T H E S I S

on

An Investigation of The Electrical Precipitation of Spray and Fog by 60 Cycle Alternation Current Fields.

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Degree of

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Introduction

In close proximity to the sea coast, Great Salt Lake, the Gulf of Mexico, and other locations the insulating value of insulators is greatly decreased due to "salt fogs." Electric Light and Power Companies operating transmission lines and other outdoor electrical equipment subject to these fogs use diverse methods for combating the conducting deposits formed. Some companies increase the size of their insulators on low voltage lines when economically feasible. The Southern California Edison Company has installed permanent fresh water spray equipment in important substations for washing the insulators daily. One company serving Vera Cruz, Mexico has built a double line into the city for some six or eight kilometers, and during a certain season of the year keep one man busy washing these insulators. All of these methods result in increased expenditures for the installation and maintenance of transmission and distribution systems.

Formation of "Salt Fogs"

"Salt fogs" are caused by the mechanical breaking up of salt water by waves, and the breakers in the surf. The fine spray of small particles containing the various dissolved constituents of the salt water are projected into the air, and are carried over the land under favorable wind conditions. This salt laden spray is deposited on insulators, and as the water is evaporated the salt residue is left on the insulating surface. This residue accumulates at a rate depending upon the frequency and duration of the "salt fogs."

Because of the nature of formation the "salt fog" particles will have a definite electrical charge, and it was believed that it would be possible to provide some kind of shielding apparatus to electrically precipitate the undesirable conducting material before it reaches the insulator surface.

Construction of Apparatus

The first part of the problem consisted in building some apparatus for the investigation. Therefore, work was started early in the fall term of 1931-'32 to assemble the necessary equipment for the experiment.

A supporting structure for the insulator under test was first assembled. This consisted of an A frame structure of the correct height to support the insulator, the electrical shield, and the spray nozzle with the screen for breaking up the spray. This structure is shown in Fig. 1.

The next problem was to arrange for a high voltage conductor from the transformer to the insulator under test. One-quarter inch pipe was selected for this purpose because it is sufficiently rigid to support its own weight, and also approximates the size of conductor that one usually finds in use on 66 KV. transmission lines. In order to reduce the mechanical load on the transformer bushing to a minimum an insulating wood support was bolted to the top of the transformer tank to support the one-quarter inch pipe conductor for energizing the insulator. The other high voltage terminal of the transformer was connected directly to ground.

It was necessary to produce a spray similar to fog, and after much experimenting the Spray Engineering Company's nozzle "Spraco" #3B with some modifications was found to be best for the purpose. This nozzle consists of an external chamber which has an opening for the water or spray to pass through. Within this chamber there is a spinner or turbine which has a central hole passing directly through it. On the outside of the spinner there are two spiral grooves running from front to back. As the water passes through these spiral grooves the spinner is caused to rotate, which gives the water a whirling motion and breaks it up into a fine spray. The central hole of the spinner within the nozzle was plugged with wood, and the resultant spray with a water pressure ranging from fifty to sixty-five pounds was fairly fine, but had a rather high velocity. In order to reduce this velocity to a low value a screen with twenty meshes per inch was placed about three inches in front of the "Spraco" nozzle. This screen not only reduced the velocity of the water particles, but also broke them up so that a very fine spray or fog was obtained. This spray was light enough to be shifted in its course by the wind, and blown around quite freely.

A spray of steam was also used in place of the water stream. This was obtained from the Apperson Hall heating system, and really produced a condition more representative of actual fog conditions.

Voltage Supply

Voltage for the experiment was obtained by transforming an adjustable 0-110 volt alternating current supply, controlled by hand rheostats to 38,200 volts, the normal line to neutral voltage for a 66,000 volt three phase circuit.

The ratio of the transformer was carefully checked by measuring the voltage on the high voltage side with a 6.25 cm. sphere gap, and simultaneous voltmeter readings on the low voltage side. The ratio under no load was found to vary from 750 at 11,820 volts to 792 at 65,800 volts. At the test voltage, 38,200 volts, the ratio was found to be 780. The transformer and control equipment is shown in Fig. 2.

Investigation of Electrical Precipitation of Spray and Fog by 60 Cycle Alternating Current Fields.

The primary object of this experiment was to observe the electric field on the fog surrounding an insulator under various conditions.

With a potential of 38,200 volts applied between the conductor on the insulator and the insulator pin the water spray was directed toward the insulator. Under this condition no particular phenomenon was observed to take place on the spray within the dielectric field.

With a flat metal plate placed on top of the insulator, and connected to the conductor the observations were repeated, and again no noticeable phenomenon on the spray took place. The same was true when a grading shield was connected to the pin or grounded side of the insulator, and with the flat shield at the top of the insulator.

With a circular grading shield connected to the conductor, and placed around the top of the insulator at a height slightly above the top shell, and a second grading shield at the base of the insulator and grounded there was a pronounced tendency for the drops of water that collected on the top shield to be repelled from the insulator as they dropped off of the shield. However, there was no noticeable effect on the spray in the dielectric field between the two shields.

An insulator with the head and entire upper surface of the top shell coated with a thin film of copper, applied by the Shoupe process, was substituted for the standard insulator, and the observations repeated. A much stronger repelling force was noticed to take place on the drops of water that fell from the top grading shield than formerly. This was to be expected because the applied potential was extended to the edge of the top shell which increased the electric field between the edge of the top shell, and the grading ring on the pin. This gave a greater repelling force against all charged particles falling within this field.

A screen having fourteen meshes per inch was tied to the grading shield so that the water spray had to pass through this screen. When directed toward the insulator it was noted that there was a great deal more run off of water from the screen when the voltage was applied than when not applied.

The same experiment was tried except the screen was placed five inches from the shielding ring. The large run off of water was noted as formerly.

Further experiments were tried with the screen at various distances from the shielding ring, and it was found that the most effective distance was about five inches. At approximately seven inches the dielectric field began to lose its effect on the water spray, and at distances much greater than this there was no noticeable effect on the water spray as it collected on the screen.

Measurements were taken of the run off of water from the insulator while shielded with a shielding ring, and shielding screen five inches from the shielding ring. With the voltage applied there was only 43.6% as much run off of water from the insulator over a period of one hour as there was with no voltage applied. This shows that the dielectric field under these particular conditions was able to repel 56.4% of the water spray away from the insulator.

The fog stream was next produced by steam from the Apperson Hall heating system. With this condition, and the shielding as above described the run off from the shielding screen was noticeable when the voltage was applied, but with no voltage applied there was no noticeable run off from the shielding screen.

The next test was to over-stress the air surrounding the insulator, and to do this a #20 AWG. bare copper wire was used for a shielding ring at the top of the insulator. The voltage was increased to 66,000 volts, and at no time was there any noticeable change that took place on the fog stream within the dielectric field.

