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The subject of high-voltage measurement by the use of the sphere-gap has been receiving considerable attention in the past few years. Articles dealing with sphere-gaps and the problems that have developed in connection with their use in voltage measurement have been appearing frequently in the current electrical periodicals. There is a real need for further information on the sphere-gap, and in particular on its polarity characteristics.

The polarity of a sphere-gap sparkover is determined by the polarity of the voltage across the gap at the time of sparkover, with the ungrounded sphere taken as reference. If sparkover occurs when the ungrounded sphere is positive then it is a positive sparkover; conversely, if the ungrounded sphere is negative then the sparkover is negative. The polarity characteristic of a sphere-gap at a given spacing is measured by the tendency of the sparkovers to be all positive, all negative, or a certain percentage of each polarity.

There is a direct correlation between sparkover polarity and sparkover voltage, for if the sparkovers are found to be 100% negative then it follows that the negative sparkover voltage is lower than is the positive sparkover voltage. The converse of course is true.

Since a sphere-gap is a voltage measuring device all factors entering in to affect the voltage at which sparkover will occur must be taken into consideration if accurate measurement is to be obtained. The factors which enter are, (1)sphere size, (2) sparking distance, (3) distance from ground plane to the gap, (4) atmospheric conditions, (5) shape of impressed voltage wave, and (6) polarity of sparkover.

It is the purpose of this thesis to present the results of a study made of polarity characteristics of the 6.25-cm. sphere-gap and to present a method of shielding whereby the polarity characteristics can be controlled. This control will of course be used in such a way as to make the sparkover polarities occur approximately in equal numbers over the range of sparking distance to be used. With such a polarity distribution the positive and negative sparkover voltages will be the same at all values of sparking distances, and it wil then be unnecessary to take the polarity factor into account.

By experimental means a method of shielding is devised which will give the maximum shielding effect with the simplest in shielding apparatus. The sphere gap shielded in the devised manner is then calibrated on both 60-cycle voltage and on impulse voltages of both polarities.

THE CONTROL OF SPHERE-GAP POLARITY CHARACTERISTICS

By

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CONTENTS.

ILLUSTRATIONS.

THE CONTROL OF SPHERE-GAP POLARITY CHARACTERISTICS

I. Introduction

Synopsis

The subject of high-voltage measurement by the use of the sphere-gap has been receiving considerable attention in the past few years. Articles dealing with sphere-gaps and the problems that have developed in connection with their use in voltage measurement have been appearing frequently in the current electrical periodicals. There is a real need for further information on the sphere-gap and in particular on its polarity characteristics. It is the purpose of this thesis to present the results of a study made of polarity characteristics of the sphere-gap, and to present a method of shielding the sphere-gap whereby the polarity characteristics can be controlled. By experimental means a method of shielding is devised which will give the maximum shielding effect with the simplest in shielding apparatus. The gap shielded in the devised manner is then calibrated on 60-cycle voltage, and for impulse voltage of both polarities.

The Spark-Gap.

The chief purpose of the measurement of high-voltage is to provide data for the correct design of insulation to withstand that high-voltage. This insulation may be in the form of a liquid, a solid, or a gas; such as transformer oil,porcelain for line insulators, and air which after all is the most used of all the types of insulations. The important point to be taken into consideration in the design of insulation is that the failure of the insulation is a function of the crest value of the applied voltage. It is evident then, that the crest value of the voltage is the thing desired. It is for this reason that the gap type of device has been used so much for the measurement of high-voltage, since it measures the crest voltage.

Spark-gaps of one type or another have been used for many years for voltage measurement. The needle-gap was the first type to be developed and was used a great deal prior to 1914. The needle-gap was not satisfactory since it was inconsistent, required a large amount of space to isolate it from the affect of surrounding objects, and the points had to be replaced frequently. The inconsistency of the needle-gap was due to several factors among which were; influence of humidity and air density, oscillations on the circuit, and the large time-lag of the gap. There are of course other types of spark-gaps such as point to plane, which has an undesirable unsymmetrical field, and the plane to plane gap which is not good because of the concentration of dielectric flux at the edges of the planes.

The sphere-gap.

The use of the sphere type of spark-gap dates back to the work of C.P.Steinmetz in 1898.(16) He used spheres as electrodes in the determination of the dielectric strength of air. In 1906 A.Russell (15) presented his work on the strength of air in which he used spherical electrodes. He presented expressions for the maximum value of electric intensity between two spheres, which was a proof by a different method of expressions previously (1860) obtained by Kirchoff. During 1912 and 1913 G.R.Dean presented three articles (5,6) dealing with the sphere-gap. These articles were a mathematical analysis of the field of the sphere-gap and contained a great deal of information essential to the use of the sphere-gap.

