THE EFFECTS OF COMBINED ELECTRIC AND MAGNETIC FIELDS
ON THE
DIELECTRIC PROPERTIES OF SULFUR

By

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The capable typist has been Patty McAffrey Howell.

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1. INTRODUCTION

The object of this investigation is to continue the compilation of data pertaining to the dielectric properties of sulfur. This experiment is merely a small part in a long range research program to study the properties of matter. The dielectric constant of sulfur has been, in the past, studied by independently varying frequency, temperature and electric intensity. The purpose of this test is to study the behavior of the dielectric properties of sulfur under a combined electric and magnetic field.

It is believed that the most information may be gained by first examining the dielectric constant of sulfur under an electric field alone; then under a magnetic field alone. These tests may be used for comparison purposes. Data will then be taken by subjecting the sulfur to a combined electric and magnetic field. Interesting facts may be brought out by varying the electric field and magnetic field in different manners. These tests will be made, not with the idea of determining absolutely correct values of dielectric constant, but rather to obtain values which are relatively correct. In this manner, the variations of dielectric constant may be examined and possible reasons for the variations suggested.

This study of sulfur was originally undertaken because it is a good insulator, because it is a pure element, and because it was readily available in the necessarily pure form. It was thought that since sulfur was a simple element, its behavior might be more easily explained than some other heterogeneous material.

II. REVIEW OF LITERATURE

A. Effect of a magnetic field on dielectrics.

It is known that the normal behavior of a dielectric is changed by placing it in a magnetic field. The exact deviation from normal characteristics depends upon a number of factors; such as, the substance concerned, state of the substance, simple or complex molecular structure, weak or strong field, and so forth.

The behavior of a general atom or molecule under a magnetic field is known as the "Anomalous Zeeman Effect[1]." This effect has been explained by showing that the energy increase of each electron in an atom under a magnetic field is additive and proportional to the strength of the field, the charge on the electron, the sum of the angular momenta, and is inversely proportional to the mass of the electron and the speed of light. This may be shown as

$$V = eH(J + S)/2mc \qquad (1)$$

where V is the perturbing energy, e is the charge, H is the field, J and S are respectively the total angular momentum of the atom and the total spin angular momentum of the electrons. From this information the change in the energy levels of the atom may be calculated. For a small value of V, one theory holds true, for a large value of V a more complicated theory is needed, and for a very strong field, it is necessary to use the

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[1] Zeeman, Philosophical Magazine, 43 (1897), 226.

solution developed by Paschen and Back.[2]

The above explanation would lead one to expect, under the proper conditions, an increase in dielectric constant when the dielectric is placed in a magnetic field. The energy stored in a condenser is proportional to the capacity and the square of the applied voltage. If the condenser is placed in a magnetic field and the dielectric gains in energy while the voltage is still held constant, then the logical explanation would be that there is an increase in capacity. Hence the dielectric constant increases with the application of a magnetic field. The above theory is based on the idea of energy storage in dielectrics. Skilling[3] says that the energy expended in producing an electrostatic field is stored in that field--hence the energy would exist in the dielectric.

From the above discussion it would seem apparent that the energy stored in a magnetic field passing through a dielectric causes an increase in the total stored energy resulting in an increase of dielectric constant.

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[2] Paschen and Back, Ann. Physik, 39 (1912), 897.

[3] Skilling, Fundamentals of Electric Waves, p. 64.

B. Effect of an electric field on dielectrics.

The behavior of a substance under the influence of an electric field is somewhat analogous to the behavior of the substance under a magnetic field. The spectroscopic studies of Stark[4] on the effect of an electric field on various atoms brought out the fact that normal spectral lines are broken into definite patterns. These effects, he observed, must be due to the perturbing effect of the field on the motion of the electrons about the nucleus of the atom. Ruark and Urey[5] point out the fact that, "In weak electric fields the energy change of the atom is proportional to the square of the field strength, but in sufficiently high fields it becomes proportional to the first power of the field." More recent theories regard this change of energy as due primarily to a separation of the center of gravity of the electric charges from the position of the positively charged nucleus which results in the creation of an electric dipole moment. Referring to a more basic explanation, if equal positive and negative electric charges occupy exactly the same point in space, the net electric field due to the charges is zero. If, however, there is a slight separation between the charges, the fields no longer cancel. The strength of a dipole is defined as the product of the distance separating the charges and the strength of either charge. This is known as the dipole moment. The use of dipole moments as a medium for

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[4] Stark, Ann. Physik, 43, 965 (1914); 56, 577 (1918).

[5] Ruark & Urey, Atoms Molecules and Quanta, p. 343.

explaining the effects of an electric field becomes quite complicated in substances with other than simple structures like helium and hydrogen. In the first place, the substance under consideration may have its positive center of gravity not coinciding with its negative center and the distance between may be invariable, that is, unaffected by an impressed electric field. This configuration of charges is known as a permanent electric dipole. In another case, although the centers may originally coincide, one center may become displaced relative to the first when an electric field is impressed upon the medium. This dipole which is produced, is called an induced electric dipole. A single particle of a dielectric may exhibit both permanent and induced dipoles under the action of an impressed field. Externally impressed fields are not the only source for the formation of diploes. Urey[6] mentions the fact that atoms may be subjected to electric fields of other atoms or ions thus causing further complications.

The energy storage in a dielectric may be considered as due to an electric force which is trying to restore the charges to their original positions. The chaotic arrangement of the permanent and induced dipoles formed and reformed under the action of an impressed electric field gives cause to the insurmountable difficulty in predicting the behavior of any dielectric material under an electric field.

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[6] Ibid, p. 348.

III. THE EXPERIMENT

A. Introduction

Since the object of this experiment was to study the dielectric properties of sulfur under a combined electric and magnetic field, it was thought best to first gather some information on the behavior of the dielectric under separate electric and magnetic fields to be used for comparison purposes.

The experiment consisted of three main parts. First, the dielectric constant was measured under a varying magnetic field, i.e., the magnetic field was increased from zero to a maximum and then decreased to zero, the electric intensity remaining zero. The second part consisted of varying the electric field from zero to a maximum and then back to zero. The electric field was then reversed in polarity and varied in the same manner. During this operation the dielectric constant was measured at values of zero, minimum, and maximum magnetic intensity. Thus the third phase of combining the electric and magnetic fields was included in the second part of the test bringing about a reduction in experiment time. During the tests under the combined fields, the leakage current through the test capacitor was also measured. The orientiation of the electric and magnetic fields was also changed from the position where the fields were normal to each other, to the position where the fields were parallel to each other. All of the tests were run at a constant freqeuncy because the variations of dielectric constant with frequency were not the primary object of the investigation.

The actual measurement of the dielectric constant proved to be a relatively simple task, but such preliminary steps as the preparation of test samples, assembly and adjustment of the test circuit proved to be laborious and time consuming. One of the major difficulties was the reduction of conductance in the circuit so that the measuring device would function properly.

There were many other aspects of the investigation that could have been investigated had there been enough time. One idea for future research is the examination of dielectric constant at a higher frequency than was used during this test. One test was made, but the results seemed unreliable and were not included in this thesis.

B. Equipment

1. General Description

The device used for the measurement of the test condenser capacity was a General Radio Twin-T Impedance Measuring Circuit. The radio frequency source for the Twin-T was a U.S. Army Signal Corps Frequency Meter BC-221-M. The detector consisted of a Signal Corps Receiver BC-348-R. A Dumont Type 164 Oscillograph and a thousand cycle filter was used to provide a reasonably clear signal trace to adjust the Twin-T. A 15 kilovolt rectifier was used to provide the electric field, and two iron core coils supplied by another low voltage rectifier were used to provide a maximum magnetic field of 1100 gauss. Provisions were made for reversing the polarity of both the electric and magnetic fields.

2. Description of Impedance Circuit

The General Radio Type 821-A Twin-T Impedance Measuring Circuit[1] is a null type instrument used to measure impedance in the frequency range of 0.460 to 30.0 megacycles per second. It is used basically with a parallel substitution method for measuring unknown impedances in terms of their parallel admittance components, namely susceptance, B, and conductance, G. The susceptance is obtained from capacitive increments, read from a dial directly calibrated in capacitance (in micromicrofarads). The conductance is obtained from a dial directly calibrated in conductance (in micromhos). Conversion from the

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[1] General Radio Co., Operating Instructions for Type 821-A Twin-T Impedance Measuring Circuit, The General Radio Company.

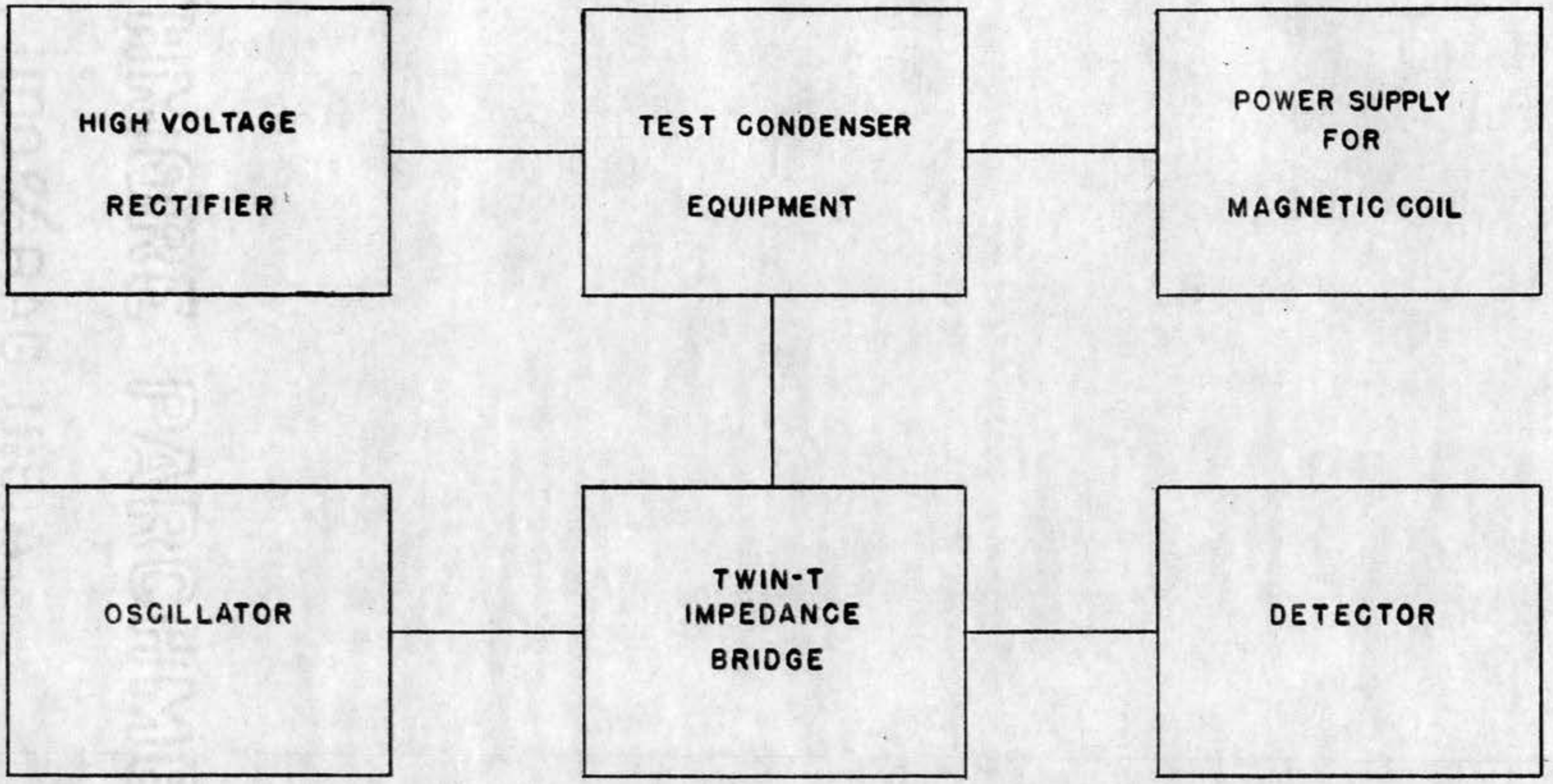


FIG. I BLOCK DIAGRAM OF TEST EQUIPMENT

parallel admittance components, G and B to series impedance components, R and X, can be made, if desired, through the relations:

$$R = G/(G^2 + B^2) \quad \text{and} \quad X = -B/(G^2 + B^2)$$

The circuit, shown in Figure 2, consists of two T networks connected so that they furnish parallel transmission paths, a-b-c and a-d-c, from the high frequency oscillator to the null detector. Zero energy transfer from the generator to the detector occurs when the transfer impedances of the two T networks are made equal and opposite, and a null balance is obtained. In measuring an unknown capacitance, the bridge is initially balanced to a null. The unknown capacitance is then connected to the UNKNOWN terminals and the circuit rebalanced by adjusting the conductance condenser C_G, and the susceptance condenser C_B. The direct values of capacitance and conductance may then be obtained from the calibrated dials. The error for the instrument is given as plus or minus 0.1% plus 2 micromicrofarads for capacity, and 2% of the reading plus 0.1% of the full scale value for conductance.

3. Description of Radio Frequency Source

As a signal source, a U.S. Army Signal Corps Frequency Meter BC-211-M manufactured by Bendix Radio Corporation, was used. This instrument gives a maximum output of 2500 microvolts over a frequency range of 125 to 20,000 kilocycles. This equipment contains a crystal controlled oscillator used as a reference standard, a heterodyne oscillator having two fundamental tuning ranges which with their harmonics provide the continuous coverage

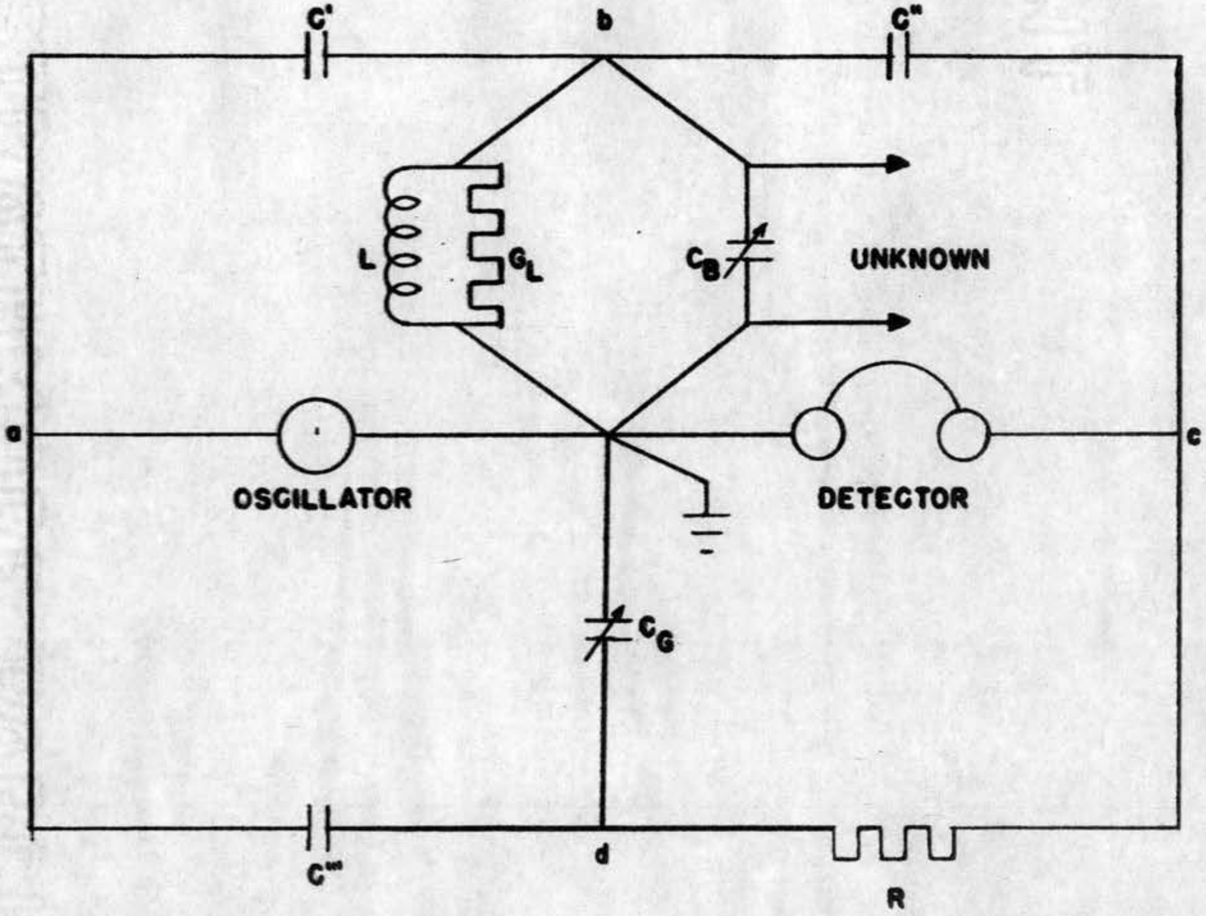


FIG.2 - BASIC DIAGRAM OF TWIN T IMPEDANCE CIRCUIT

of frequency, and an audio frequency amplifier used in the calibration operation. The crystal is ground for operation at plus 20°C. and has a temperature coefficient of combined crystal, holder, and circuit which is less than 0.0001% per degree centigrade over a range of 80°C. A pair of 600 ohm headphones may be connected through jacks in the panel to the output transformer. This instrument has possible errors of plus or minus 0.02% in the 125-2000 kilocycle range, and plus or minus 0.01% in the 2000 to 20,000 kilocycle per second range. These specified accuracies may be obtained if the input voltage of which the instrument was calibrated, does not vary more than plus or minus 10% during the time interval between calibration and measuring operations.

4. Description of Detector

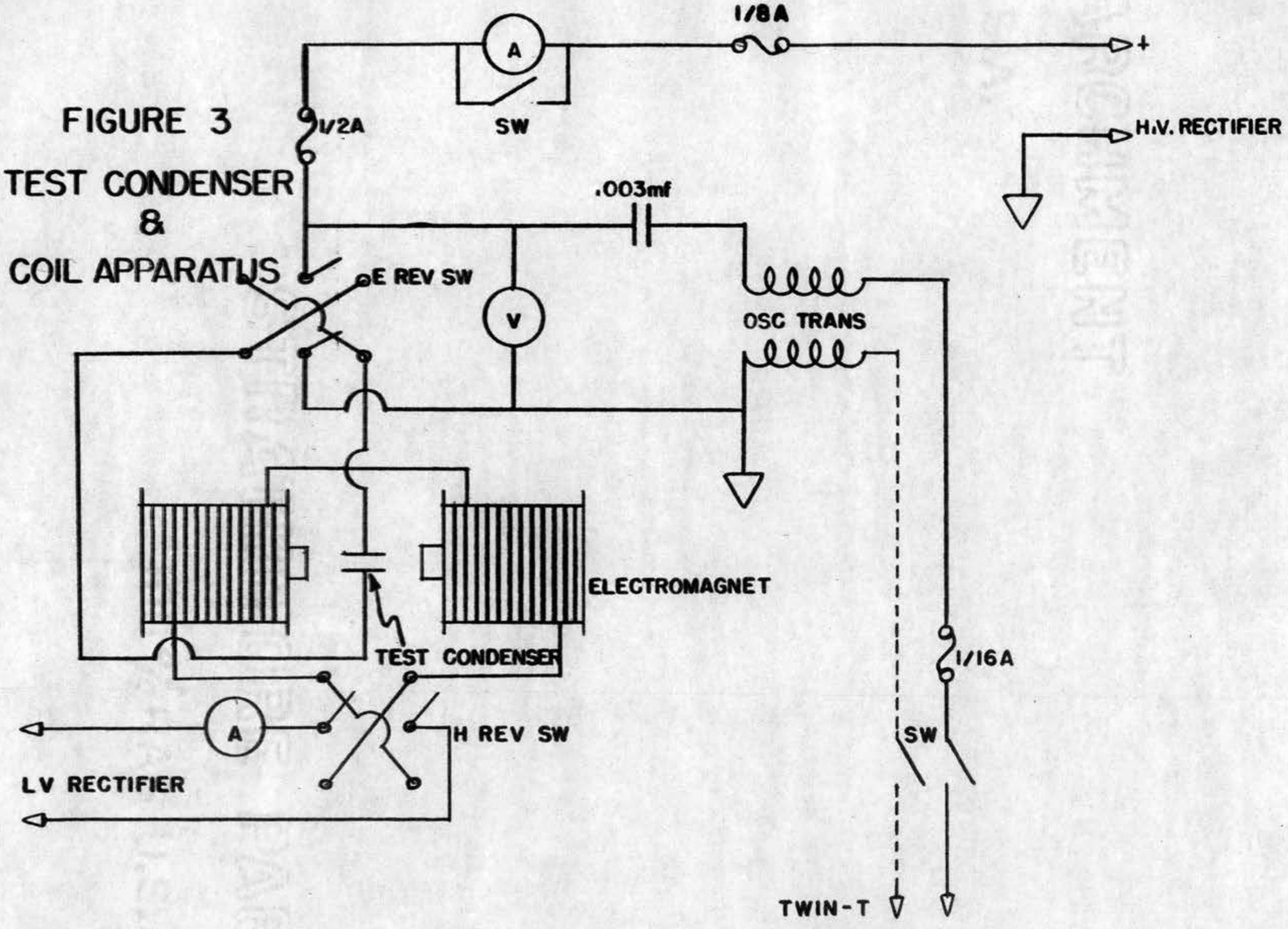
A U.S. Army Signal Corps Radio Receiver BC-348-R was used as a detector for the Twin-T Circuit. This instrument has a frequency range of 0.2 to 0.5 megacycles and 1.5 to 18.0 megacycles per second. The beat frequency oscillator was used in conjunction with a crystal filter to reduce noise and make the null more easily discernable. The noise level however, was still too great to permit the required accuracy, so a filter was connected to the receiver output. The bandpass filter was tuned sharply to 1000 cycles per second. When the receiver output signal was adjusted to this frequency, the result was a signal which contained an extremely small amount of noise. This output signal was observed on earphones. A Du Mont type 146 Oscillograph was used in conjunction with the earphones from the receiver output. A phase shifting arrangement, consisting of a precision 240 micromicrofarad condenser, was connected between the vertical and horizontal plates of the oscilloscope to give an elliptical trace which aided in a more accurate detection of the null.