Insulator Leakage

A number of different insulators were tested for leakage current when dry, when subject to a water spray, and when subject to a steam bath. The results obtained are shown in Table I. The insulators tested are shown in Figures 3 and 4. General information on these insulators is given in Table II.

Distance Traveled by a Charged Water Particle in an Alternating Electric Field.

In order to determine whether the experimental results obtained are in accordance with the laws of mechanics and electricity equations were derived for calculating the distance traveled in one-half cycle by a charged water particle, in air, acted upon by the combined forces of gravity and a sinusoidal alternating electric field. The equations used are shown in Appendix I.

Since the action on a water particle in an electric field depends on both the field voltage gradient, and the charge on the particles, calculations were made to determine the maximum possible electric charge on a fog particle of the mean size as determined by W. J. Humphreys The maximum charge possible is the quantity of electricity that will raise the voltage gradient at the surface of the particle to the ionizing point for the surrounding air. These calculations are given in Appendix II.

The maximum electric field obtainable is determined by the dielectric strength of air which is approximately 30 kv. per centimeter at 25 degrees temperature, and a barometric pressure of 76 centimeters of mercury. For other conditions of atmospheric temperature, and pressure the dielectric strength of the air is directly proportional to the air density factor δ.

$$\delta = \frac{3.92 \times b}{273 + t}$$

Where

b = barometric pressure in Cm. of Hg.
t = temperature in degrees C

Curves were plotted for various conditions of dielectric field gradient, charge on particle, and size of particle.

The distance traveled in one-half cycle by a 0.000508 cm. radius water particle having an electric charge of 10 electrons, and acted upon by a 60 cycle sinusoidal electric field varying in gradient from 0 to 30 kv. maximum per centimeter is shown graphically in Figure 5. The size 0.000508 cm. was selected because it is the mean size for fog particles found by W. J. Humphreys. It will be observed that with no electric field such a particle will fall 0.000258 cm. in 0.00833 seconds (one-half of a 60 cycle wave) because of the action of gravity. A sinusoidal 60 cycle voltage gradient of 1.8 kv. maximum per centimeter applied in opposition to gravity will just return the particle to the starting position at the end of one-half cycle. The maximum distance this average size of water particle, with a ten electron charge, can travel with the maximum possible electric field gradient of 30 kv. per centimeter is 0.00512 centimeters with gravity, and 0.00461 centimeters in opposition to gravity.

The distance traveled in one-half cycle by a 0.000508 cm. radius water particle having the maximum electric charge of 54,700 electrons, and with all other conditions as above is shown in Figure 6. It will be observed that the maximum distance traveled by this highly charged particle under the maximum field gradient of 30 kv. per centimeter is 26.58 cm. in one-half cycle. The action of gravity is so small in comparison to the action caused by the electric field that it can be neglected.

The distance traveled in one-half cycle by a 0.000508 cm. radius water particle having a charge varying from 0 to 54,700 electrons, and acted upon by a 60 cycle 1.5 kv. maximum per cm. dielectric field is shown in Figure 7. It will be observed that the maximum distance traveled by this particle when charged with 54,700 electrons is 1.33 cm. The action of gravity is small in comparison to the action caused by the electric field, and may be neglected.

The distance traveled in one-half cycle by a 0.000508 cm. radius water particle having a charge varying from 0 to 54,700 electrons, and acted upon by a 60 cycle 30 kv. maximum per centimeter dielectric field is shown graphically in Figure 8. It will be observed that the maximum distance traveled by this particle in one-half cycle when charged with 54,700 electrons is 26.58 cm. The action of gravity is so small in comparison to the action caused by the electric field that it may be neglected.

The distance traveled in one-half cycle by a water particle varying in size, and having a charge of 10 electrons, and acted upon by a 60 cycle 1.5 kv. maximum per centimeter dielectric field is shown in Figure 9. It will be observed that with very small sizes of particles the action of the electric field is very pronounced while the influence of gravity is practically nil. With large particles the opposite is true as the action of the electric field is practically nil. With a radius of 0.00000-508 cm. the particle travels 0.0243 cm. in one-half cycle either with or against gravity. With a radius of 0.00036 cm. the action of the field just counteracts the action of gravity. With all sizes larger than 0.0004 cm radius the force due to the electric field has practically no action on the particles. The same is true for the force due to gravity on all particles smaller than 0.002 cm. radius. This gives sizes between 0.0004 and 0.002 cm. radius on which neither gravity or this particular electric field and charge have any apprereciable effect. However for larger than 0.002 cm. radius gravity takes hold, and the particles fall toward the earth.

Conclusions

The results show that we can only precipitate out with alternating current fog particles that are actually charged by mechanical contact with the electric circuit. Those particles that are actually charged by contact with the electric circuit can be filtered out by alternating current fields. It should be kept in mind that the dielectric field is changing 120 times per second on a sixty cycle system which does not give the particles much time to settle on an anode or cathode. The particles therefore must be charged by the anode or cathode, and be made to cling thereto until gravity pulls them off.

The results obtained under the insulator leakage tests show that on every type of insulator tested the leakage current is greater under a steam bath than under the water spray. This was to be expected since the steam more nearly duplicates fog conditions, and settles on all surfaces of the insulator while the water spray covers the top and sides of the insulator. With the exception of the results obtained on the line post type insulator #C-88 the difference in leakage current on the several insulators is not large enough to merit special consideration. The line post type insulator because of its very much greater leakage distance and smaller circumference, decreases the leakage current materially as compared to the ordinary insulator.

Acknowledgment

This problem was undertaken at the suggestion of Mr. F. O. McMillan, Research Professor of Electrical Engineering. I wish to take this opportunity to thank him for his interest, and suggestions throughout the experiment.

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Many engineering articles were investigated for references on the subject. Those few that have any bearing on the subject are given below.

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TABLE I

Insulator Leakage Current

Insulator No.	Leakage Distance	Milliamperes Leakage			Percent Leakage In Respect To Dry Insulator		Percent Leakage Under Steam Bath In Respect to Water Spray
		Dry	Water Spray	Steam Bath	Water Spray	Steam Bath	
A-61	29½	.586	.845	1.200	144	205	142
A-44	28½	.470	.540	.680	115	145	126
B-44	31	.400	.520	.710	130	177	136
C-88	44¼	.120	.142	.190	118	158	134
D-51	31½	.418	.468	.650	112	155	139
E-51	30	.450	.468	.680	104	151	145
F-42	35	.320	.426	.510	133	159	122

TABLE II

General Information on Insulators Tested for Leakage Current

Insulator No.	A-44	B-44	C-88	D-51	E-51	F-42	A-61
Catalog No.	3555	7215	8281	3060	82-A	12552	Special
Nominal Voltage Rating	60,000	66,000	66,000	66,000	60,000	66,000	60,000
Dry Flashover Voltage	180,000	195,000	175,000	180,000	180,000	not given	not given
Wet Flashover Voltage	not given	140,000	not given	125,000	140,000	not given	not given
Weight	27.62 lbs.	31.88 lbs.	45.25 lbs.	32.19 lbs.	31.12 lbs.	30.44 lbs.	28.62 lbs.
Test Voltage of Manufacturer	not given	not given	not given	not given	not given	190,000	not given
Measured Leakage Distance	28.50 in.	31.00 in.	44.25 in.	31.50 in.	30.00 in.	35.00 in.	29.25 in.
Wet Arcing Distance	10.00 in.	10.50 in.	17.50 in.	10.20 in.	10.00 in.	9.50 in.	8.50 in.