S.W.Farnsworth and C.L.Fortescue (8) in 1910 made a sphere-gap which they used in some work they were doing on air strength measurements and were so impressed by the consistency of the sphere-gap that they recommended its use as a standard rather than the needle-gap. In the sphere-gap the sparkover preceded corona formation if the gap was less than diameter spacing, and for this reason humidity had no affect on the sparkover. Other factors favoring the sphere-gap were its short time lag, the fact that the air density correction could be easily made, and the convenience of its use since it could be used for thousands of sparkovers without any harm to the sphere surface. Furthermore the sphere-gap due to the shorter sparking distance for a given voltage than for the needle-gap does not require the clearance from surrounding objects that is required by the needle-gap.

L.W.Chubb and C.L.Fortescue(4) immediately set about to the determination of calibration curves for the sphere-gap. These calibration curves were determined at normal-frequency alternating voltage of from 25 to 60 cycles per second, and were determined for the three sizes of spheres that had been suggested by Farnsworth and Fortescue. F.W.Peek Jr. (13) did a great deal of work on the determination of the characteristics of the sphere-gap. He developed the air density correction factor, developed equations for calculating the theoretical sparkover curves for various spacings, radii, and air densitys. Peek's paper was very thorough in its treatment of the characteristics of the sphere-gap, and together with the recommended sphere-gap calibrations, marked an important advance in the accuracy of high-voltage measurement. In 1913 the calibration curves for the 25-cm.,37.5-cm., and 50-cm. sphere-gaps were suggested as standard in a paper (4) presented before the American Institute of Electrical Engineers. The standards committee realized the superiority of the sphere-gap over the needle-gap, and also realized the thoroughness of the work of Chubb and Fortescue, and in 1914 the curves were adopted and included in the A.I.E.E. Standards #4.

At the time of the adoption of the calibration curves for the sphere-gap, the use of high-voltage for long distance transmission of power was developing rapidly. There was developed a system of large generating plants supplying large areas. This of course meant that long transmission lines were necessary, with the resultant increase in the line voltage. Even to-day with the erection by the government of large plants for the generation of electrical energy from water power, the length of transmission lines is constantly being increased, and the operating voltages are being increased to higher values as rapidly as high-voltage research and engineering development makes such increases economically feasible. The design of the transmission line, the line insulation, circuit breakers, transformers, and the generators for the modern system operating at high voltage presents problems that can be solved only by a correct application of the right insulation. In modern electrical systems continuity of service is of prime importance and a great deal of study has been given to the development of equipment to the end that the number of failures will be reduced to a minimum. Through the correct design of insulation the gaseous, self healing dielectrics are made to act as safety valves, protecting the solid and liquid dielectrics from breakdown. Provision is thus made for taking care of the failures against which it is uneconomical to design against. It is in instances such as these that the accurate measurement of the dielectric strength of insulation is so important.

II. The Polarity Effect in Sphere-Gaps.

The influence of polarity.

In 1930, F.O.McMillan and E.C.Starr (11) presented a paper before the American Institute of Electrical Engineers which dealt with the influence of polarity on high-voltage discharges. They pointed out that polarity has a distinct affect upon the sparking voltages of all types of gaps, and emphasised that impulse measurements with grounded sphere-gaps will be seriously in error unless the effects of polarity are taken into consideration. The error in the impulse measurements was due to the fact that the measurements were made on a unidirectional voltage on a grounded sphere-gap, and then the magnitude of the voltage was determined by the use of the standard calibration curve for the sphere-gap used, which calibration curve it will be remembered was based on the early experimental work using normal frequency alternating voltage for the calibration. In using a calibration curve which was determined by the use of an alternating voltage of low frequency for the evaluation of impulse data it must be assumed that the impulse voltage for sparkover is the same for the positive half of the wave as it is for the negative half.If the voltage required for sparkover on the positive half of the wave for an alternating voltage or for the positive impulse in unidirectional discharges is different than that required for the negative half cycle or discharge, then the use of the standard calibration curve for the evaluation of impulse voltages will lead to serious errors. That this is exactly the situation will now be shown.

