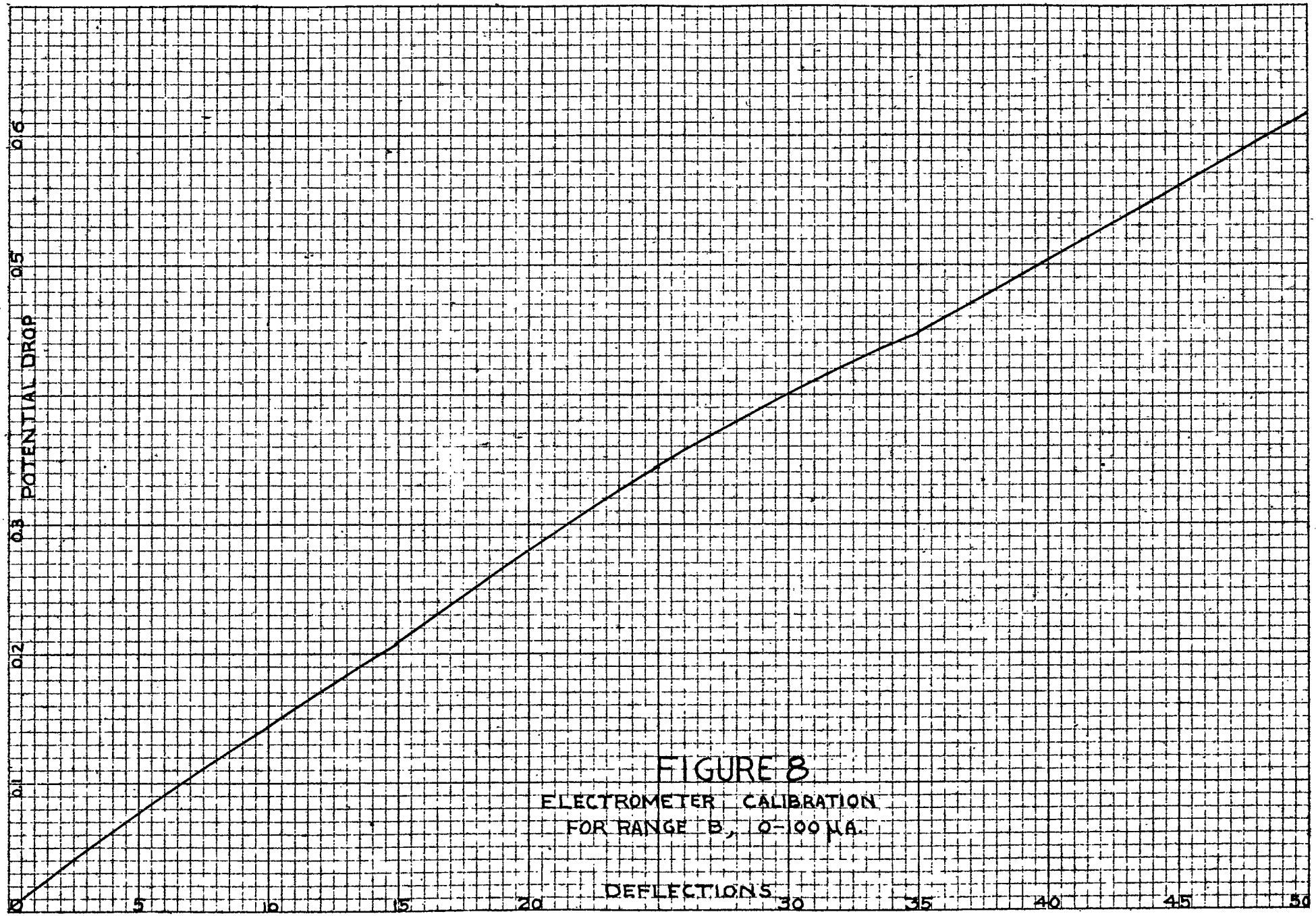


FIGURE 8

ELECTROMETER CALIBRATION
FOR RANGE B, 0-100 μA.