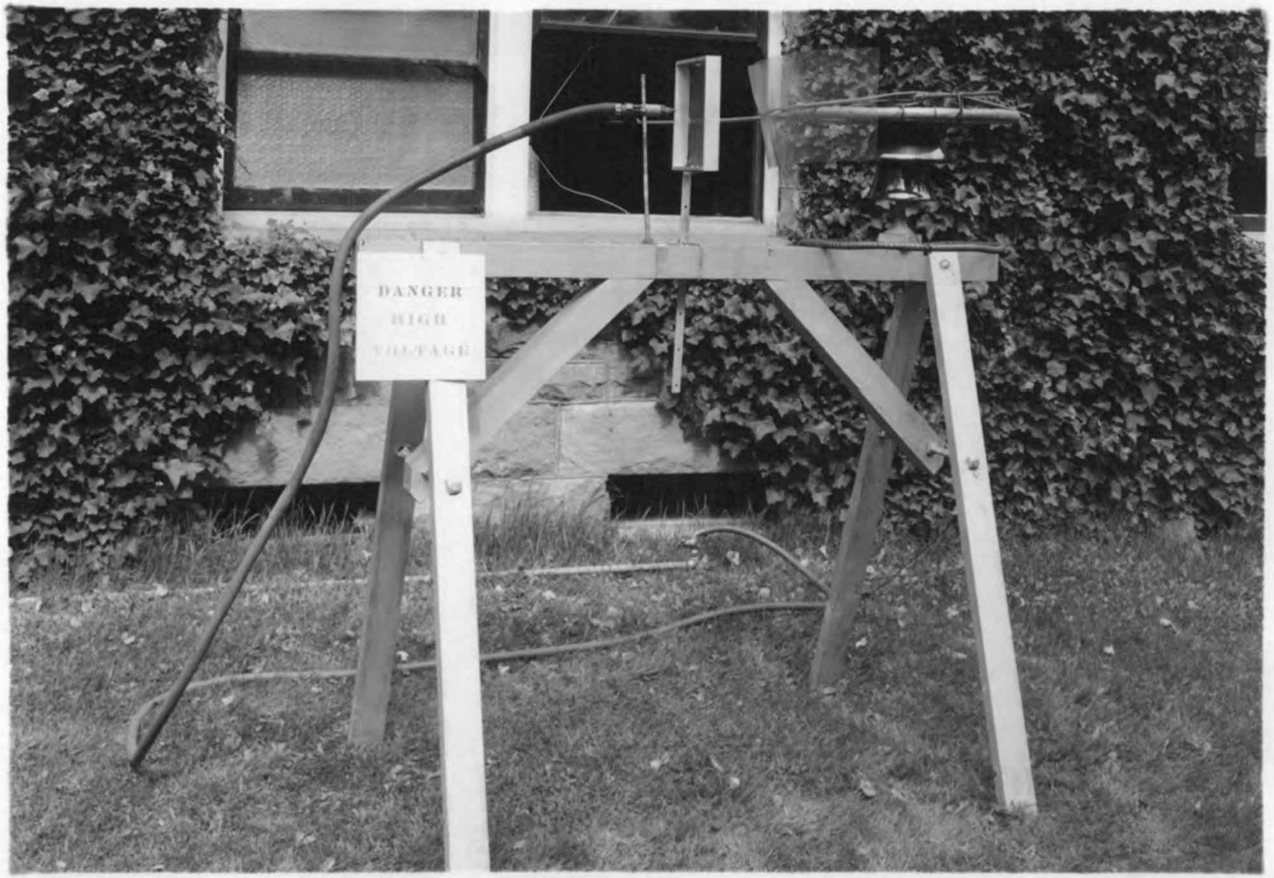


Fig. 1 Outdoor Equipment for Spray and Fog Precipitation Tests on Pin Type Insulators.