In the paper by McMillan and Starr, there are given data showing the polarity distribution as a function of the gap spacing. Figure 6 of this thesis shows the same effect, namely that there is a range of sparking distances over which the sparkovers are all negative. At spacings greater and smaller than this range positive sparkovers occur. This phenomenon of the variations of the polarity of the voltage wave at the time of sparkover with the spacing is called the polarity characteristic of the sphere-gap. J.R.Meador (12) of the General Electric Company has done considerable work on the calibration of the sphere-gap and has determined the polarity characteritics of the standard sphere-gaps up to and including the 200 cm. sphere-gap. They show the same characteristic range of 100 per cent negative sparkovers. There is only one conclusion that can be drawn from this experimental fact, and that is that in this range of 100 per cent negative sparkovers the negative sparkover voltage is less than the positive sparkover voltage. This theory can be tested by an impulse test of the sphere-gap made in such a manner that the polarity can be either controlled or determined. This was done by McMillan and Starr and it was found that as was expected the sphere-gap had two calibration curves, one for positive impulse discharges and the other for negative impulse discharges. These two curves are together at short sparking distances but as the distance is lengthened the negative sparkover voltage curve drops below the positive curve and remains below for the major portion of the sparking distance. At a large spacing however the negative sparkover voltage curve takes a sudden turn upward and crosses the positive curve. From these two calibration curves it is a simple matter to explain the polarity characteristic curves obtained using 60 cycle voltage. At small spacings the two curves are together and both positive and negative sparkovers occur. However, as the spacing is increased the negative sparkover voltage curve begins to drop below the positive curve and it is obvious that as the voltage is increased under these conditions the sparkover will occur on the negative half cycle of the wave since the negative sparkover voltage is lower than the positive. Thus the range of 100 per cent negative sparkovers is accounted for. At large gap spacings the negative sparkover voltage curve crosses the positive curve, therefore the positive sparkover voltage is the lower and the sparkovers will of course be 100 per cent positive.

This shows conclusively that there is some influence present in the sphere-gap which causes the negative sparkover voltage to be lower than the positive sparkover voltage over the major portion of the sparking distances, and that probably there is a second affect which causes the sudden increase in the negative sparkover voltage at a large spacing. The explanation of this polarity effect in sparkover has been given by Dr. L.E.Reukema (14) and also by McMillan and Starr in the paper previously referred to. The action taking place is as follows.

Cause of the Polarity Effect.

Consider a sphere-gap with the lower sphere grounded and with the sparking distance considerably less than the diameter of the spheres. When voltage is applied to the gap a dielectric field will be set up between the two spheres which will be somewhat unsymmetrical with respect to the gap due to the influence of the ground plane. A part of the dielectric flux from the upper sphere will terminate on grounded objects extraneous to the gap and as a result there will be a greater concentration of flux at the upper sphere. Since the potential gradient is proportional to the dielectric flux density it is then evident that there will be a greater potential gradient at the upper sphere than at the lower sphere. The larger the spacing of the gap the greater will be the distortion of flux and consequently the greater will be the difference in potential gradient at the two sphere surfaces. The voltage applied to the gap in addition to setting up this unsymmetrical dielectric field also has its affect on the free electrons existing in the gap. These free electrons are present in a fairly constant number in all air and are produced in the following ways; radiation from radioactive substances in the earths atmosphere and in the earths surface;ionization due to radiation from the sun, and; cosmic radiation. These free electrons which are present in the air between the spheres are at once repelled from the negative sphere, which here will be assumed to be the upper ungrounded sphere. If the voltage gradient is sufficiently high these electrons will attain ionizing speeds and will produce more electrons and positive ions by ionization of the air molecules. The newly formed electrons will also be repelled from the negative sphere and they too will ionize the air molecules as they travel toward the positive sphere. The many positive ions which are formed by this avalanche ionizing action are attracted to the negative sphere but due to their large relative size and immobility form a positive space charge near that sphere. Now it will be remembered that this upper negative sphere has a higher potential gradient than does the lower sphere, and due to the fact that the sphere is negative a positive space charge is formed in this high gradient field. Positive ions and electrons are formed at the negative sphere perhaps due to ionization by the positive ions, or by electron extraction from the sphere itself. The electrons formed travel across the gap to the positive sphere, each one forming many positive ions as it goes.When the positive ion concentration in the gap has been built up in this manner to a certain point the space is no longer insulating and current flows between the spheres through the positive ions. This constitutes a breakdown and was seen in this case to begin from the negative sphere.

Reversing the polarity of the sphere-gap we have the upper ungrounded sphere positive. The electrons will be attracted to this sphere, and the positive ions which are formed by an avalanche action as in the preceding case are attracted to the lower grounded sphere. The positive ion space charge will be formed as before but in this case it is important to notice that it is formed at the sphere which has the lower potential gradient of the two. The ionization is thereby reduced and the formation of positive ions is very materially retarded from that of the former case. Since the breakdown of the gap consists of a current flow through the positive ions, it is evident that breakdown will take place at a lower gap potential when the upper ungrounded sphere is negative. This explains why the negative sparkover voltage of a sphere-gap is lower than the positive sparkover voltage over the major portion of the range of sparking distances.