5. Description of Test Capacitor and Coil Apparatus

The arrangement of the magnetic coil apparatus and test capacitor is shown in Figure 3. The coil was taken from a Signal Corps radar set and used to provide the magnetic field. The coil was calibrated by taking data to plot a flux versus current curve. A Leeds and Northrup Ballistic Galvanometer was used to determine the values of flux-density from 0-1100 gauss for current readings of 0-237 milliamperes. A platform was built to place the test condenser at the point of maximum magnetic intensity between the electromagnet poles. A well regulated low voltage power supply was used to provide the coil current. A reversing switch was placed in the power supply circuit to provide for the reversal of current and hence a reversal of magnetic field. The electric field was obtained by placing a high direct current potential across the plates of the test condenser. This high direct current potential was obtained from a rectifier having a variable voltage output of 108 to 15,000 volts. This high voltage was applied to the test condenser without damaging the bridge by the insertion of a blocking condenser and series choke arrangement. A reversing switch was also provided in this rectifier circuit to provide for the reversal of the voltage and hence the electric field. A microammeter was also placed in the high voltage rectifier circuit to measure the value of leakage

FIGURE 3

TEST CONDENSER
&
COIL APPARATUS



current flowing through the test condenser. The circuit was adequately protected by the use of fuses. A switch was inserted in the circuit adjacent to the Twin-T to provide a quick means of removing the test circuit from the bridge during calibration operations.

C. Test Samples

The method used to determine the dielectric constant of sulfur consisted of measuring the capacity of the test condenser with an air dielectric directly across the Twin-T Impedance Circuit, and then measuring the capacity with a sulfur dielectric. The dielectric constant could then be calculated by dividing the sulfur capacity by the air capacity.

The first problem was then to make a test condenser with a sulfur dielectric. Variable 30uuf. air condensers were chosen with uniform spacing and non-silvered plates. If the plates were not equally spaced, gradients were unequal and the results were not reliable. That is, the test condenser might break down at a smaller potential when the plates were bent closer together, than when they were normally spaced. It was found also, that silver and sulfur reacted to form silver sulfide, a non-soluble substance. The silver plates were then avoided so as to maintain a pure sulfur dielectric between the plates. It was found that the air content of powdered sulfur was quite high and would vary, thus invalidating test results.

The second problem was then how to get a nearly perfect sulfur dielectric. The sulfur was then melted and poured into molds containing the test condensers to solidify. It was soon found, that due to air pockets in the molded sulfur, the results were again not reliable. Finally a scheme was devised wherein the condenser was dipped in the liquid sulfur and then removed, allowing a few drops of molten sulfur to cling to the condenser. By allowing the condenser to cool, the few drops of sulfur would harden, then by repeating the process of dipping and cooling, the sulfur slowly built up thru the condenser plates until the entire condenser was evenly covered with sulfur containing no air pockets. The condenser was then allowed to fully harden before testing it.

The sulfur used was of the commercially pure type because it was the most readily available. It was heated in a pyrex beaker over an electric stove.

D. Test Procedure

The special circuit for the test condenser introduced some complications into the calculation of the dielectric constant. This difficulty was taken care of in the following manner. First, the test condenser capacity with the air dielectric was measured directly across the bridge and designated C_a. The special circuit without the test condenser was then measured directly across the bridge and its capacity called C_c. The test condenser was then prepared with the sulfur dielectric and again measured across the bridge. Its capacity was called C_s. It was then inserted into the special circuit. The tests were made and the capacity of both the test condenser and special circuit were measured and designated C'. The dielectric constant was then calculated in the following way. To refer the sulfur dielectric capacity back to a direct bridge reading, C_c was subtracted from C' at zero or rest conditions. This figure $(C' - C_c)$ corresponded to C_s. To obtain a multiplying factor to convert the remaining readings, the quantity C_s was divided by $(C' - C_c)$.

$$M = \frac{C_s}{(C' - C_c)} \qquad (1)$$

Then, in order to find the true capacities of the remaining readings, the value C_c was subtracted from each C' value and the remainder was multiplied by M. The dielectric constant was then determined by dividing the air capacity of the test condenser into the true capacity of the sulfur dielectric condenser.

The tests were all run at a constant frequency of 500 kilocycles so as not to introduce frequency variations in the dielectric constant.

It was decided to first run a test to determine the affect of the magnetic field alone upon the dielectric constant. The magnetic field was varied in 50 gauss steps from zero to 1000 gauss and back to zero. For each figure recorded in Table I, and for every test, a minimum of three separate bridge readings were made and averaged. The bridge was re-calibrated between every reading to insure some degree of accuracy. The breakdown voltage of the sulfur dielectric was not known, so three tests were run by varying the electric field up to the point where the capacitor broke down. At each level of electric field, the capacity was measured under a zero magnetic field, a minimum magnetic field, and a maximum magnetic field. The next few tests were run by making a complete loop of the direct current potential, that is, the voltage was varied from zero to a positive maximum to zero again, and then varied to a negative maximum and then reduced to zero. As before, readings were taken at zero, minimum, and maximum values of magnetic field for each voltage step. Several of the tests included values of leakage current through the test condenser for corresponding values of capacity. On one test, the magnetic field was reversed at every voltage step. Several of these tests were made with the test condenser placed between the poles of the electromagnet in such a manner as to provide an electric field normal to the magnetic field. Other tests were run with the electric field parallel to the magnetic field. The last two tests were run by varying the magnetic field from zero to a maximum value of 1000 gauss and back to zero in 200 gauss steps. At each value of magnetic field, measurements were made at direct current potential values of 0, 200, 400, 600, 800, 1000, and 1200 volts. These two tests were made with the electric field normal to, and parallel to the magnetic field.

Test Data

Table I

Dielectric Constant versus Magnetic Flux-Density

Test was made by varying magnetic flux-density from zero to a maximum of 1000 gauss and then back to zero. Electric field was zero, frequency was 500 kc, and temperature was 25°C. Capacity in air was 30.9uuf.

Flux-Density gauss	Capacity uuf	Dielectric Constant K
0	99.35	3.215
50	100.17	3.242
100	100.17	3.242
150	100.25	3.244
200	100.17	3.242
250	100.14	3.241
300	100.12	3.240
350	100.12	3.240
400	100.12	3.240
450	100.12	3.240
500	100.20	3.243
550	100.25	3.244
600	100.17	3.242
650	100.17	3.242
700	100.20	3.243
750	100.17	3.242
800	100.08	3.239
850	100.08	3.239
900	100.20	3.243
950	100.14	3.241
1000	100.14	3.241
950	100.12	3.240
900	100.08	3.239
850	100.08	3.239
800	100.08	3.239
750	100.08	3.239
700	100.12	3.240
650	100.12	3.240
600	100.14	3.241
550	100.14	3.241
500	100.12	3.240
450	100.12	3.240
400	100.08	3.239
350	100.12	3.240
300	100.14	3.241
250	100.12	3.240
200	100.08	3.239
150	100.12	3.240
100	100.08	3.239
50	100.08	3.239
0	99.41	3.217

Test Data

Table II

Dielectric Constant versus Direct Voltage

Test was made under zero, minimum, and maximum magnetic fields. Minimum magnetic field had a value of 3 gauss, while the maximum magnetic field had a value of 1100 gauss. Temperature was constant at 25°C. Capacity in air was 62.35uuf., and the frequency was 500 kc. The condenser was placed so that the electric field was normal to the magnetic field. The electric field was increased until the test condenser broke down.

D.C. Potential volts	C_0 uuf	K_0	C_1 uuf	K_1	C_2 uuf	K_2
0	196.33	3.149	197.69	3.169	197.88	3.174
200	196.23	3.147	197.93	3.174	197.15	3.162
400	196.07	3.145	197.43	3.166	197.32	3.165
600	196.40	3.150	197.72	3.171	197.32	3.165
800	196.73	3.155	198.14	3.178	197.98	3.175
1000	196.61	3.153	198.21	3.179	197.96	3.175
1100	196.49	3.151	198.04	3.176	198.04	3.176
1200	196.99	3.159	197.93	3.174	197.27	3.164
1300	Condenser broke down at this voltage.					

NOTE: In this and the following tables, the subscript $_0$ indicates zero magnetic field, the subscript $_1$ indicates minimum field, and the subscript $_2$ indicates maximum magnetic field.

Test Data

Table III

Dielectric Constant versus Direct Voltage

Test was made under zero, minimum, and maximum magnetic fields. Minimum magnetic field had a value of 3 gauss, while the maximum magnetic field had a value of 1100 gauss. Temperature was 25°C, and the frequency was 500 kc. The condenser was placed so that the electric field was normal to the magnetic field. The electric field was increased until the condenser broke down. The capacity in air was 33.52uuf.

D.C. Potential volts	C_0 uuf	K_0	C_1 uuf	K_1	C_2 uuf	K_2
0	105.58	3.150	106.06	3.164	106.30	3.171
200	107.09	3.195	107.46	3.206	107.33	3.202
400	106.00	3.162	106.62	3.181	106.58	3.180
600	105.82	3.157	105.95	3.161	105.66	3.152
800	105.39	3.144	106.06	3.164	105.90	3.159
1000	105.37	3.143	106.27	3.170	105.95	3.161
1100	105.58	3.150	106.46	3.176	105.74	3.155
1200	105.26	3.140	105.66	3.152	105.26	3.140
1300	105.74	3.155	105.90	3.159	106.06	3.164
1400	Condenser borke down at this voltage.					

Test Data

Table IV

Dielectric Constant versus Direct Voltage

Test was made under zero, minimum and maximum magnetic fields. Minimum magnetic field had a value of 3 gauss, while the maximum magnetic field had a value of 1100 gauss. Temperature was constant at 25°C., and the frequency was 500 kc. The condenser was placed so that the electric field was normal to the magnetic. The electric field was increased until the test condenser broke down. Capacity in air was 66.00uuf.

D.C. Potential volts	C_o uuf	K_o	C_1 uuf	K_1	C_2 uuf	K_2
0	207.79	3.148	208.32	3.156	208.75	3.163
100	207.65	3.146	208.54	3.160	208.39	3.157
200	207.75	3.148	208.32	3.156	207.96	3.151
300	207.91	3.150	208.92	3.165	208.80	3.164
400	208.04	3.152	308.78	2.163	208.78	3.163
500	208.25	3.155	208.63	3.161	208.80	3.164
600	208.70	3.162	209.35	3.172	209.40	3.173
700	208.90	3.165	209.57	3.175	209.09	3.168
800	208.42	3.158	208.87	3.165	208.87	3.165
900	208.22	3.155	209.14	3.169	209.50	3.174
1000	208.63	3.161	209.01	3.167	208.97	3.166
1100	208.18	3.154	209.16	3.169	209.21	3.170
1200	208.87	3.165	209.40	3.175	209.33	3.172
1300	208.75	3.163	209.44	3.173	209.19	3.170
1400	208.29	3.156	208.90	3.165	208.80	3.164
1500	208.42	3.158	209.37	3.172	209.59	3.176
1600	210.20	3.185	209.83	3.179	209.83	3.179
1700	Condenser broke down at this voltage.					