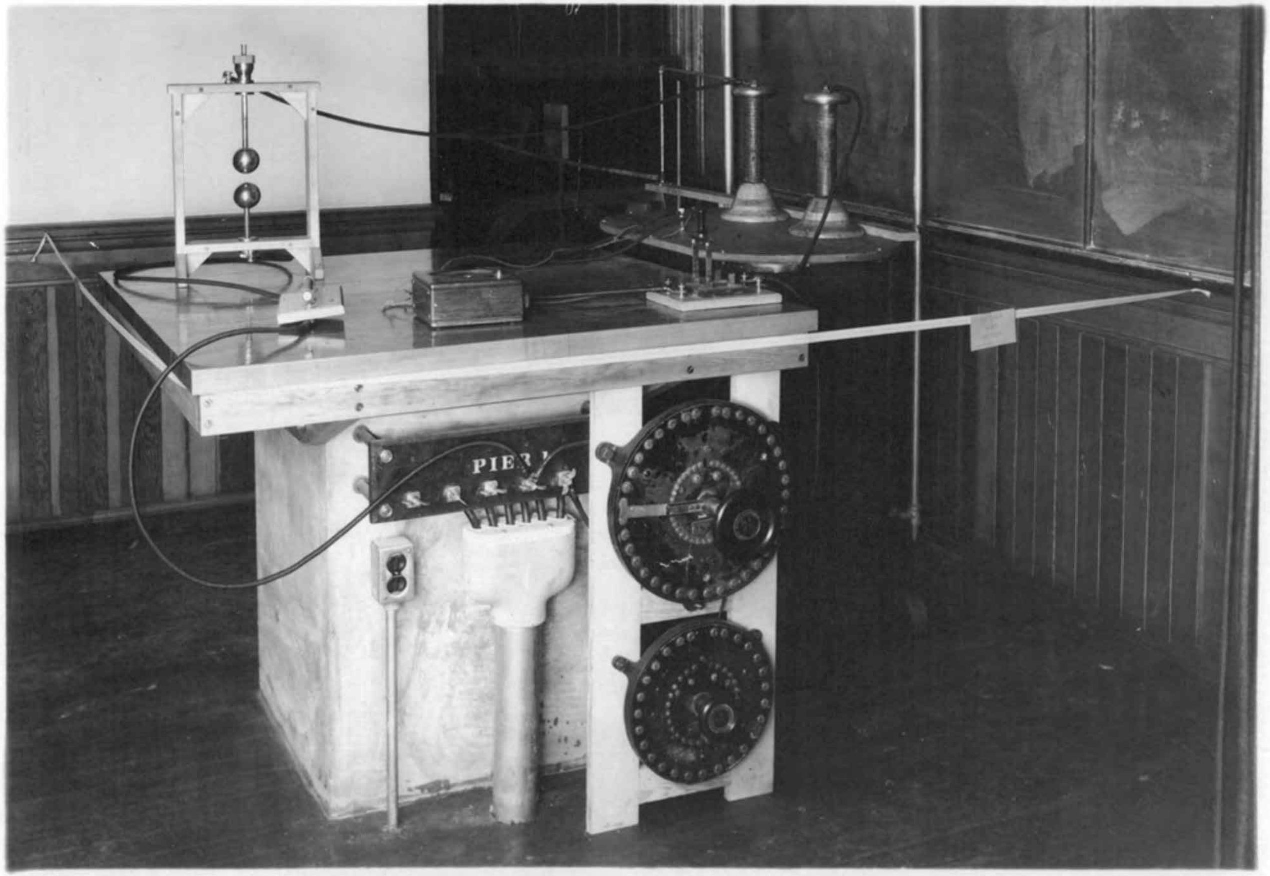
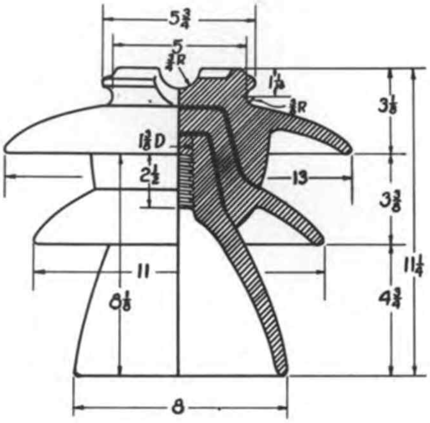
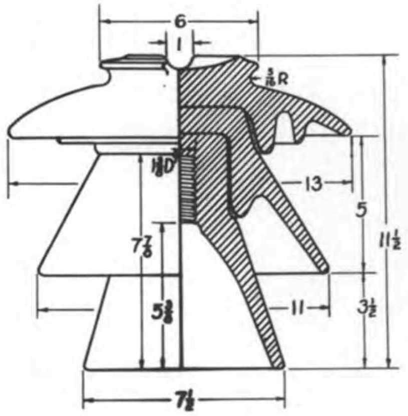


Fig. 2 Transformer and Control Equipment for Spray and Fog Precipitation Tests on Insulators.

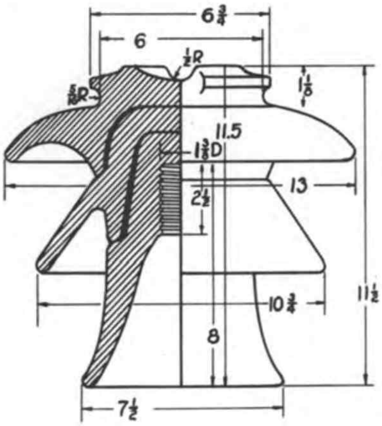
A 44



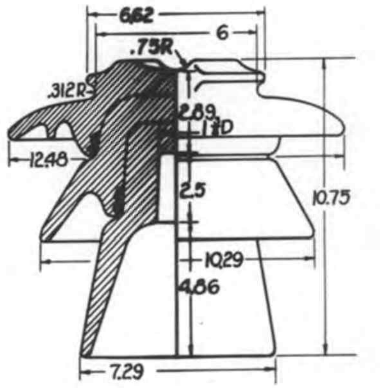
D 51



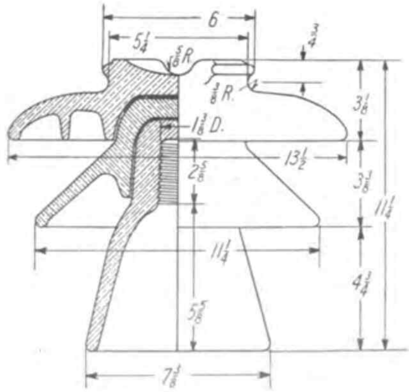
B 44



E 51



A 61



F 42

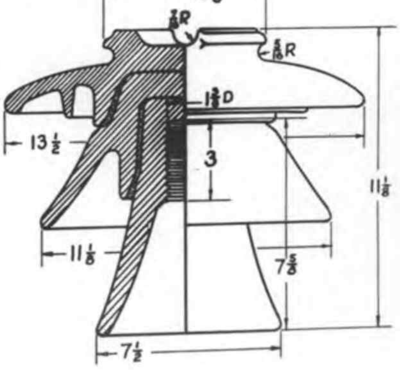


Fig. 3 Insulators used for the Surface Leakage Tests.