At short sparking distances the distortion of the field by grounded objects has very little effect on the gradients at the sparking surfaces of the spheres. Consequently these gradients are so near equal that the breakdown will take place at the same voltage for both positive and negative directions of voltage.

For long sparking distances of the order of 1.4 to 1.5 times sphere diameter the negative sparkover voltage curve takes a sudden upward turn and crosses the positive sparkover voltage curve. At these large spacings the formation of corona precedes the breakdown and the characteristics of the gap are materially altered. The gap then takes on the characteristics of a gap with electrodes having a marked dissimilarity. The upper sphere in corona acting as a point and the lower sphere and ground plane act as a composite electrode. The condition is a compromise between a point to sphere gap and a point to plane gap. On page 567 of Volume II of, "Conduction of Electricity Through Gases" by J.J. and G.P.Thomson, are shown curves of breakdown and discharge voltages for alternating voltages applied to a point and to spheres of various radii, the other electrode being the ground plane. It is interesting to note that there is a constant ratio of 1.44 between the spacing at which the initial discharge voltage is equal to the point to plane voltage and the diameter of the sphere. This is approximately the same ratio of spacing to sphere diameter at which the negative sparkover voltage curve takes the turn upward, thus substantiating the theory given that the gap at these large spacings assumes the characteristics of the point to plane gap. The range of spacing in which this phenomenon occures is not of practical importance since the sphere-gap is never used to measure voltage at these spacings.If the voltage is in this range a sphere-gap with spheres of larger diameter must be used to obtain reliable measurements.

The Polarity Effect as a Factor in the Inaccuracies of High-Voltage Measurement.

The polarity effect in sphere-gaps, which was not considered when the gaps were originally calibrated, has lead to the necessity for the re-calibration of the grounded sphere-gaps taking the polarity effect into consideration. A report (18) by the lightning and insulator subcommittee of the power transmission and distribution committee of the American Institute of Electrical Engineers in 1934 revealed that the discrepencies in insulator flashover voltages were, for similar insulators, something to be alarmed about. Tests were made on similar insulators to determine both 60 cycle and impulse flashover voltages, and the results differed by as much as 30 per cent for the 60 cycle tests and by as much as 60 per cent for the impulse tests. These discrepencies in the insulator flashover voltages were attributed in 60 cycle case to three factors. Quoting;

1. Moisture content of the air.
2. Measuring instruments; spheres or needle gaps.
3. Sphere-gap calibration.

For the impulse tests the discrepency was attributed to seven factors. Quoting;

1. Use of different test waves, and of different designations for the same wave.
2. Failure to designate flashover as front, crest or tail of wave flashover.
3. Failure to observe polarity effect of test wave.
4. Inaccuracies in measuring test voltages.
5. Presence of oscillations in the test wave.
6. Questionable reproduction of the actual applied voltage wave to the different types of potentiometers, and oscillations in the test circuit.
7. Air conditions; density and humidity.

It will be noticed that in both the 60 cycle and impulse testing the matter of sphere-gap calibration, and of the polarity effect with both of which this thesis is particularly concerned, enter as important causes of the inaccuracies of this high-voltage measurement.

A great deal of work has been done in the past two years on the re-calibration of the sphere-gap, and the reports of this work have been appearing at frequent intervals in the current electrical literature. McMillan and Starr were the first to point out that polarity effects must be taken into consideration in voltage measurement by the use of the sphere-gap, particularly for impulse measurements. This appeared in 1930. J.T.Lusignan (9) had previously (1929) observed the polarity characteristics of a high-voltage a-c. flashover for the 50-cm. sphere-gap at two different spacings, but made no correlation of it to the problem of high-voltage measurement. Early in 1933 the lightning and insulator subcommittee of the A.I.E.E. made a report (17) giving recommendations for impulse testing.