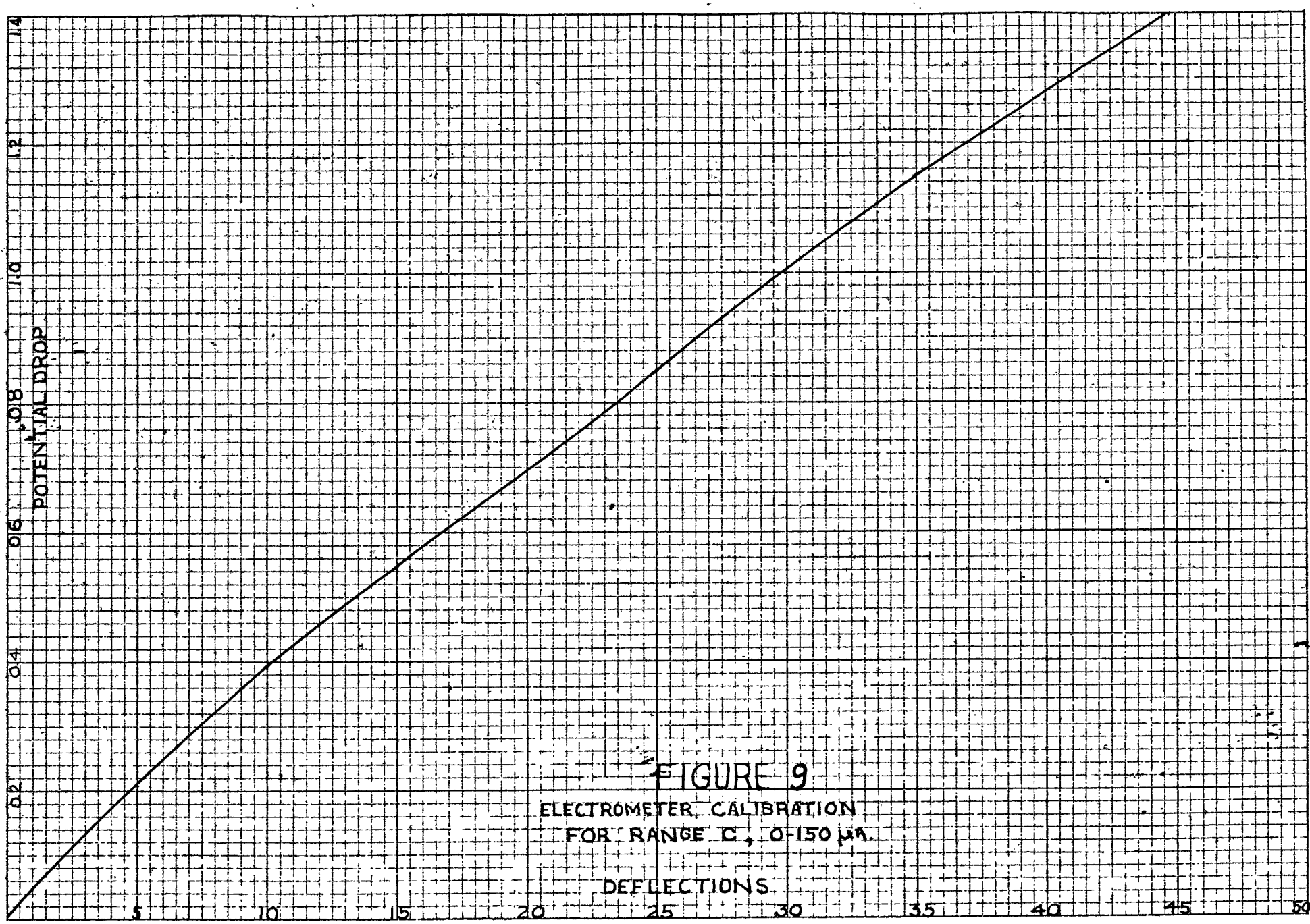