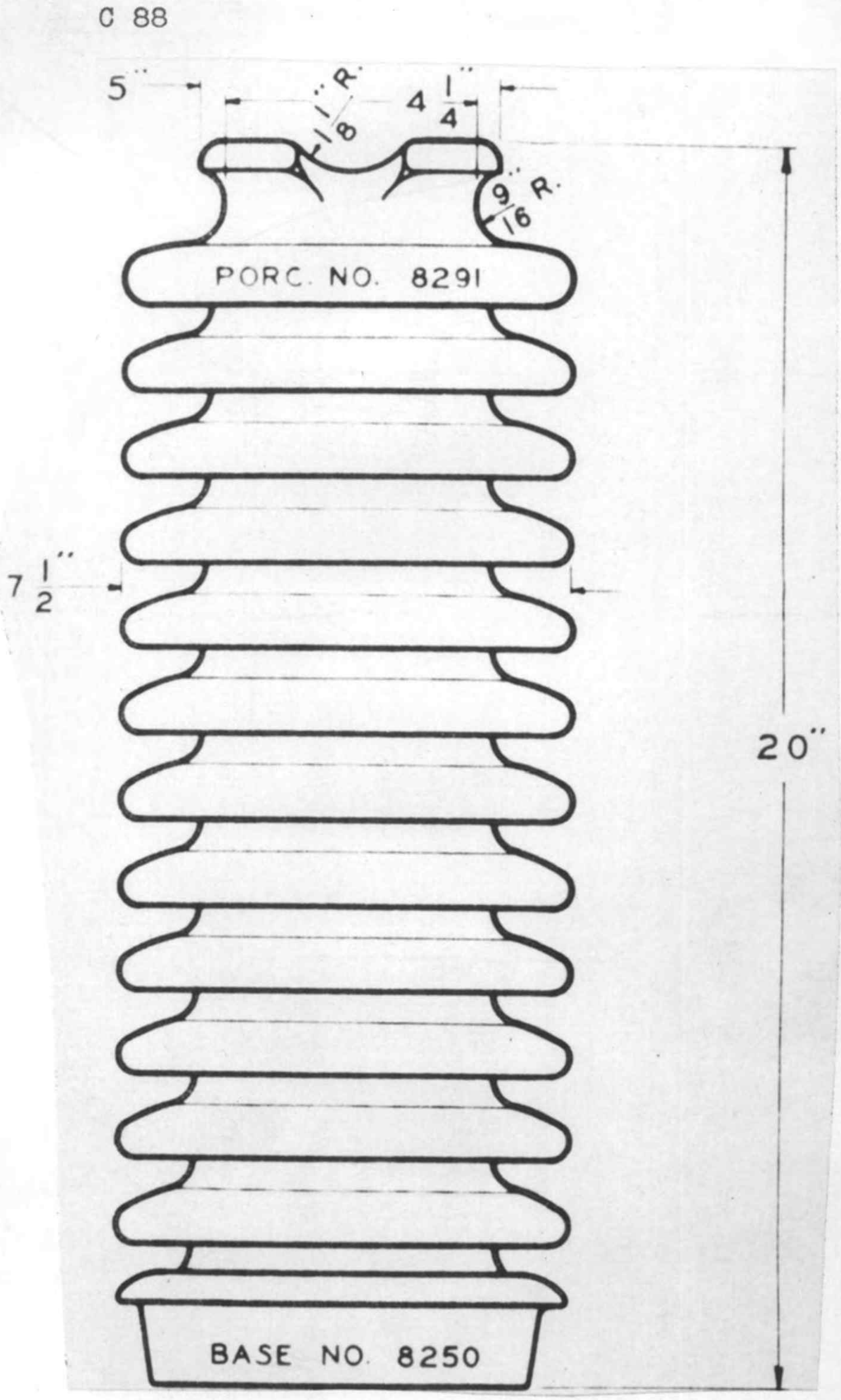


Fig. 4
Line Post Type Insulator Used for Surface Leakage Tests.

FIG. 5

DISTANCE TRAVELED IN ONE-HALF CYCLE BY A CHARGED WATER PARTICLE IN AIR UNDER THE INFLUENCE OF AN ALTERNATING DIELECTRIC FIELD

CONDITIONS

WATER PARTICLES 0.000508 CM. RADIUS THE MEAN SIZE FOUND IN FOG BY W. J. HUMPHREYS

CHARGE ON PARTICLE, 10 ELECTRONS OR 47.1×10^{-10} E.S.U

FREQUENCY OF DIELECTRIC FIELD 60 CYCLES PER SECOND

COEFFICIENT OF VISCOSITY OF AIR $\mu = 1.824 \times 10^{-4}$

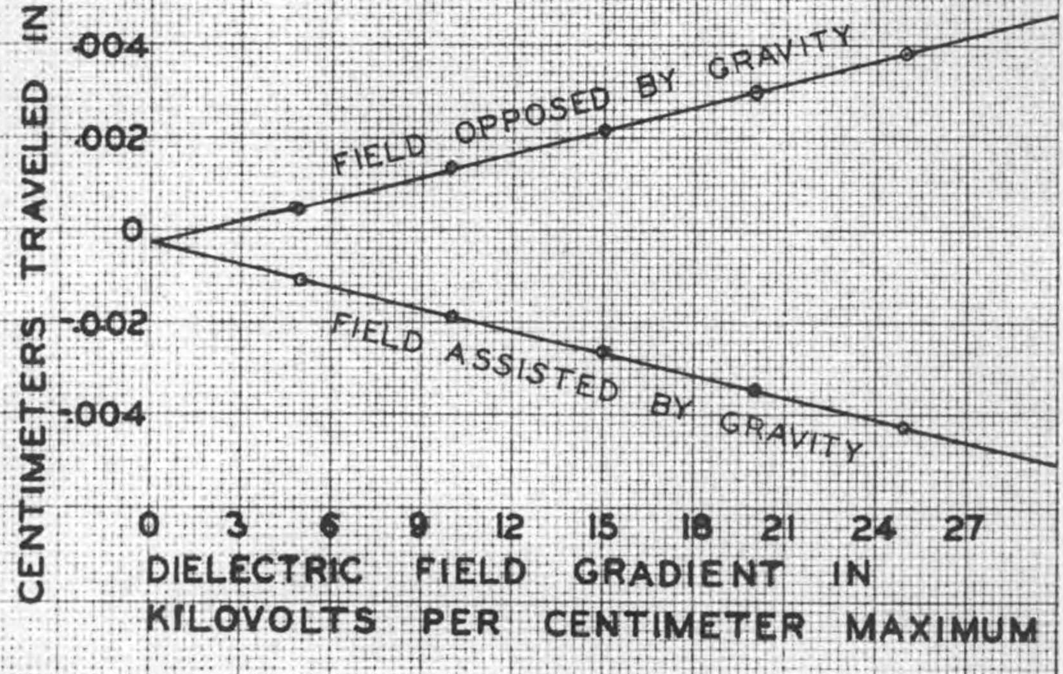


FIG. 6

DISTANCE TRAVELED IN ONE-HALF CYCLE BY A CHARGED WATER PARTICLE IN AIR UNDER THE INFLUENCE OF AN ALTERNATING DIELECTRIC FIELD