Test Data

Table V

Dielectric Constant versus Direct Voltage

Test was made under zero, minimum and maximum magnetic fields. Minimum magnetic field had a value of 3 gauss, while the maximum magnetic field had a value of 1100 gauss. Temperature was constant at 25°C. Capacity in air was 32.22uuf., and the frequency was 500 kc. The condenser was placed so that the electric field was normal to the magnetic field.

D.C. Potential volts	C_o uuf	K_o	C_1 uuf	K_1	C_2 uuf	K_2
0	101.52	3.151	102.25	3.173	102.28	3.174
200	101.75	3.158	102.20	3.172	102.20	3.172
400	101.56	3.152	102.20	3.172	102.17	3.171
600	101.44	3.151	102.07	3.168	102.09	3.169
800	101.52	3.151	101.99	3.165	101.96	3.164
1000	101.56	3.152	102.36	3.177	102.41	3.178
1100	101.75	3.158	102.30	3.175	102.60	3.184
1200	101.70	3.156	103.31	3.206	103.49	3.212
1100	101.62	3.154	102.25	3.173	102.36	3.177
1000	101.67	3.155	102.04	3.167	102.20	3.172
800	101.46	3.149	102.12	3.169	102.17	3.171
600	101.48	3.150	102.01	3.166	102.09	3.169
400	101.54	3.151	102.04	3.167	102.12	3.169
200	101.54	3.151	102.14	3.170	102.14	3.170
0	101.56	3.152	102.12	3.169	102.14	3.170
-200	101.46	3.149	102.12	3.169	102.09	3.169
-400	101.48	3.150	102.54	3.182	102.67	3.187
-600	101.70	3.156	102.48	3.181	102.46	3.180
-800	101.93	3.164	102.30	3.175	102.44	3.179
-1000	101.56	3.152	102.20	3.172	102.33	3.176
-1100	101.78	3.159	102.38	3.178	102.52	3.182
-1200	102.04	3.167	102.56	3.183	102.46	3.180
-1100	101.97	3.165	102.60	3.184	102.41	3.178
-1000	101.83	3.160	102.64	3.186	102.52	3.182
-800	101.64	3.155	102.25	3.173	102.62	3.185
-600	102.01	3.166	102.62	3.185	102.60	3.184
-400	102.07	3.168	102.56	3.183	102.54	3.182
-200	101.72	3.157	102.48	3.181	102.38	3.178
0	101.64	3.155	102.33	3.176	102.28	3.174

Test Data

Table VI

Dielectric Constant versus Direct Voltage

Test was made under zero, minimum, and maximum magnetic fields. Minimum magnetic field had a value of 3 gauss, while the maximum magnetic field had a value of 1100 gauss. Temperature was constant at 25°C. Capacity in air was 30.44uuf, and the frequency was 500 kc. The condenser was placed so that the electric field was perpendicular to the magnetic field.

D.C. Potential volts	C_o uuf	K_o	C_1 uuf	K_1	C_2 uuf	K_2
0	96.35	3.165	97.04	3.188	97.04	3.188
200	96.54	3.171	96.96	3.185	96.96	3.185
400	96.35	3.165	97.09	3.189	97.09	3.189
600	96.41	3.167	97.09	3.189	97.09	3.189
800	96.35	3.165	97.09	3.189	97.28	3.195
1000	96.54	3.171	97.09	3.189	97.09	3.189
1100	96.67	3.175	97.15	3.191	97.22	3.194
1200	96.67	3.175	97.15	3.191	97.22	3.194
1300	96.48	3.169	97.22	3.194	97.15	3.191
1200	96.41	3.167	96.96	3.185	97.60	3.206
1100	96.48	3.169	97.34	3.197	97.34	3.197
1000	96.59	3.173	97.22	3.194	97.34	3.197
800	96.54	3.171	97.22	3.194	97.34	3.197
600	96.59	3.173	97.22	3.194	97.28	3.195
400	96.59	3.173	97.15	3.191	97.28	3.195
200	96.67	3.175	97.28	3.195	97.15	3.191
0	96.48	3.169	96.96	3.185	97.09	3.189
-200	96.96	3.185	97.71	3.209	97.65	3.208
-400	96.96	3.185	97.84	3.214	97.89	3.216
-600	97.09	3.189	97.71	3.209	97.78	3.212
-800	97.04	3.188	97.78	3.212	97.84	3.214
-1000	97.28	3.195	97.84	3.214	97.97	3.218
-1100	97.15	3.191	97.89	3.216	98.02	3.220
-1200	97.15	3.191	98.02	3.220	98.02	3.220
-1300	97.41	3.200	98.02	3.220	97.84	3.214
-1200	97.04	3.188	97.71	3.209	97.65	3.208
-1100	96.85	3.181	97.71	3.209	97.84	3.214
-1000	97.15	3.191	97.84	3.214	97.89	3.216
-800	97.15	3.191	97.71	3.209	98.08	3.222
-600	97.04	3.188	97.84	3.214	97.89	3.216
-400	97.15	3.191	97.84	3.214	97.84	3.214
-200	97.09	3.189	97.71	3.209	97.89	3.216
0	96.85	3.181	97.52	3.203	97.41	3.200

Test Data

Table VI B

Leakage Current versus Direct Voltage

This data was taken at the same time as the data in Table VI was taken and under the same conditions.

D.C. Potential volts	I_o uamps	I_1 uamps	I_2 uamps
0	0	0	0
200	9.13	9.20	9.20
400	16.00	16.00	16.00
600	24.50	24.50	24.50
800	28.30	28.30	29.00
1000	36.00	35.80	35.60
1100	39.00	39.00	39.16
1200	43.50	43.66	43.56
1300	47.00	47.10	46.50
1200	44.00	43.93	43.43
1100	40.00	40.00	39.50
1000	37.00	37.00	37.00
800	31.00	31.00	31.00
600	23.53	23.30	23.00
400	16.50	16.50	16.50
200	9.20	9.20	9.20
0	0	0	0
-200	8.50	8.50	8.80
-400	16.00	16.00	16.00
-600	23.00	23.00	23.00
-800	30.00	30.00	30.00
-1000	36.86	36.80	36.80
-1100	40.00	40.00	40.00
-1200	43.50	43.50	43.50
-1300	47.20	47.50	47.13
-1200	43.80	43.50	43.50
-1100	40.50	40.50	40.20
-1000	37.50	37.50	37.50
-800	30.43	30.50	30.50
-600	23.20	23.20	23.20
-400	16.00	16.00	16.00
-200	9.50	9.50	9.50
0	0	0	0

Test Data

Table VII

Dielectric Constant versus Direct Voltage

Test was made under zero, minimum, and maximum magnetic fields. Minimum magnetic field had a value of 3 gauss, while the maximum magnetic field had a value of 1100 gauss. Temperature was constant at 25°C. Capacity in air was 30.44uuf, and the frequency was 500 kc. The condenser was placed so that the electric field was perpendicular to the magnetic field.

D.C. Potential volts	C_0 uuf	K_0	C_1 uuf	K_1	C_2 uuf	K_2
0	96.34	3.165	96.97	3.185	97.20	3.193
200	96.52	3.171	97.21	3.193	97.15	3.191
400	96.47	3.169	97.08	3.189	97.02	3.187
600	96.41	3.167	97.02	3.187	96.97	3.185
800	96.52	3.171	97.21	3.193	97.15	3.191
1000	96.52	3.171	97.08	3.189	97.15	3.191
1100	96.41	3.167	97.08	3.189	97.26	3.195
1200	96.52	3.171	97.15	3.192	97.21	3.193
1300	96.41	3.167	97.08	3.189	97.15	3.191
1200	96.41	3.167	97.02	3.187	97.15	3.191
1100	96.52	3.171	97.26	3.195	97.15	3.191
1000	96.52	3.171	97.21	3.193	97.15	3.191
800	96.52	3.171	97.26	3.195	97.21	3.193
600	96.65	3.175	97.26	3.195	97.08	3.189
400	96.34	3.165	97.08	3.189	97.33	3.198
200	96.34	3.165	96.89	3.183	96.97	3.185
0	96.34	3.165	96.89	3.183	96.89	3.187
-200	96.76	3.179	97.50	3.203	97.39	3.199
-400	96.76	3.179	97.39	3.199	97.39	3.199
-600	96.71	3.177	97.57	3.205	97.50	3.203
-800	96.65	3.175	97.44	3.201	97.44	3.201
-1000	96.65	3.175	97.39	3.199	97.44	3.201
-1100	96.76	3.179	97.50	3.203	97.63	3.207
-1200	96.76	3.179	97.50	3.203	97.50	3.203
-1300	96.76	3.179	97.21	3.193	97.13	3.191
-1200	96.28	3.163	96.89	3.183	96.84	3.181
-1100	96.65	3.175	97.50	3.203	97.50	3.203
-1000	96.65	3.175	97.50	3.203	97.50	3.203
-800	96.84	3.181	97.02	3.187	96.95	3.185
-600	96.10	3.157	97.08	3.189	97.13	3.191
-400	96.28	3.163	97.08	3.189	97.08	3.189
-200	96.21	3.161	97.02	3.187	97.08	3.189
0	95.84	3.149	96.71	3.177	96.47	3.169

Test Data

Table VII B

Leakage Current versus Direct Voltage

This data was taken at the same time as the data in Table VII was taken and under the same conditions.

D.C. Potential volts	I_o uamps	I_1 uamps	I_2 uamps
0	0	0	0
200	8.86	8.93	9.20
400	16.00	16.00	16.00
600	23.00	23.00	23.00
800	30.00	30.00	30.00
1000	37.50	37.50	37.50
1100	40.00	40.00	40.00
1200	43.50	43.50	43.50
1300	47.50	47.50	47.50
1200	44.50	44.50	44.00
1100	40.50	40.50	40.50
1000	37.00	37.00	37.00
800	30.50	30.50	30.50
600	24.00	24.00	24.00
400	16.50	16.50	16.50
200	10.00	10.00	10.00
0	0	0	0
-200	8.80	8.80	8.80
-400	15.26	15.50	15.50
-600	22.86	23.00	23.00
-800	30.70	30.80	30.70
-1000	37.00	37.00	37.00
-1100	40.60	41.00	41.00
-1200	43.00	42.80	43.00
-1300	47.66	48.00	48.00
-1200	43.33	43.80	43.60
-1100	40.00	40.00	40.00
-1000	36.50	35.66	35.50
-800	31.00	31.00	31.00
-600	23.60	23.50	23.50
-400	16.50	16.50	16.50
-200	9.20	9.00	9.00
0	0	0	0

Test Data

Table VIII

Dielectric Constant versus Direct Voltage

Test was made under zero, minimum, and maximum magnetic field in one direction and in a direction exactly opposite or 180° to the first direction. Minimum magnetic field had a value of 3 gauss, while the maximum magnetic field had a value of 1100 gauss. Temperature was constant at 25°C. Capacity in air was 27.048uuf., and the frequency was 500 kc. The condenser was placed so that the electric field was always normal to the magnetic field.