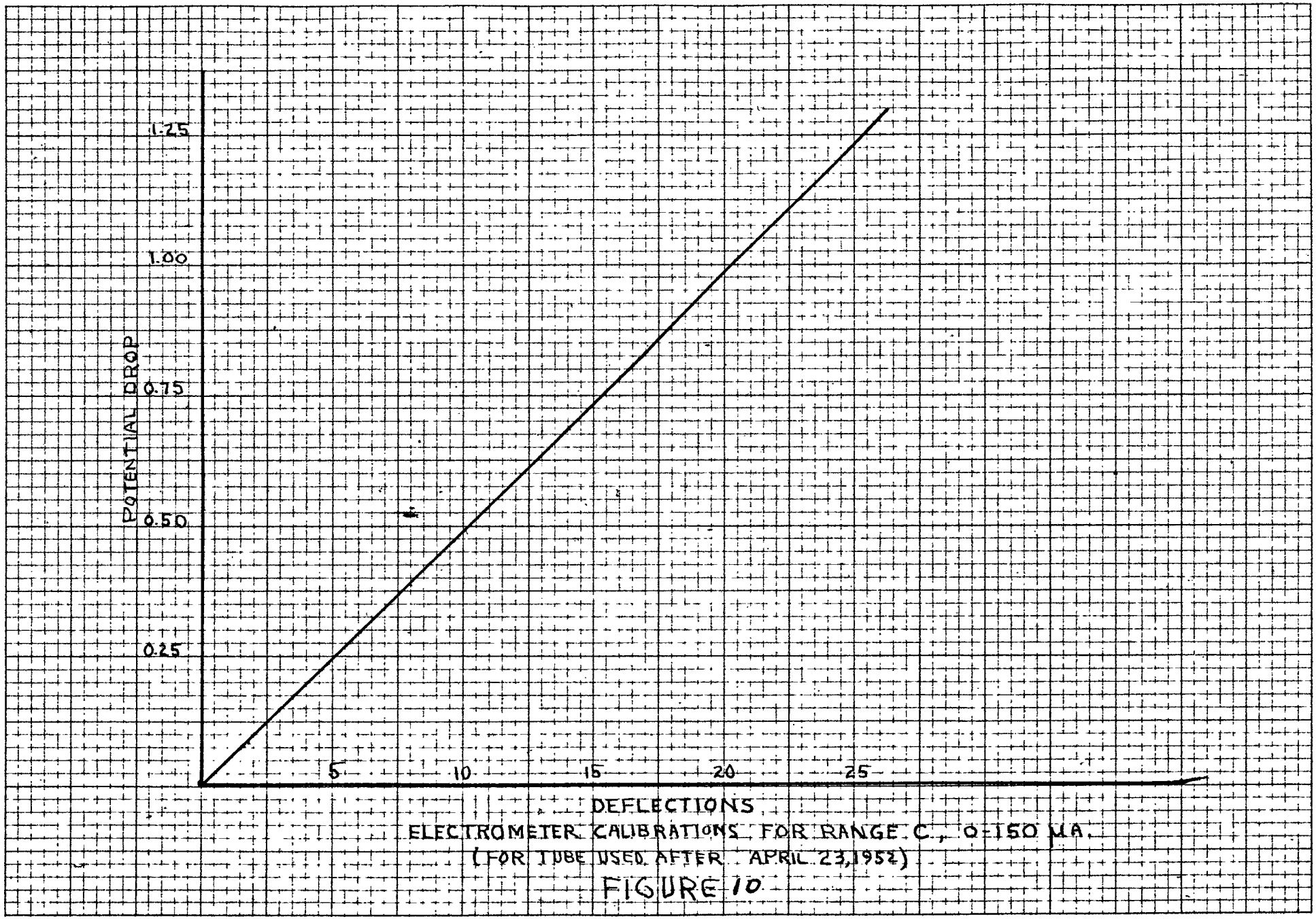