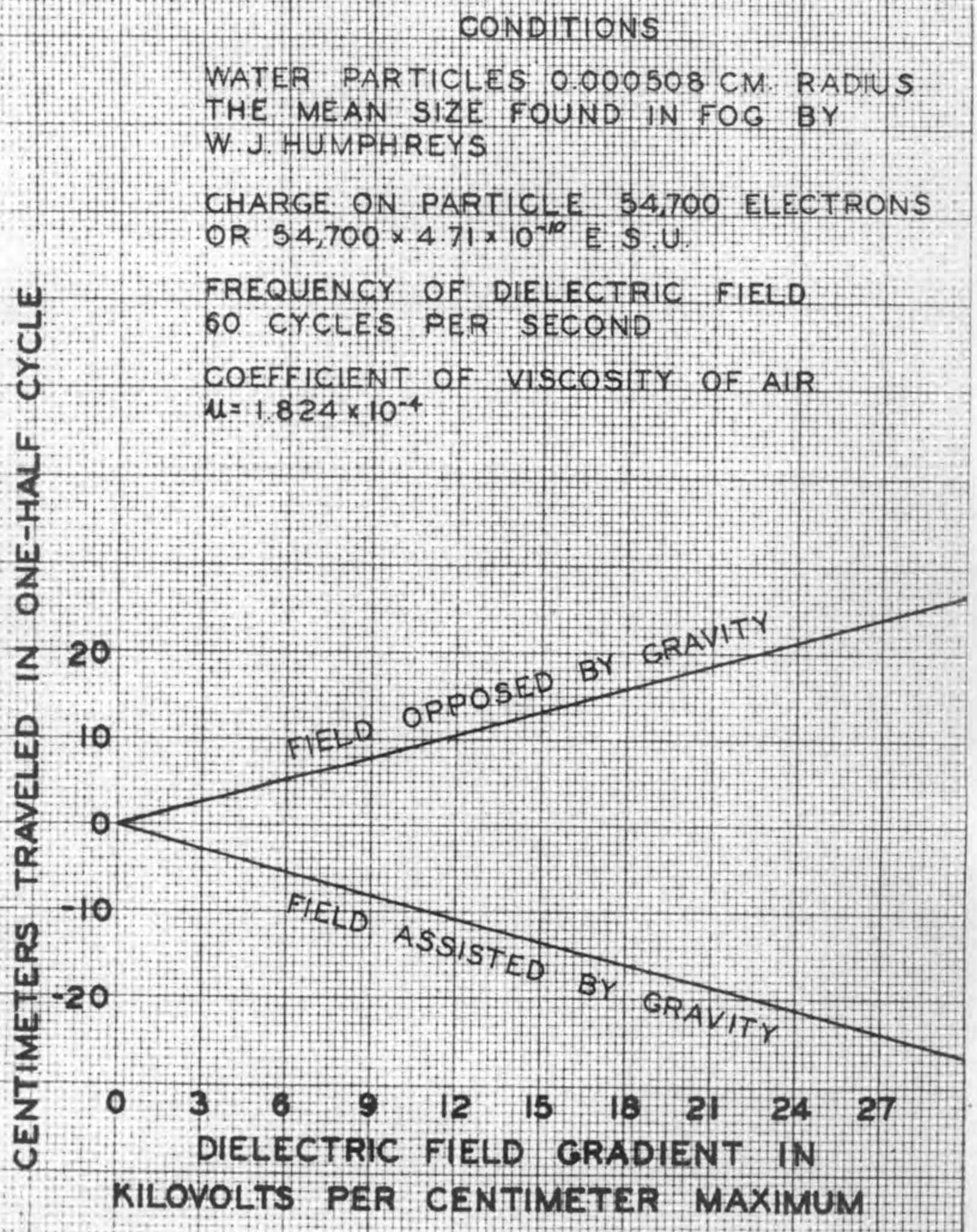


FIG. 7

DISTANCE TRAVELED IN ONE-HALF CYCLE BY A CHARGED WATER PARTICLE IN AIR UNDER THE