D.C. Volts	C_o	K_o	$+C_1$	$+K_1$	$-C_1$	$-K_1$	$+C_2$	$+K_2$	$-C_2$	$-K_2$
0	85.15	3.148	88.69	3.279	88.87	3.286	88.87	3.286	89.17	3.297
200	86.02	3.180	89.76	3.319	89.83	3.321	89.58	3.312	89.48	3.308
400	85.97	3.178	89.66	3.315	89.66	3.315	89.66	3.315	89.41	3.306
600	86.09	3.150	89.41	3.306	89.48	3.308	89.48	3.308	89.28	3.301
800	85.92	3.177	89.41	3.306	89.53	3.310	89.66	3.315	89.58	3.312
1000	85.84	3.174	89.66	3.315	89.58	3.312	89.66	3.315	89.71	3.317
1100	86.02	3.180	89.76	3.319	89.66	3.315	89.71	3.317	89.76	3.319
1200	86.09	3.183	89.76	3.319	90.47	3.345	90.47	3.345	90.30	3.339
1100	86.15	3.185	89.88	3.323	89.76	3.319	89.76	3.319	89.76	3.319
1000	86.09	3.183	89.83	3.321	89.76	3.319	90.01	3.328	90.01	3.328
800	85.84	3.174	89.83	3.321	89.94	3.325	89.89	3.323	89.76	3.319
600	86.20	3.187	89.83	3.321	89.76	3.319	89.94	3.325	89.89	3.323
400	86.15	3.185	89.76	3.319	89.94	3.325	89.83	3.321	89.89	3.323
200	86.15	3.185	89.66	3.315	89.66	3.315	89.76	3.319	89.83	3.321
0	85.31	3.154	88.87	3.286	88.94	3.325	88.87	3.286	88.87	3.286
-200	85.67	3.167	89.58	3.312	89.76	3.319	89.58	3.312	89.89	3.323
-400	85.92	3.177	89.76	3.319	89.58	3.312	89.48	3.308	89.48	3.308
-600	85.49	3.161	89.35	3.303	89.48	3.308	89.71	3.317	89.66	3.315
-800	86.02	3.180	89.83	3.321	89.83	3.321	89.71	3.317	89.83	3.321
-1000	85.97	3.178	89.53	3.310	89.53	3.310	89.71	3.317	89.58	3.312
-1100	85.92	3.177	89.83	3.321	89.71	3.317	89.83	3.321	89.58	3.312
-1200	85.92	3.177	89.83	3.321	89.83	3.321	89.76	3.319	89.87	3.323
-1100	85.84	3.174	89.83	3.321	89.71	3.317	89.76	3.319	89.53	3.310
-1000	85.79	3.172	89.53	3.310	89.76	3.319	89.83	3.321	89.48	3.308
-800	85.26	3.152	89.17	3.297	89.17	3.297	89.35	3.303	89.35	3.303
-600	85.43	3.158	89.05	3.292	89.05	3.292	89.17	3.297	89.12	3.295
-400	85.26	3.152	89.17	3.297	89.30	3.302	89.30	3.302	89.12	3.295
-200	85.26	3.152	89.05	3.292	88.82	3.284	88.82	3.284	89.00	3.290
0	85.20	3.150	89.53	3.310	89.66	3.315	89.48	3.308	89.41	3.306

Test Data

Table VIII B

Leakage Current versus Direct Voltage

This data was taken at the same time as the data in Table VIII was taken and under the same conditions.

D.C. Potential	I_o	$+I_1$	$-I_1$	$+I_2$	$-I_2$
0	0	0	0	0	0
200	8.60	8.60	8.60	8.60	8.60
400	16.50	16.50	16.50	16.40	16.20
600	23.53	23.50	23.50	23.36	23.30
800	29.96	29.80	30.00	29.80	29.80
1000	36.50	36.50	36.50	36.50	36.30
1100	39.80	39.80	39.60	39.60	39.40
1200	43.00	43.00	43.06	43.00	43.00
1100	40.16	40.00	40.00	40.00	40.00
1000	37.00	36.96	36.80	36.60	36.40
800	30.60	30.60	30.60	30.33	30.20
600	22.40	22.40	22.40	22.40	22.40
400	16.60	16.69	16.60	16.50	16.50
200	7.43	7.30	7.30	7.30	7.03
0	0	0	0	0	0
-200	9.00	9.00	9.00	9.00	8.86
-400	16.80	17.00	17.00	17.00	17.00
-600	23.60	23.80	24.00	23.80	23.86
-800	29.20	29.20	29.20	29.20	29.20
-1000	37.40	37.40	37.40	37.40	37.20
-1100	40.36	40.50	40.50	40.23	40.20
-1200	44.00	44.00	44.00	43.30	43.00
-1100	40.20	40.00	40.00	40.00	40.00
-1000	36.93	37.00	37.00	37.00	37.00
-800	30.20	30.20	30.00	30.00	30.30
-600	22.86	22.80	22.60	22.40	22.3
-400	15.30	15.20	15.20	15.20	15.00
-200	7.00	7.00	7.00	7.00	7.00
0	0	0	0	0	0

Test Data

Table IX

Dielectric Constant versus Direct Voltage

Test was made under zero, minimum, and maximum magnetic field. Minimum magnetic field had a value of 3 gauss, while the maximum magnetic field had a value of 1100 gauss. Temperature was constant at 25°C. Capacity in air was 32.27uuf, and the frequency was 500 kc. The condenser was placed so that the electric field was parallel to the magnetic field.

D.C. Potential volts	C_o uuf	K_o	C_1 uuf	K_1	C_2 uuf	K_2
0	101.63	3.149	104.47	3.227	104.60	3.241
200	101.68	3.150	104.78	3.247	105.14	3.258
400	102.10	3.163	105.09	3.257	105.09	3.257
600	102.17	3.166	105.20	3.260	105.20	3.260
800	102.28	3.169	105.27	3.262	105.27	3.262
1000	102.36	3.171	105.32	3.264	105.27	3.262
1100	102.28	3.169	105.45	3.268	105.45	3.268
1200	102.41	3.173	105.38	3.266	105.56	3.271
1300	102.47	3.175	105.38	3.266	105.38	3.266
1200	102.47	3.175	105.45	3.268	105.63	3.273
1100	102.65	3.180	105.56	3.271	105.56	3.271
1000	103.50	3.207	105.69	3.275	105.74	3.277
800	102.65	3.180	105.69	3.275	105.69	3.275
600	102.54	3.177	105.27	3.262	105.27	3.262
400	102.28	3.169	105.32	3.264	105.32	3.264
200	102.23	3.167	105.20	3.260	105.20	3.260
0	102.17	3.166	105.09	3.257	105.20	3.260
-200	102.17	3.166	105.14	3.258	105.20	3.266
-400	102.23	3.167	105.20	3.260	105.32	3.264
-600	102.23	3.167	105.27	3.262	105.51	3.270
-800	102.10	3.163	105.20	3.260	105.20	3.260
-1000	102.28	3.169	105.27	3.262	105.27	3.262
-1100	102.17	3.166	105.27	3.262	105.32	3.264
-1200	102.17	3.166	105.09	3.257	105.27	3.262
-1300	102.17	3.166	105.27	3.262	105.32	3.264
-1200	102.36	3.171	105.32	3.264	105.51	3.270
-1100	102.36	3.172	105.51	3.270	105.51	3.270
-1000	102.41	3.174	105.51	3.270	105.63	3.273
-800	102.47	3.175	105.56	3.271	105.56	3.271
-600	102.54	3.178	105.63	3.273	105.69	3.275
-400	102.54	3.178	105.63	3.273	105.51	3.270
-200	102.47	3.175	105.69	3.275	105.63	3.273
0	102.36	3.172	105.27	3.262	105.63	3.273

Test Data

Table IX B

Leakage Current versus Direct Voltage

This data was taken at the same time as the data in Table IX was taken and under the same conditions.

D.C. Potential	I_0 uamps	I_1 uamps	I_2 uamps
0	0	0	0
200	9.00	9.00	9.00
400	15.43	15.60	15.60
600	22.73	22.80	22.80
800	29.50	29.80	29.80
1000	36.50	36.50	36.50
1100	40.50	40.50	40.50
1200	43.20	43.00	42.60
1300	46.00	46.00	46.00
1200	43.06	43.00	43.00
1100	40.00	40.00	40.00
1000	37.00	37.00	37.00
800	30.06	30.00	30.00
600	23.30	23.20	23.20
400	16.50	16.20	16.13
200	7.80	7.60	7.60
0	0	0	0
-200	8.20	8.30	8.50
-400	16.00	16.00	16.00
-600	22.50	22.66	22.80
-800	30.00	30.00	30.00
-1000	37.00	37.06	37.66
-1100	40.30	40.50	40.50
-1200	44.06	44.06	43.06
-1300	46.06	46.20	46.13
-1200	44.33	44.36	44.06
-1100	40.20	40.30	40.40
-1000	37.00	37.00	37.00
-800	30.00	30.00	29.93
-600	24.00	24.00	24.00
-400	15.20	15.00	15.00
-200	10.00	10.00	10.00
0	0	0	0

Test Data

Table X

Dielectric Constant versus Direct Voltage

Test was made under zero, minimum, and maximum magnetic fields. Minimum magnetic field had a value of 3 gauss, while the maximum magnetic field had a value of 1100 gauss. Temperature was constant at 25°C. Capacity in air was 32.27uuf, and the frequency was 500 kc. The condenser was placed so that the electric field was parallel to the magnetic field.

D.C. Potential volts	C_o uuf	K_o	C_1 uuf	K_1	C_2 uuf	K_2
0	100.00	3.099	100.74	3.122	100.74	3.122
200	100.12	3.103	100.79	3.124	100.68	3.120
400	100.04	3.100	100.60	3.118	100.68	3.120
600	100.42	3.112	101.12	3.133	101.16	3.135
800	100.49	3.114	101.24	3.137	101.16	3.135
1000	100.36	3.110	101.16	3.135	101.11	3.134
1100	99.93	3.097	101.24	3.138	101.11	3.134
1200	100.12	3.103	101.16	3.135	100.86	3.126
1300	100.04	3.100	100.86	3.126	100.86	3.126
1200	100.30	3.109	100.92	3.128	100.98	3.130
1100	100.04	3.100	100.92	3.128	100.92	3.128
1000	100.04	3.100	100.98	3.129	100.79	3.124
800	100.17	3.105	100.86	3.126	100.98	3.130
600	100.30	3.109	101.24	3.138	100.92	3.128
400	100.17	3.105	101.11	3.134	101.16	3.135
200	99.99	3.099	100.92	3.128	100.92	3.128
0	100.30	3.109	101.16	3.135	101.11	3.134
-200	100.42	3.112	101.05	3.132	101.11	3.134
-400	100.42	3.112	101.42	3.134	101.29	3.139
-600	100.73	3.122	101.29	3.139	101.53	3.147
-800	100.17	3.105	100.92	3.128	100.92	3.128
-1000	100.36	3.110	100.98	3.130	100.97	3.130
-1100	100.17	3.105	101.11	3.134	101.05	3.132
-1200	100.36	3.110	102.09	3.164	101.05	3.132
-1300	100.17	3.105	101.05	3.132	101.11	3.134
-1200	100.23	3.106	100.92	3.128	101.05	3.132
-1100	100.17	3.105	102.09	3.164	101.16	3.135
-1000	100.17	3.105	102.09	3.164	101.16	3.135
-800	100.49	3.114	100.92	3.128	101.11	3.134
-600	100.23	3.106	100.92	3.128	101.05	3.132
-400	100.30	3.109	100.92	3.128	101.16	3.135
-200	100.04	3.100	101.11	3.134	101.05	3.132
0	100.42	3.112	101.05	3.132	100.97	3.130

Test Data

Table X B

Leakage Current versus Direct Voltage

This data was taken at the same time as the data in Table X was taken and under the same conditions.