FIGURE 9

ELECTROMETER CALIBRATION
FOR RANGE C, 0-150 μa.



ELECTROMETER CALIBRATIONS FOR RANGE C, 0-150 μA.
(FOR TUBE USED AFTER APRIL 23, 1952)

FIGURE 10

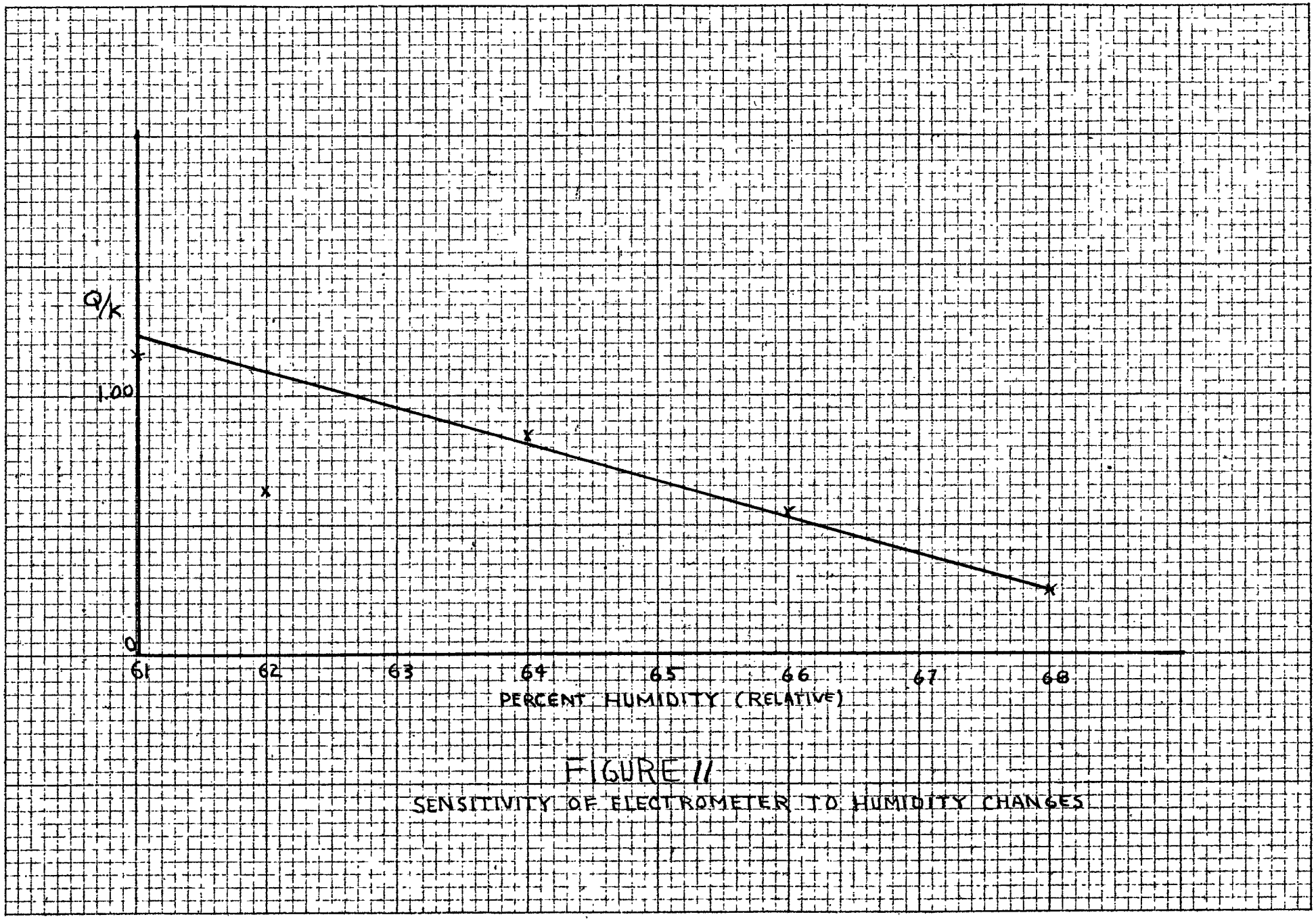


FIGURE II

SENSITIVITY OF ELECTROMETER TO HUMIDITY CHANGES

FIGURE 12

VACUUM TUBE ELECTROMETER CIRCUIT USED TO OBTAIN DATA