Some of the recommendations were not approved, especially by one, F.D.Fielder who answered with an article (7) stressing the point that better standards were necessary for accurate surge testing. In June, 1934 J.R.Meador reported the results of his work on the re-calibration of the sphere-gap. Meador makes the following statement in the introduction to the paper previously referred to, "It would seem that enough evidence has accumulated in the past few years to justify a general revision and extension of the A.I.E.E. sphere-gap calibrations." His paper presents calibration curves for sphere-gap sparkover for 60 cycle voltages and for impulse voltages of both polarities for the standard sizes of sphere-gaps up to and including the 200-cm. spheres. At the same time that Meador's paper appeared, P.L.Bellaschi and P.H.McAuley (2) presented impulse calibration curves for sphere-gaps, derived from their experimental work. Their calibrations agreed very well with those of Meador, but there were differences of the order of 2 to 5 per cent at large gap spacings. In England as well as in America the necessity for the re-calibration of the sphere-gap was realized. Quoting from a paper by T.E.Allibone, W.G.Hawley, and F.R.Perry (1) which appeared in November 1934.

> "In general when measuring impulse voltages spheres should not be used at a setting greater than the radius of the sphere, as with one sphere earthed the breakdown voltage under a positive impulse may begin

> to diverge from those obtained with a negative impulse, and at spacings equivalent to diameter both polarity values may differ from the normal frequency breakdown voltages."

In March 1935 Bellaschi and W.L.Teague (3) presented their results on the investigation of the characteristics of sphere-gaps on very short impulses. Their results show that a given size of gap requires a higher crest voltage for sparkover as the time from zero to sparkover is decreased. In other words, the impulse ratio of the sphere-gap which is a measure of the time lag, becomes larger as the steepness of the wave front is increased.

III. <u>The Control of the Polarity Effect in Sphere-Gaps.</u>

Theory of Method of Control.

From the consideration of the fundamental cause of the polarity effect in sphere-gaps a method was conceived for its elimination and the resulting elimination of polarity differences in the measurement of high-voltage by the use of the sphere-gap. The accomplishment of such a result if done in a fairly simple manner should provide a measuring gap that is more consistent than the ordinary sphere-gap in 60 cycle measurement, and more important would allow the gap to be used to full diameter spacing without the necessity for the determination of polarity and the use of two calibration curves. With the sphere-gap as now used a correlation of data for all standard sizes of spheres shows that 30 per cent of diameter spacing cannot be exceeded without taking polarity into consideration.

As has been seen the polarity effect is due to the unsymmetrical field existing between the two spheres which causes the potential gradient at the upper sphere to be greater than that at the lower grounded sphere. The affect of the ground plane is the disturbing factor. One solution of the problem would be to isolate both spheres from ground but this is not practical since transformers and other equipment would of necessity be insulated from ground. Also the gap would have to be placed so that grounded objects such as walls, ceilings, etc. would not affect the gap.

The method here used is that of shielding the spheres in such a way that the field of the gap is made very nearly symmetrical. The method is to place a metallic shield in the form of a toroid around the spheres. With such an arrangement the flux from the upper sphere terminates on the lower shield and on the lower sphere. Practically all of the flux to ground is from the shields. The concentration of flux on the sparking surface of each sphere is thus made essentially the same, with the resultant equalization in the potential gradient at these points. When the potential gradient has been made equal on the two spheres the breakdown will take place at the same gap potential for both positive and negative voltages.

The shields used were cast aluminum with brass brackets provided for holding the shields on the sphere shanks in position around the spheres. Each shield could be raised or lowered a certain amount, with respect to the sphere. The dimensions of the shield are shown in Figure 1 and the shields are pictured in Figures 4 and 5. The shields were fitted to a 6.25-cm. sphere-gap and this size of spheres was used throughout the experimental work.

Experimental Verification of the Theory of the Shields.

The effectiveness of the shields was tested by determining the polarity characteristics for the 6.25-cm. sphere-gap shielded in any one of the various manners. The voltage for sparkover was supplied by a 110,000 volt testing transformer which in turn was supplied by one phase of a 30 Kw. 220/127 volt alternator. The transformer was loaded to improve the output wave shape by means of a water tube resistor made up of a section of rubber hose through which water was circulated to maintain a constant temperature. The output voltage of the transformer was controlled by means of a rheostat in the field of the alternator exciter. The high-voltage line from the transformer to the sphere-gap was made of half-inch pipe polished to prevent as far as possible the formation of corona on the circuit. The polarity of sparkover was determined by means of the Lichtenberg Figure Polarity Indicator. The complete setup is shown by diagram in Figure 2 and by picture in Figure 3.