INFLUENCE OF AN ALTERNATING DIELECTRIC FIELD

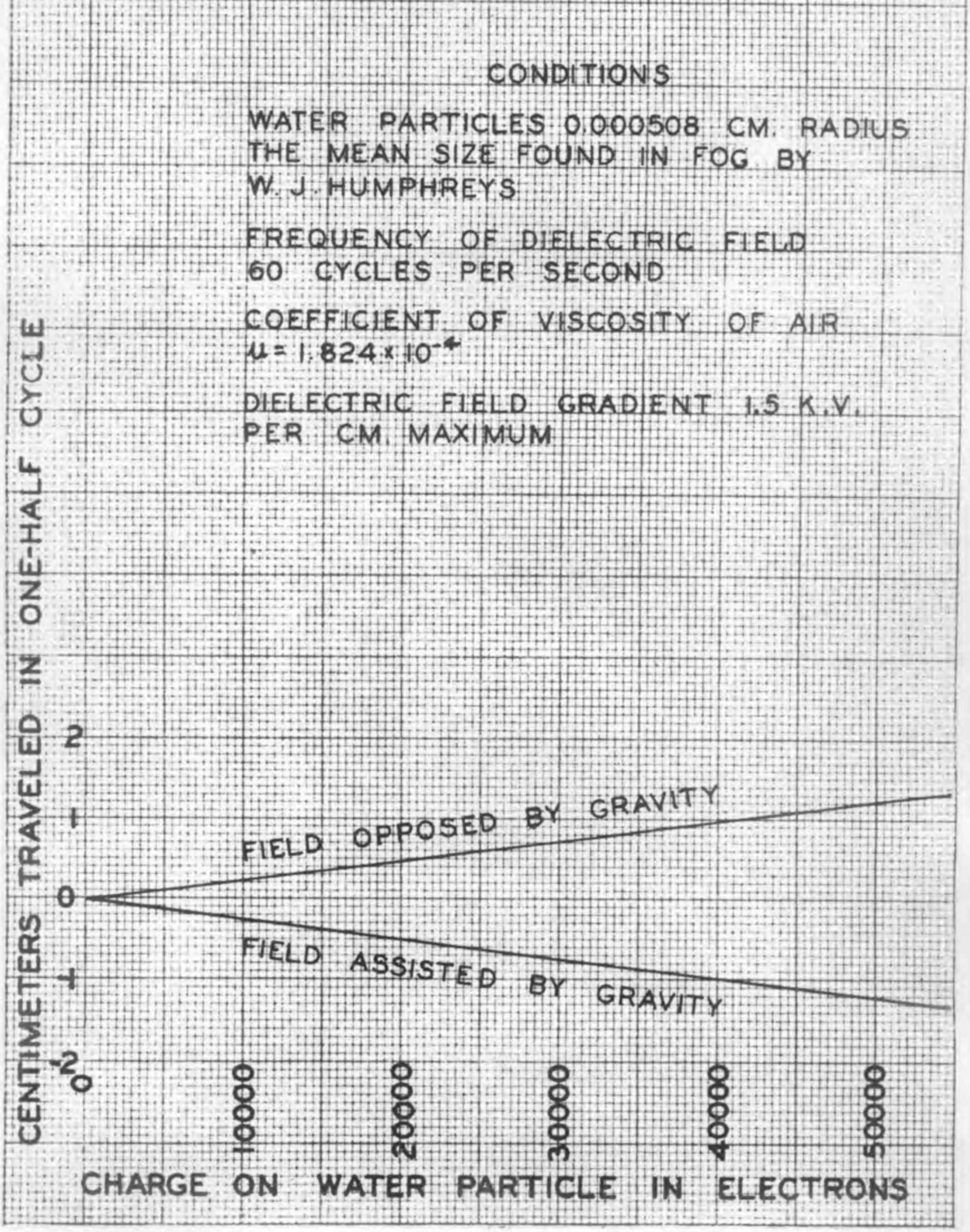
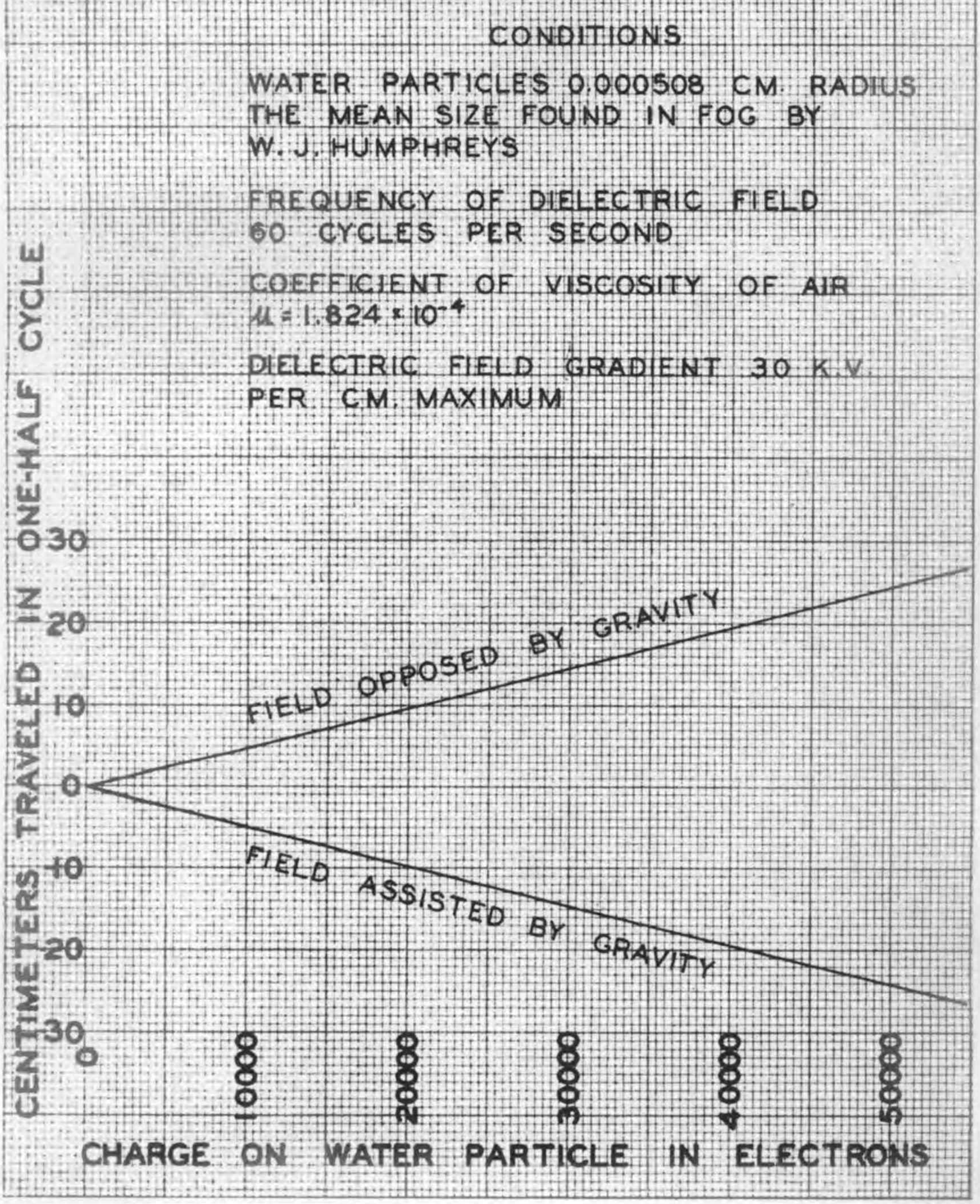