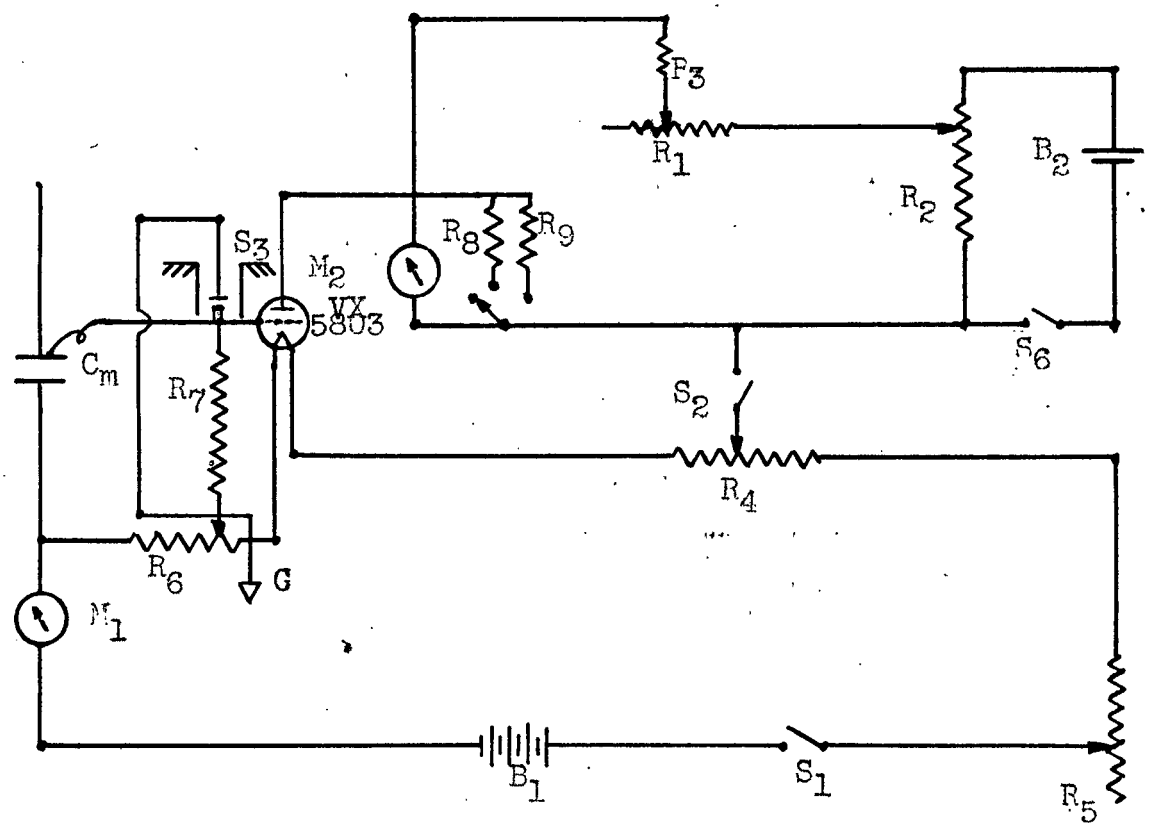
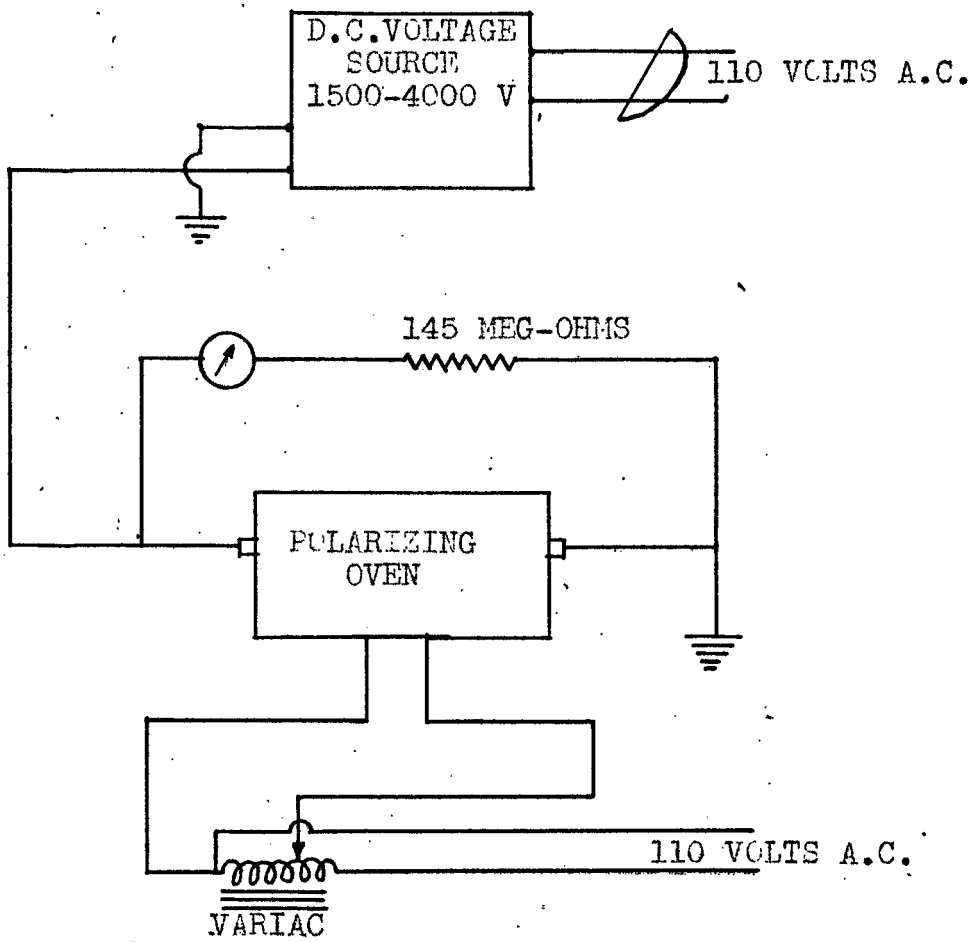
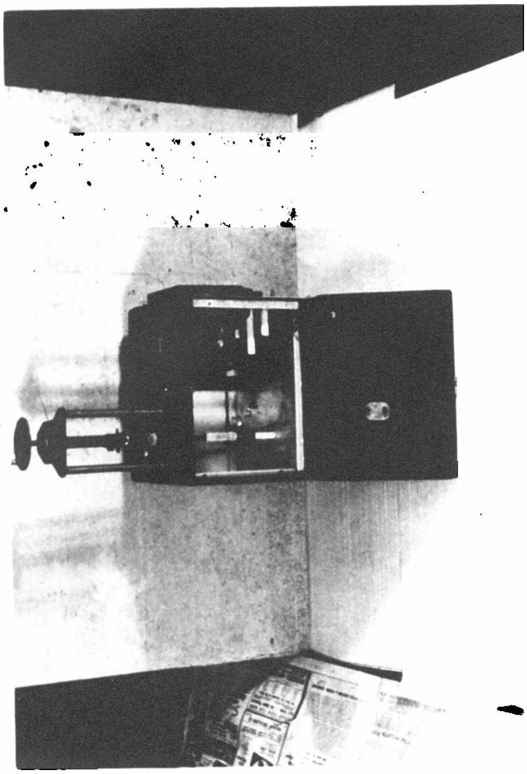
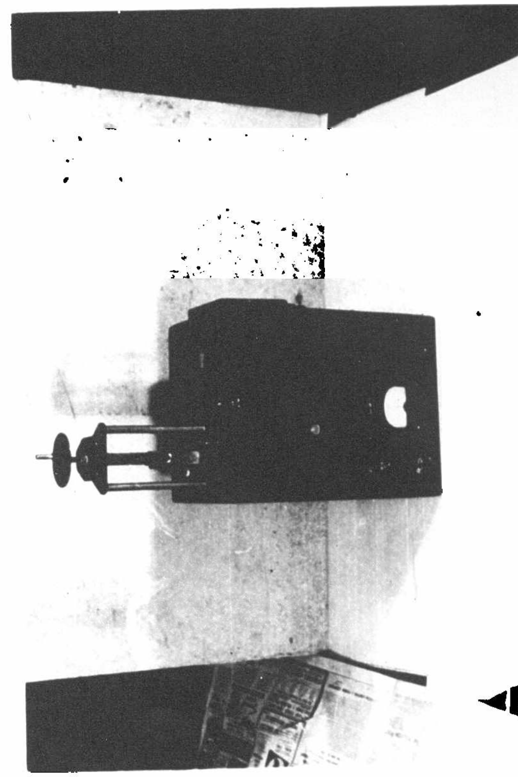