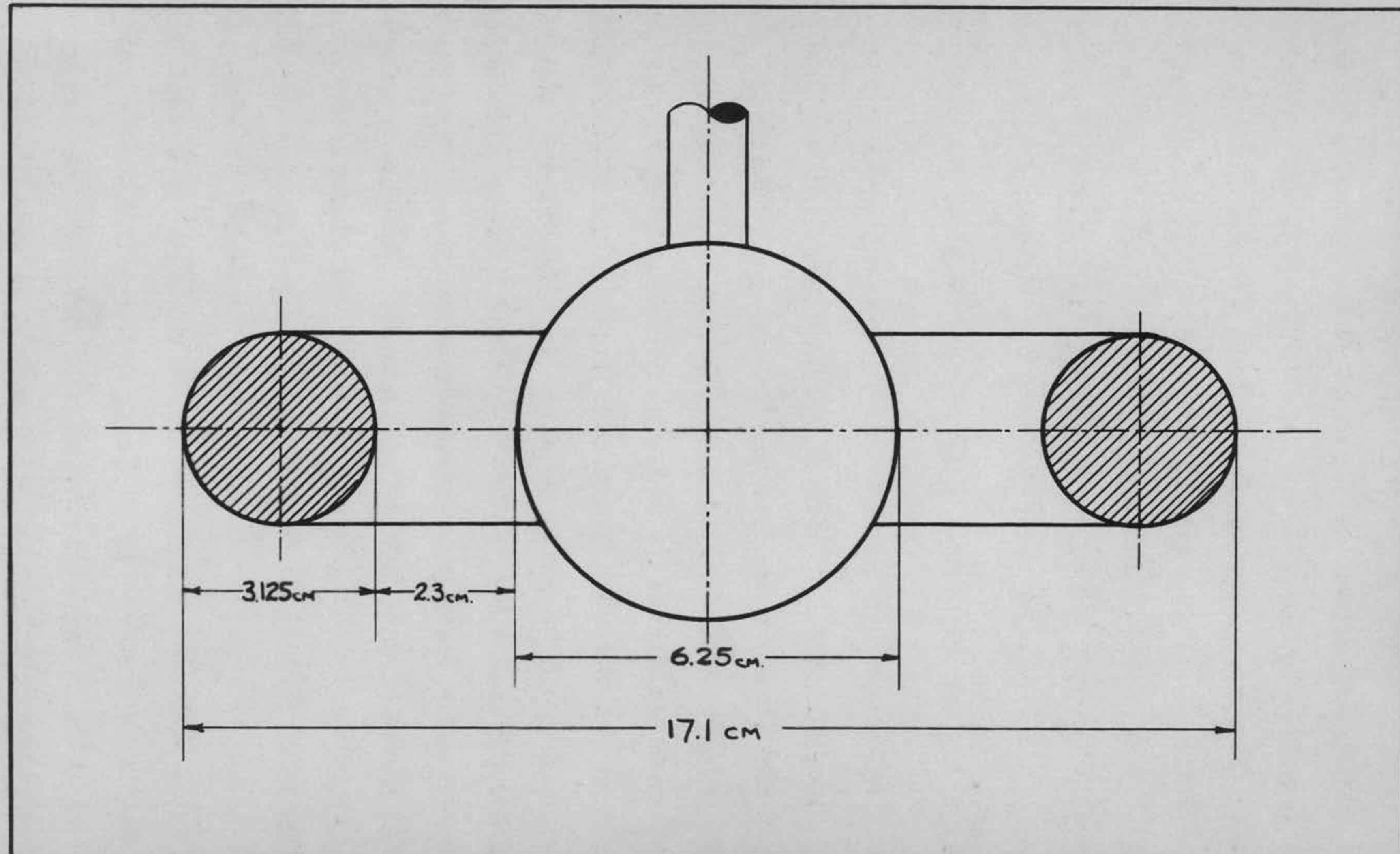


FIGURE 1
SHIELD DIMENSIONS

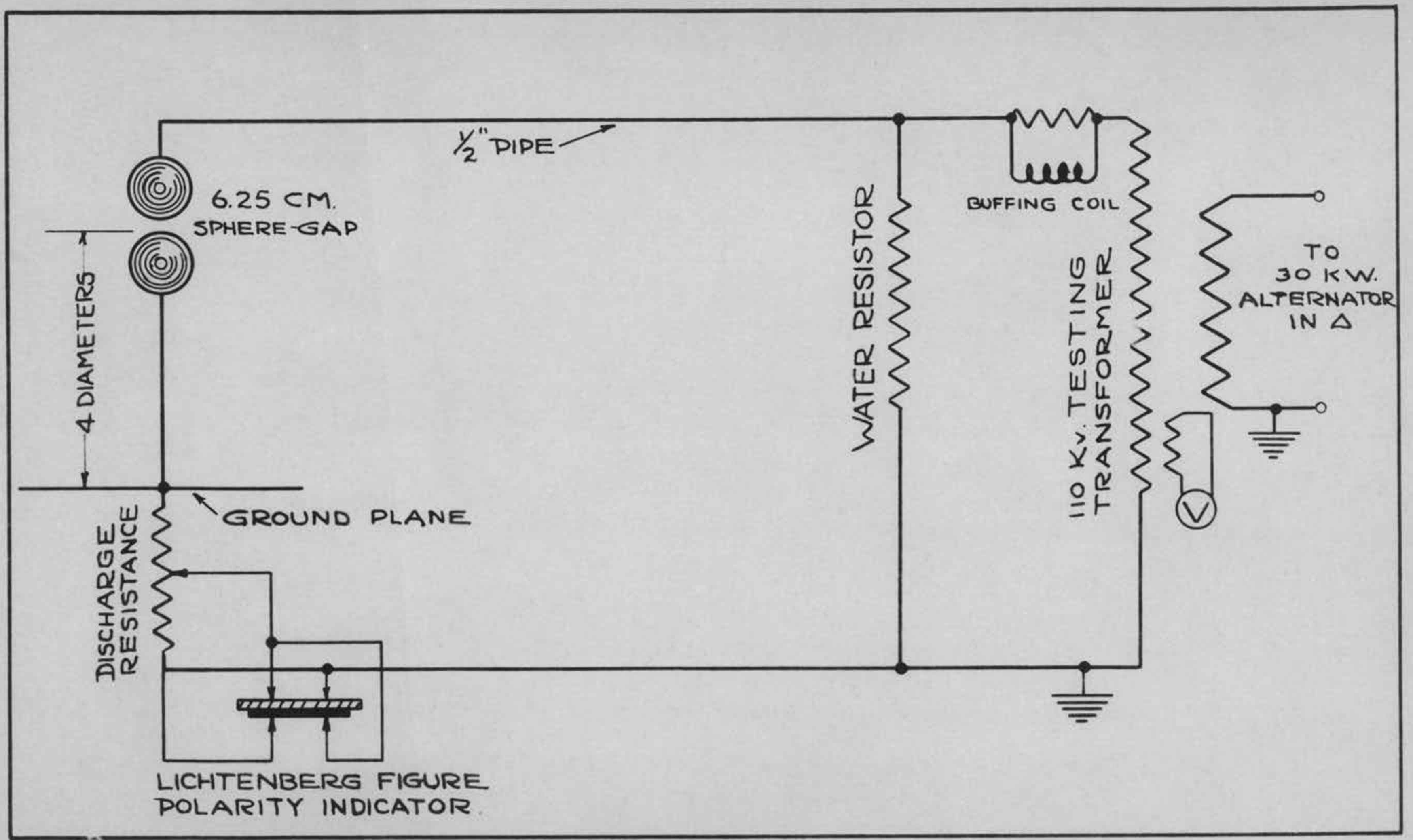


FIGURE 2

CIRCUIT FOR OBTAINING POLARITY CHARACTERISTICS OF A SPHERE-GAP.

FIG.3 LABORATORY APPARATUS FOR DETERMINING POLARITY CHARACTERISTICS OF 6.25-cm.

SPHERE-GAP.