D.C. Potential volts	I_o uamps	I_1 uamps	I_2 uamps
0	0	0	0
200	8.46	8.50	8.50
400	16.30	16.30	16.30
600	22.70	22.80	23.80
800	29.50	29.66	29.80
1000	35.80	35.80	36.20
1100	40.60	40.80	40.80
1200	43.50	43.73	43.76
1300	46.00	46.20	46.20
1200	43.56	43.40	43.10
1100	40.00	40.00	39.80
1000	37.00	37.00	37.00
800	30.20	30.80	30.80
600	23.86	24.00	24.00
400	16.40	17.00	17.00
200	8.80	8.80	8.80
0	0	0	0
-200	8.80	8.80	8.80
-400	16.50	16.90	17.00
-600	23.20	23.20	23.20
-800	29.80	29.80	29.80
-1000	36.40	36.40	36.20
-1100	39.30	39.30	39.30
-1200	44.20	44.20	44.20
-1300	47.00	47.50	47.50
-1200	43.80	43.80	44.00
-1100	40.20	40.20	40.20
-1000	37.60	37.60	37.60
-800	31.00	31.00	30.80
-600	22.80	22.80	22.80
-400	16.40	16.20	16.00
-200	9.13	9.13	9.00
0	0	0	0

Test Data

Table XI

Dielectric Constant versus Magnetic Flux-density

Test was made under constant values of electric field and varying values of magnetic field. The electric field varied from zero to 1200 volts, and the magnetic field varied from zero to 1000 gauss and then to zero. Temperature was constant at 25°C., frequency was 500 kc., and the air capacity was 30.9uuf. The condenser was placed so that the electric field was normal to the magnetic field.

	E = 0		E = 200		E = 400		E = 600		E = 800		E = 1000		E = 1200	
H	C	K	C	K	C	K	C	K	C	K	C	K	C	K
0	99.29	3.213	99.23	3.211	99.29	3.213	99.34	3.215	99.20	3.210	99.12	3.208	99.23	3.211
200	100.01	3.237	100.01	3.237	100.05	3.238	100.07	3.239	100.01	3.237	99.93	3.234	99.99	3.236
400	100.05	3.238	100.01	3.237	100.01	3.237	100.07	3.239	100.01	3.237	99.99	3.236	100.01	3.237
600	100.01	3.237	100.01	3.237	100.05	3.238	100.10	3.239	99.96	3.235	100.05	3.238	100.05	3.238
800	100.01	3.237	100.01	32.37	100.05	3.238	100.05	3.238	99.96	3.235	99.99	3.236	100.05	3.238
1000	100.05	3.238	100.01	3.237	100.05	3.238	100.07	3.239	99.99	3.236	100.05	3.238	100.05	3.238
800	100.10	3.239	100.01	32.37	100.05	3.238	100.01	3.237	100.01	3.237	100.01	3.237	100.07	3.239
600	100.10	3.239	100.01	3.237	100.05	3.238	99.99	3.236	99.99	3.236	99.93	3.234	100.01	3.237
400	100.01	3.237	99.99	3.236	99.99	3.236	100.01	3.237	100.01	3.237	99.96	3.235	99.99	3.236
200	100.05	3.238	99.96	3.235	100.01	32.37	100.07	32.39	99.96	3.235	99.99	3.236	99.99	3.236
0	99.17	3.209	99.20	3.210	99.23	3.211	99.29	3.213	99.14	3.208	99.20	3.210	99.20	3.210

Test Data

Table XII

Dielectric Constant versus Magnetic Flux-density

Test was made under constant values of electric field and varying values of magnetic field. The electric field varied from zero to 1200 volts, and the magnetic field varied from zero to 1000 gauss and then back to zero. Temperature was constant at 25°C., and the frequency was 500 kc., and the air capacity was 30.9uuf. The condenser was placed so that the electric field was parallel to the magnetic field.

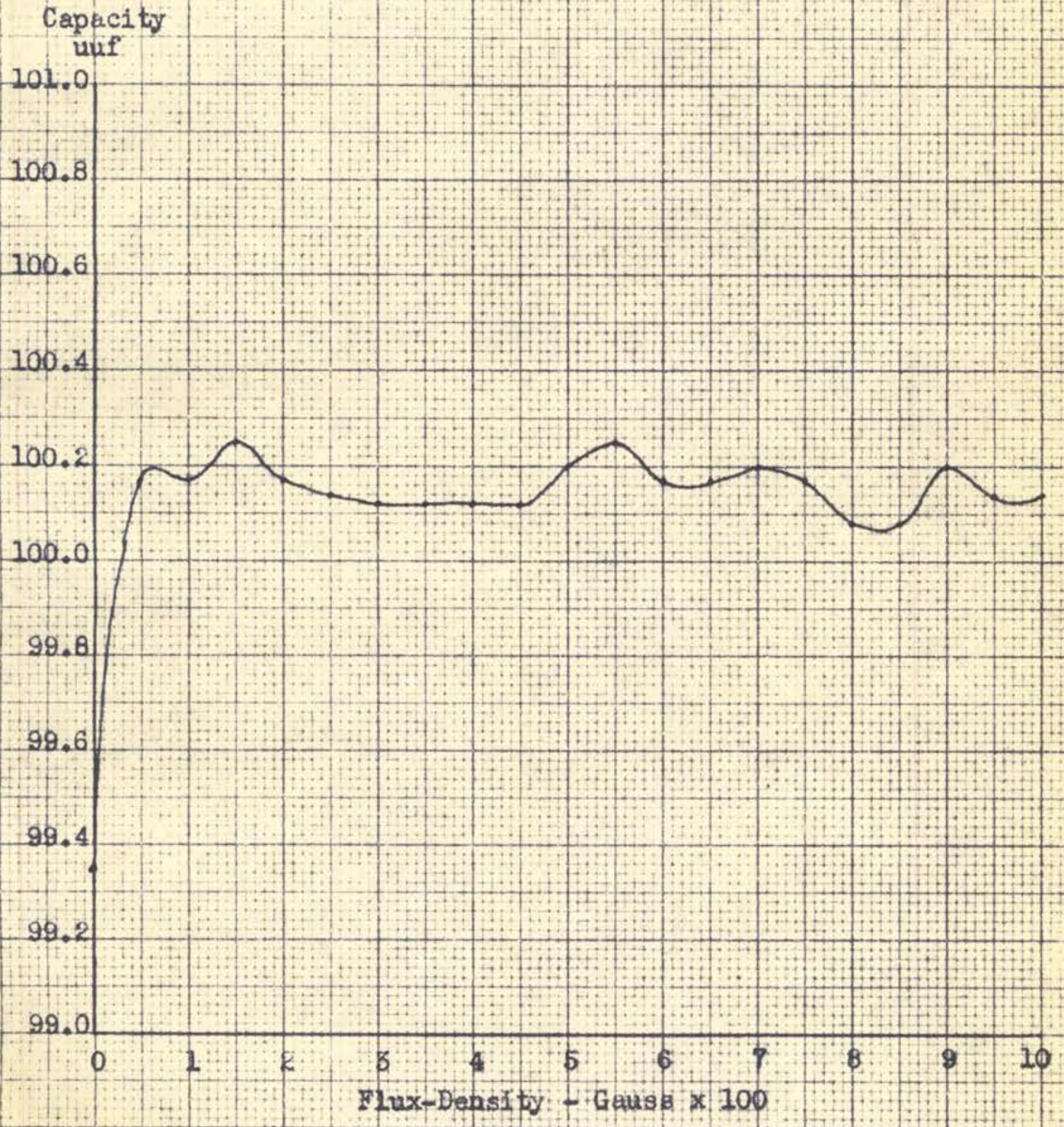
	E = 0		E = 200		E = 400		E = 600		E = 800		E = 1000		E = 1200	
H	C	K	C	K	C	K	C	K	C	K	C	K	C	K
0	99.30	3.214	99.36	3.216	99.47	3.219	99.38	3.216	99.30	3.214	99.24	3.212	99.36	3.216
200	100.34	3.247	100.39	3.249	100.37	3.248	100.37	3.248	100.22	3.243	100.16	3.241	100.31	3.246
400	100.28	3.245	100.39	3.249	100.39	3.249	100.34	3.247	100.25	3.244	100.16	3.241	100.30	3.246
600	100.31	3.246	100.37	3.248	100.37	3.248	100.34	3.247	100.16	3.241	100.22	3.243	100.25	3.244
800	100.28	3.245	100.34	3.247	100.34	3.247	100.37	3.248	100.21	3.243	100.14	3.241	100.25	3.244
1000	100.37	3.248	100.37	3.248	100.37	3.248	100.31	3.246	100.22	3.243	100.16	3.241	100.25	3.244
800	100.31	3.246	100.37	3.248	100.34	3.247	100.28	3.245	100.20	3.243	100.16	3.241	100.16	3.241
600	100.39	3.249	100.39	3.249	100.39	3.249	100.34	3.247	100.20	3.243	100.20	3.243	100.20	3.243
400	100.39	3.249	100.42	3.250	100.42	3.250	100.37	3.248	100.20	3.243	100.16	3.241	100.20	3.243
200	100.34	3.247	100.37	3.248	100.39	3.249	100.34	3.247	100.25	3.244	100.14	3.241	100.16	3.241
0	99.38	3.216	99.49	3.220	99.47	3.219	99.44	3.218	99.30	3.214	99.24	3.212	99.24	3.212