FIG. 8

DISTANCE TRAVELED IN ONE-HALF CYCLE BY A CHARGED WATER PARTICLE IN AIR UNDER THE INFLUENCE OF AN ALTERNATING DIELECTRIC FIELD



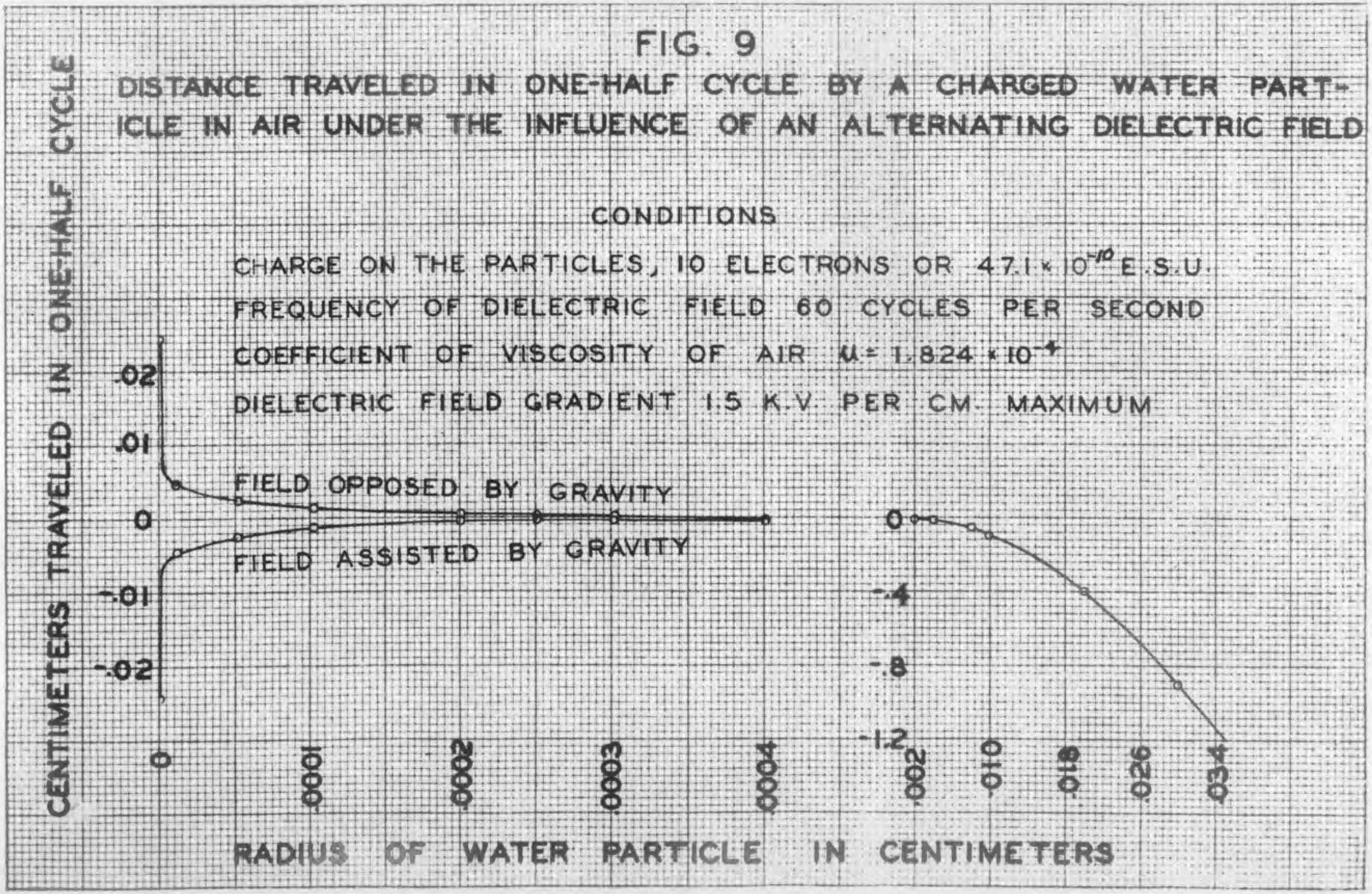


FIG. 9
DISTANCE TRAVELED IN ONE-HALF CYCLE BY A CHARGED WATER PARTICLE IN AIR UNDER THE INFLUENCE OF AN ALTERNATING DIELECTRIC FIELD
CONDITIONS
CHARGE ON THE PARTICLES, 10 ELECTRONS OR 47.1 × 10⁻¹⁰ E.S.U.
FREQUENCY OF DIELECTRIC FIELD 60 CYCLES PER SECOND
COEFFICIENT OF VISCOSITY OF AIR μ = 1.824 × 10⁻⁴
DIELECTRIC FIELD GRADIENT 1.5 K.V. PER CM. MAXIMUM
FIELD OPPOSED BY GRAVITY
FIELD ASSISTED BY GRAVITY
CENTIMETERS TRAVELED IN ONE-HALF CYCLE
.02
.01
0
-.01
-.02
0
-.4
-.8
-1.2
0
.0001
.0002
.0003
.0004
.002
.010
.018
.026
.034
RADIUS OF WATER PARTICLE IN CENTIMETERS

APPENDIX I

DERIVATION OF THE EQUATION FOR THE DISTANCE TRAVELED BY A CHARGED WATER PARTICLE IN AN ALTERNATING ELECTRIC FIELD

$$e_1 = \frac{4\pi}{3}\left(\frac{9\mu}{2}\right)^{3/2}\left(\frac{1}{g\rho}\right)^{1/2}\frac{V_o V_g^{1/2}}{F}$$

$$e_1 = 5.04 \times 10^{-10}$$

μ = COEF. OF VISCOSITY OF AIR = 1.824×10^{-4}

g = 980.6 CM./SEC.^{2}

ρ = GRAMS/CM.^{3} = 1 FOR WATER

$$V_g = \frac{2 g r^2 \rho}{9 \mu} = \frac{2 \times 980.6\ r^2}{9 \times 1.824 \times 10^{-4}} = 120\,000\ r^2$$

$$(V_g)^{1/2} = 346\ r$$

$$V_o = \frac{V_g + V_F}{n} = \frac{120\,000\ r^2 + V_F}{n}$$

n = NUMBER OF ELECTRONS ON DROP

$$F = \frac{\text{PLATE VOLTAGE}}{\text{CM. BETWEEN PLATES} \times \text{CON. FACTOR}} = \frac{e_p}{300}$$

LET $K = \frac{4\pi}{3}\left(\frac{9\mu}{2}\right)^{3/2}\left(\frac{1}{g\rho}\right)^{1/2} = 3.12 \times 10^{-6}$

$$e_1 = K\frac{V_o V_g^{1/2}}{F} = 3.12 \times 10^{-6}\,\frac{\left(\frac{120\,000\ r^2 + V_F}{n}\right) 346\ r}{e_p/300}$$

$$V_F = \frac{15.55 \times 10^{-10}\ n\, e_p}{r} - 120\,000\ r^2$$

VELOCITY DUE TO ELECTRIC FIELD: $V_F + V_g = V_{eF}$

$$V_{eF} = \frac{15.55 \times 10^{-10} \, n \, e_p}{r}$$

$$\frac{ds}{dt} = V_{eF} = \frac{15.55 \times 10^{-10} n e_p}{r}$$

$$e_p = E_m \text{ SIN } \omega t$$

$$\therefore \frac{ds}{dt} = \frac{15.55 \times 10^{-10} n E_m \text{ SIN } \omega t}{r}$$

$$S = \frac{15.55 \times 10^{-10} n E_m \text{ COS } \omega t}{r \omega} + C$$

WHEN $t = 0 \quad S = 0$

$$\therefore C = \frac{15.55 \times 10^{-10} n E_m}{r \omega}$$

AND $$S = \frac{15.55 \times 10^{-10} n E_m}{r \omega} + \frac{15.55 \times 10^{-10} n E_m}{r \omega}$$

$$= 2\left(\frac{15.55 \times 10^{-10} n E_m}{120 \pi r}\right)$$

$$= \frac{8.25 \times 10^{-12} n E_m}{r}$$

IN THE ABOVE EQUATIONS

S = DISTANCE

ω = ANGULAR VELOCITY = 120π

$t = \frac{1}{120}$

$\omega t = \pi$

APPENDIX II

DERIVATION OF THE EQUATION FOR THE NUMBER OF ELECTRONS ON A CHARGED WATER PARTICLE WITH A SURFACE GRADIENT OF 30 KV.

$$C = 4\pi \hbar K \frac{R\,r}{R-r}$$

$$= 4\pi \hbar K r \qquad \text{FOR LARGE RATIOS OF } \frac{R}{r}$$

$$\text{GRADIENT} = \frac{D}{K} = \frac{\psi / 4\pi r^2}{K} = 30 \times 10^3$$

$$\psi = 4\pi r^2 \times 30 \times K \times 10^3 = 120\pi r^2 K \times 10^3$$

$$e = \frac{\psi}{C} = \frac{120\pi r^2 K \times 10^3}{4\pi r \hbar K} = \frac{30 r \times 10^3}{\hbar}$$

$$Q = Ce = 4\pi \hbar K r \frac{30 r \times 10^3}{\hbar} = 120\pi K r^2 \times 10^3$$

$$= 120\pi K r^2 10^3 \times 3 \times 10^9 \text{ E.S.U.}$$

$$= 360\pi K r^2 10^{12} \text{ E.S.U.}$$

$$K = 8.84 \times 10^{-14} \text{ FARADS PER CM}^3$$

$$\text{NUMBER OF ELECTRONS} = \frac{Q}{4.71 \times 10^{-10}}$$

$$= \frac{360\pi K r^2 10^{12}}{4.71 \times 10^{-10}} = \frac{360\pi r^2\, 8.84 \times 10^{-14} \times 10^{12}}{4.71 \times 10^{-10}}$$

$$= \frac{360\pi r^2\, 8.84 \times 10^8}{4.71} = 2120\, r^2 \times 10^8$$