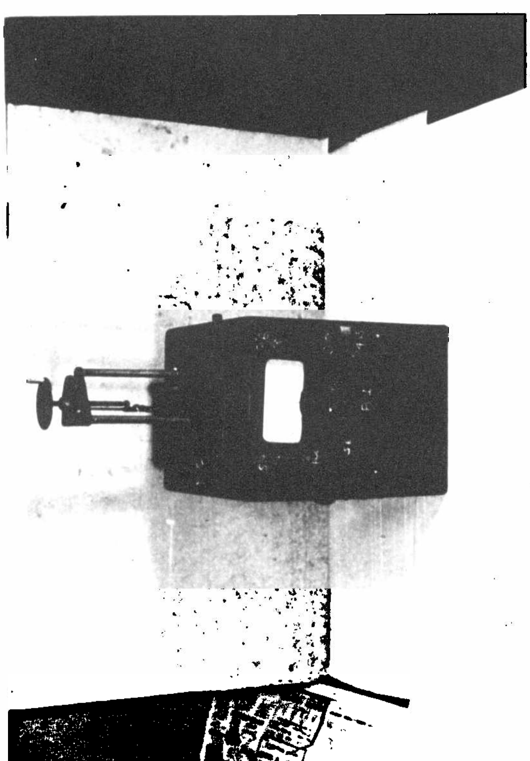
FIGURE 13

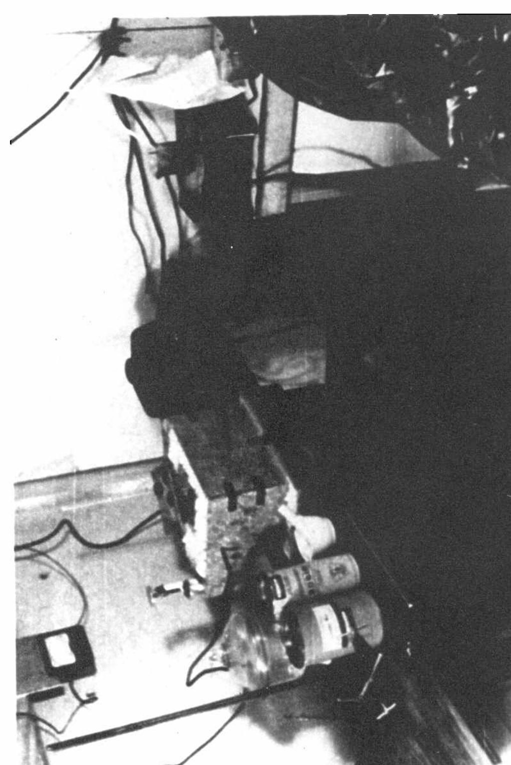
ELECTRET OVEN ARRANGMENT











CHAPTER V Conclusion

This investigation has shown that the type of electrets formed depended on the composition and the solidification field. The 50% ratio of Carnauba wax and resin yielded a reversal of effective charge thus producing a true electret. A mixture of 25% Carnauba wax and resin showed a reversal but occurred after a longer period of time than for a 50% ratio. Also the net difference of the effective charges of the two surfaces was smaller than the observed difference for the two surfaces of an electret of 50% Carnauba wax and resin composition. A pure sulfur electret yielded only a heterocharge with both surfaces having the same sign of charge but always the same surface showed a higher value of effective charge. (All curves were average value curves to eliminate the effects of high humidity. The effect of high humidity on the sensitivity of the electrometer was found to be serious; as the humidity increased, the sensitivity of the electrometer decreased. If the low points on the 100% sulfur curve are compared with the relative daily humidities it was observed that the low points were present the day after a high in humidity, and as the humidity decreased the apparent values of the effective charge increased. Hence average value curves for studying changes in the effective charge were made.) The 25%

Carnauba wax and 25% resin showed only a heterocharge, but showed a decay, hence at some later time it might show a reversal but probably will decay to zero because Gemant stated that an electret will be formed in one to fourteen days. A heterocharge was obtained when a 50% Carnauba wax and 50% sulfur ratio was used. The pure Carnauba wax gave only a heterocharge, probably because the solidification field used was not strong enough.

Gamma-rays cause the effective charge or field to decrease, but the field recovered upon discontinuing gamma radiation. An effect was not noted if the source of radiation was too weak (case 1), but gave the effect in all other cases. But no total disappearance of effective charge was found as Eguchi observed in the case of X-rays. The amount of lowering depends on the dosage received. An electret was exposed to air only, and showed a negligible change in the effective charge.

From the condenser calibration it can be correlated that the electrets in this investigation are within the range of charge magnitude that other investigators observed.

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