CAPACITY VERSUS MAGNETIC FLUX-DENSITY

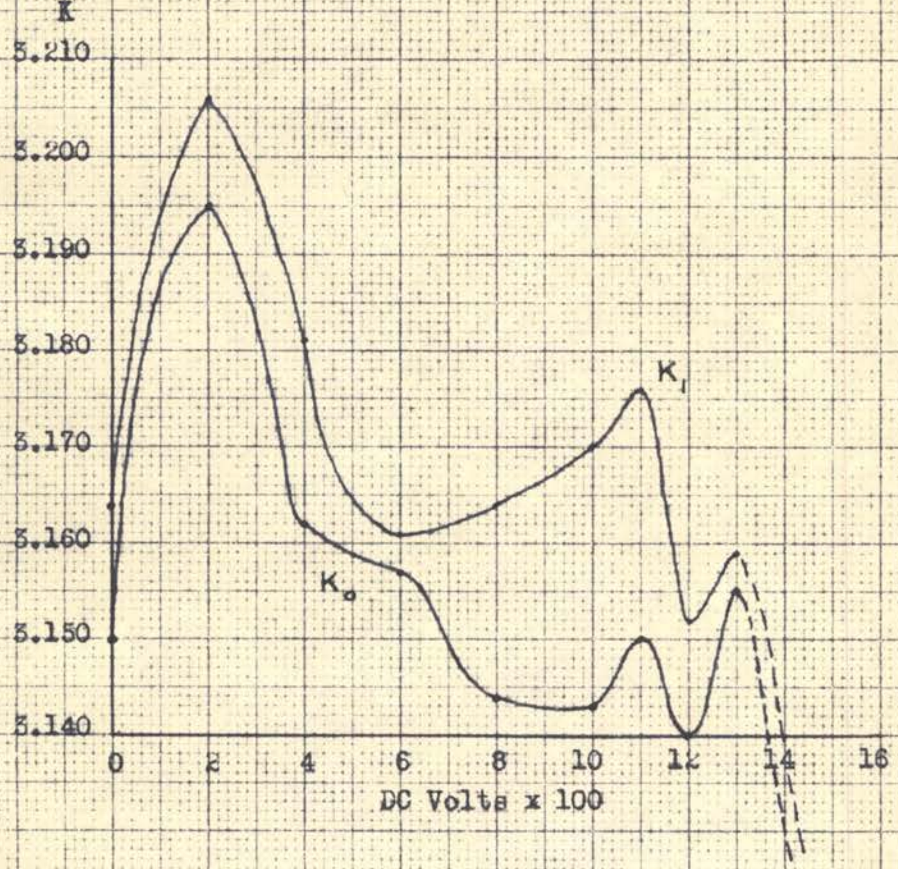
C vs B

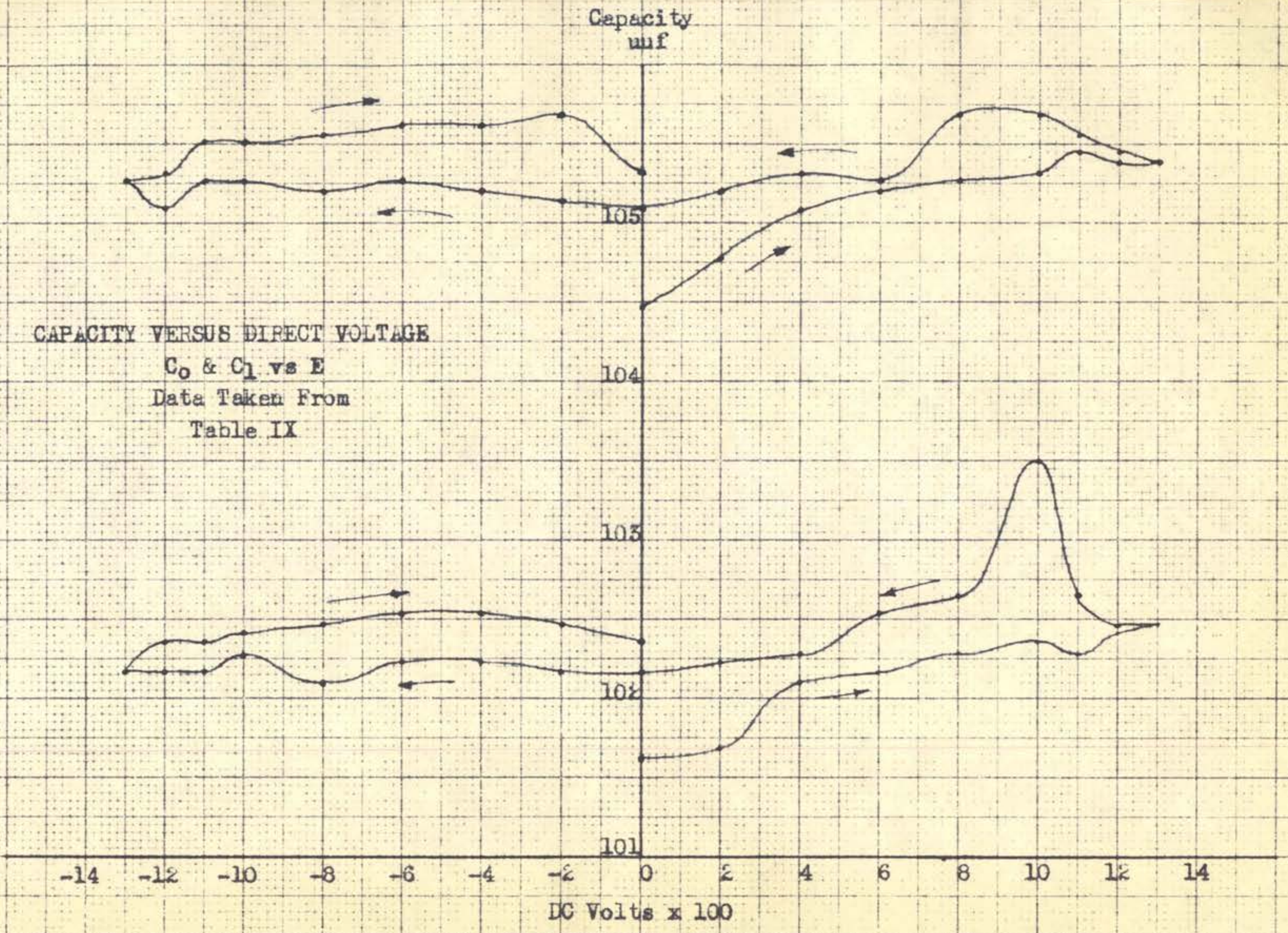
Data Taken From

Table I

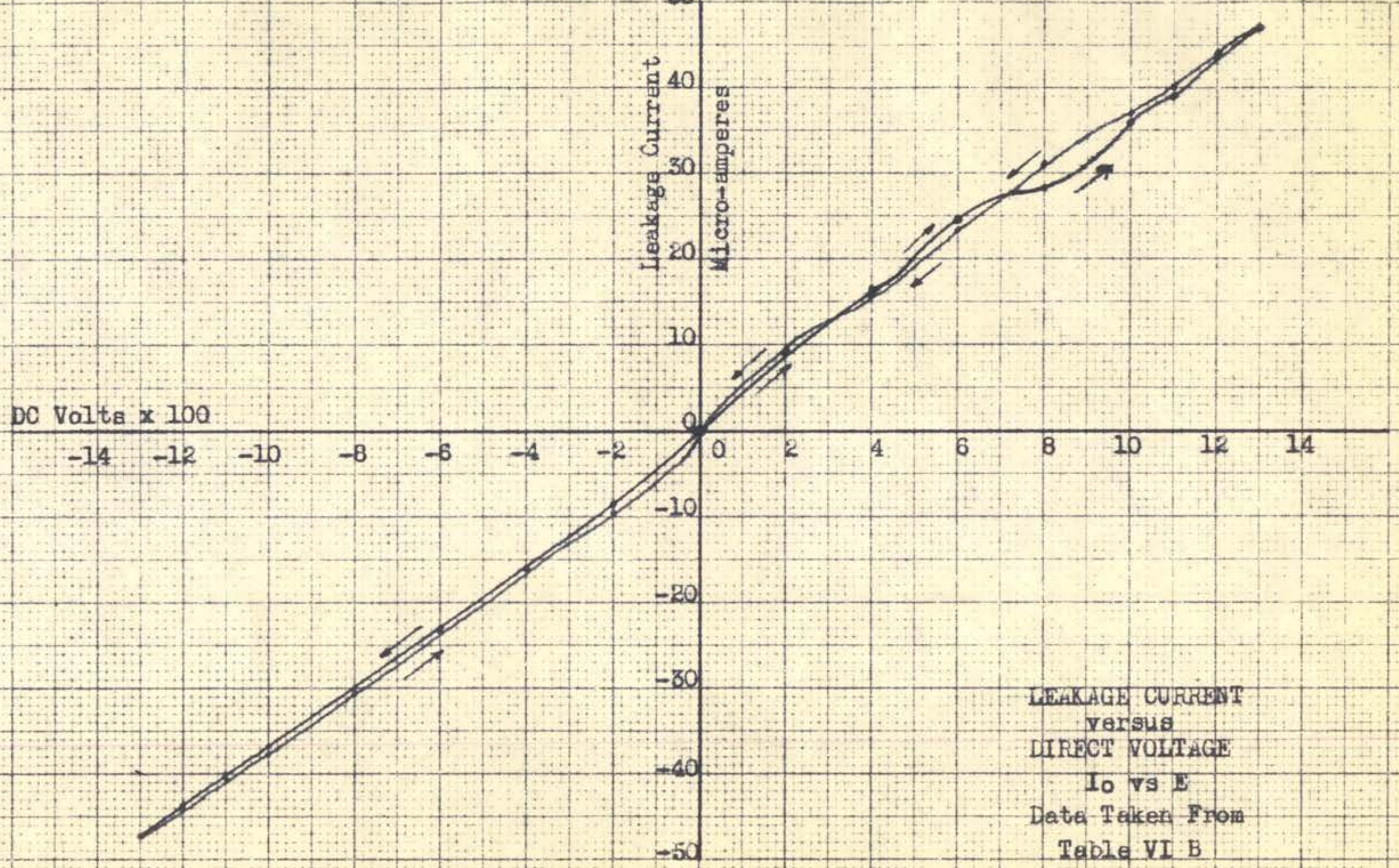


DIELECTRIC BREAKDOWN CURVES
AT
CONSTANT H
K_0 & K_1 vs E
Data Taken From
Table III

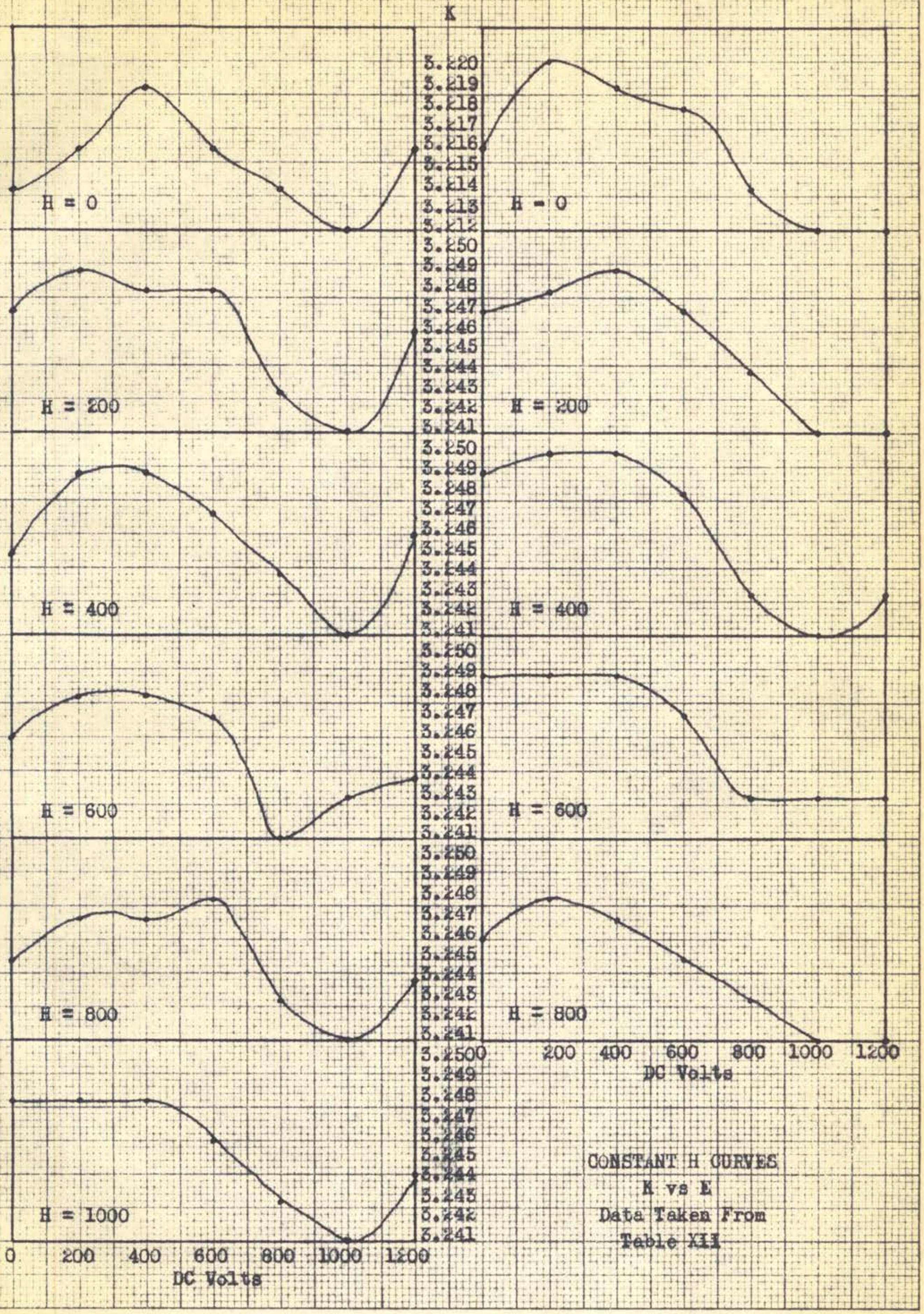




CAPACITY VERSUS DIRECT VOLTAGE
C_0 & C_1 vs E
Data Taken From
Table IX



LEAKAGE CURRENT
versus
DIRECT VOLTAGE
Io vs E
Data Taken From
Table VI B

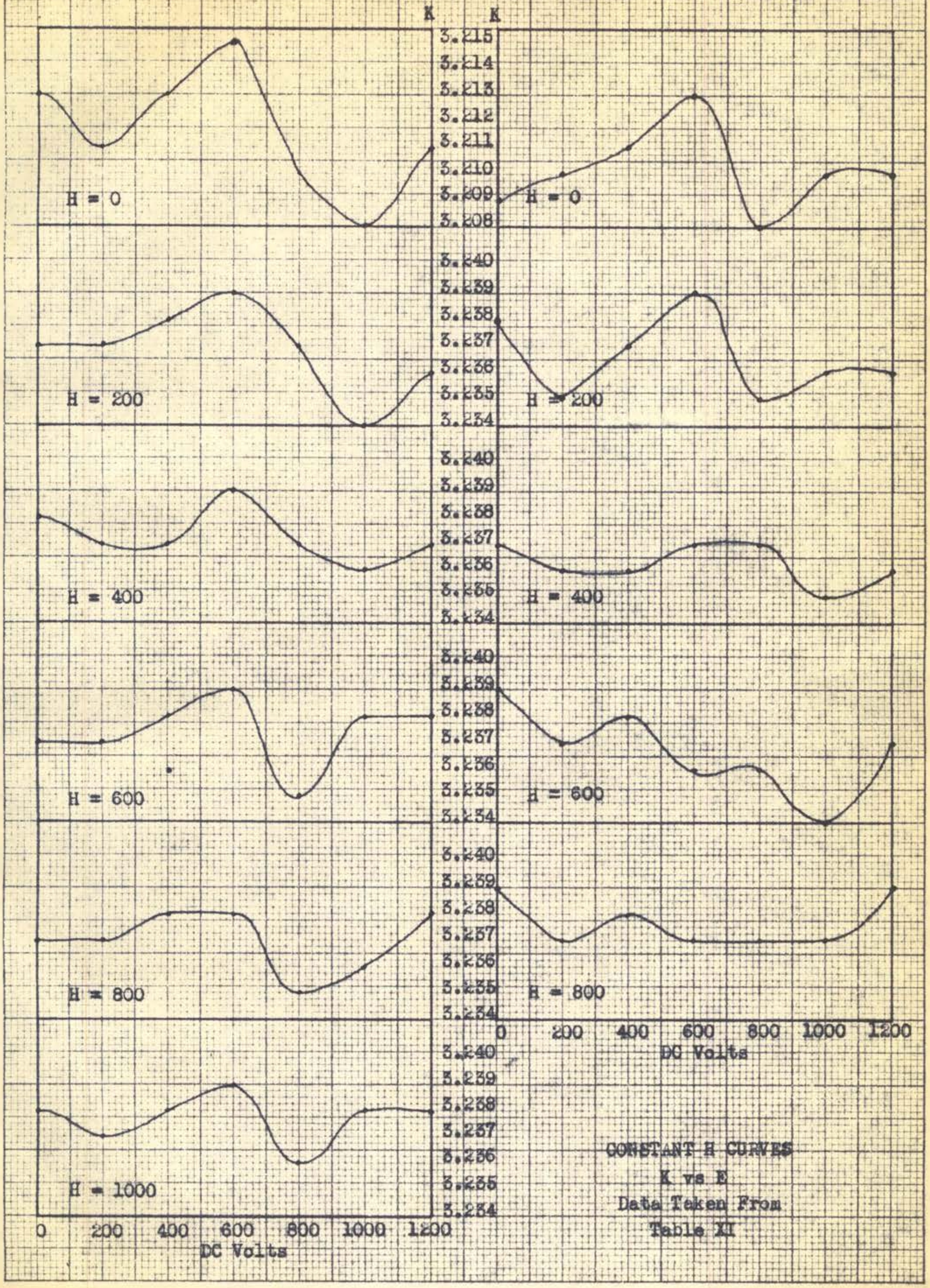


CONSTANT H CURVES

K vs E

Data Taken From

Table XII



CONSTANT H CURVES

K vs E

Data Taken From

Table XI

IV. CONCLUSIONS AND INTERPRETATION OF DATA.

The objective of this investigation was to continue the compilation of data pertaining to the dielectric properties of sulfur. Perhaps the reader wonders why the dielectric properties of a substance have been investigated when they may be found in any one of a hundred different handbooks. The reader may answer his own query by referring to several of these handbooks. Some typical findings for the dielectric constant of sulfur may be cited. From "Electrical Engineers' Handbook" by Pender and McIllwain; K at a frequency less than 2kc equals 3.6 or 4.22, K at frequencies between 100 and 2000kc equals 4.0. The "Standard Handbook for Electrical Engineers" by A. E. Knowlton shows that the dielectric constant of sulfur varies from 3.6 to 4.2. The book "Reference Data for Radio Engineers" published by Federal Telephone and Radio Corporation does not list the constant for sulfur, but it does have the dielectric constants for many other materials broken up under different frequency headings of 60, 10^3, 10^6, 10^8, 3×10^9 and 2.5×10^{10} cycles per second. The "Microwave Transmission Design Data" handbook by Moreno lists sulfur as having a dielectric constant of 3.44 at frequencies of 3×10^9 and 1×10^{10} cycles per second. It also notes that the samples were measured at 25°C. and zero humidity. The book "Radio Engineering" by F. E. Terman lists only twelve materials which does not include sulfur. The constants mentioned have no reference made to the conditions they were measured under or the mode of measurement. And so it goes, look through another twenty books and the results will be much the same. Very few sources mention the variable conditions under which the dielectric constants may change values. There is no simple "Ohms Law" to determine the value of a dielectric constant under some peculiar set of conditions. This thesis will not offer any such revolutionary idea, and it is not probable that the next ten or one hundred research projects will either. But--by combining the results found in a great number of these insignigicantly small investigations, something definite may be determined.

The most important fact brought out by this investigation is that the dielectric constant of sulfur definitely changes when under the action of a magnetic field. In every table listed, K increased when the test condenser was placed in the magnetic field. For example in Table I, under a zero magnetic field K = 3.215, under a field of 50 gauss K = 3.242. This is admittedly, a small variation, but the fact remains that K did increase a definite amount. Another significant fact is that during the further variation of the magnetic field alone, the dielectric constant remained relatively constant. That is, it varied only .005 overall from a minimum of 3.239 to a maximum of 3.244. In a simple substance like hydrogen, it would be expected that the dielectric constant increase as the magnetic field was increased. It is found that in the more complicated crystalline structure of sulfur, the dielectric constant does not increase as the field increases. It is suggested that possibly the sulfur molecules may become energy saturated, that is, the molecules may only require a very small field to cause the maximum variation in structure and any further increase in magnetic intensity will not have an effect. Perhaps the variations would have been more pronounced if the magnetic field had been increased to a value of 100 kilogausses instead of just one. Theoretical physics books point out the fact that there are separate theories to cover weak fields, strong fields and extremely strong fields. Later tests took advantage of the stability of the dielectric constant and only measurements at minimum and maximum magnetic fields were taken.

The data in Tables II and III was taken primarily to determine the breakdown potential of sulfur in the particular condensers being used. This value was found to be in the vicinity of 1300 volts. With a condenser plate spacing of approximately 1/64", the voltage gradient was found to be 80,000 volts per inch. The capacity decreased quite sharply as the breakdown point was reached. This fact was also brought out in Noel's[1] investigation. This data established the maximum of 1300 volts for the variation of potential used in later tests.

Tables IV through XB were completed by taking measurements of capacity and leakage current at zero, minimum, and maximum values of magnetic intensity for constant electric intensity values. The electric field was varied in a complete loop of zero to positive maximum to negative maximum to zero. A plot of capacity versus dc voltage may be examined on page 40. One noticeable fact brought is that in 16 out of 20 cases, the final

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[1] Noel, C. A., Dielectric Properties of Sulfur Under High Voltage Stress, p. 60.

value of capacity after completing the loop is higher than the initial value. Twenty cases are not enough to state the fact as a law, but they do show a definite trend. This indicates that possibly the sulfur structure was strained in such a manner that it was unable to give back as much energy as was originally absorbed by it. This difference in energy may either have been retained by the sulfur or it may have been completely expended in changing the crystalline structure of the dielectric. If the energy was completely lost in changing the structure, it apparently did not permanently alter the sulfur structure because the sulfur was used time after time and almost always returned to a representative value of dielectric constant. Another fact that was found was that the capacity increase under a magnetic field was fairly constant, that is, the increase followed the variations of the capacity with the electric intensity. Several of the tests were run with the condenser placed so that the electric field was normal to the magnetic field, others were run with the electric field parallel to the magnetic field. The variations of capacity in both cases were much the same.

Page 41 shows a curve of leakage current versus dc potential. This curve is representative of all the leakage current data that was taken. The current seemingly varies semi-linearly with the impressed voltage. There is apparently no effect on the current by the magnetic field. The variations of current do not follow the capacity variations. The orientation of electric field with respect to magnetic field did not cause any variation of leakage current.

The curves on pages 42 and 43 show the variations of dielectric constant with electric intensity at constant values of magnetic field. Actually, the values of magnetic intensity were varied from zero to maximum and then back to zero at constant values of electric intensity. The curves are read from the upper left corner downward, and then back up the right side of the page.

These various changes in dielectric constant under the combined electric and magnetic fields have not been explained in literature except theoretically and for very simple elements such as helium or hydrogen. There are no formulas or laws to explain the behavior of dielectrics under varying electric and magnetic fields, varying temperatures or varying frequencies. No startling conclusions have been reached as a result of this investigation, but it is hoped that someone may be able to use part of the information gained from this project as a basis for a formulation of some concrete theories.

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