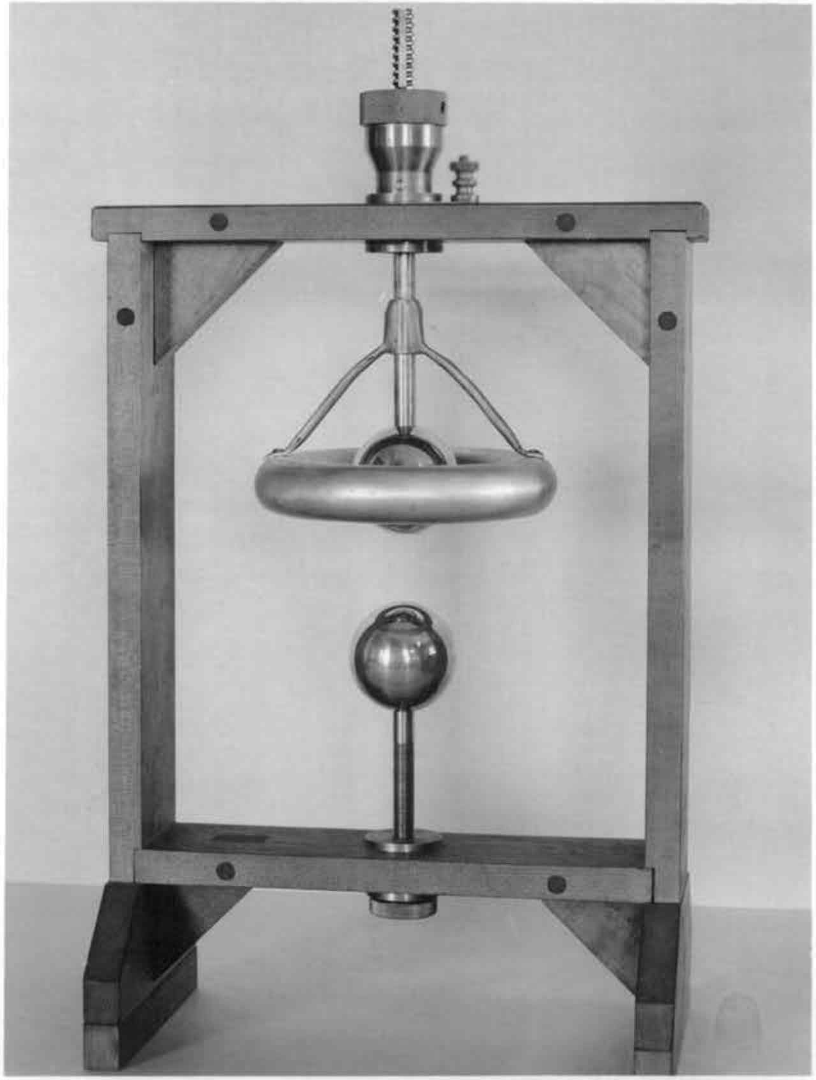


FIG.4 SHIELDED 6.25-cm. SPHERE-GAP, USING UPPER SHIELD ONLY.

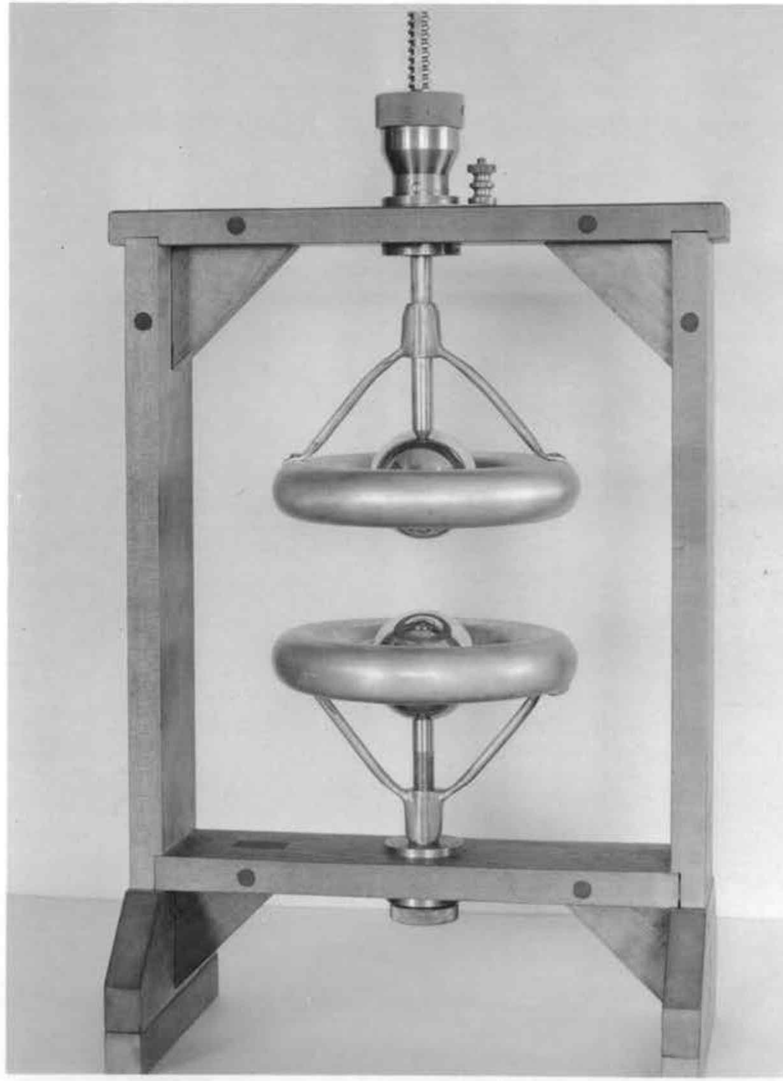


FIG.5 SHIELDED 6.25-cm. SPHERE-GAP, USING BOTH SHIELDS.

Unshielded Sphere-Gap.

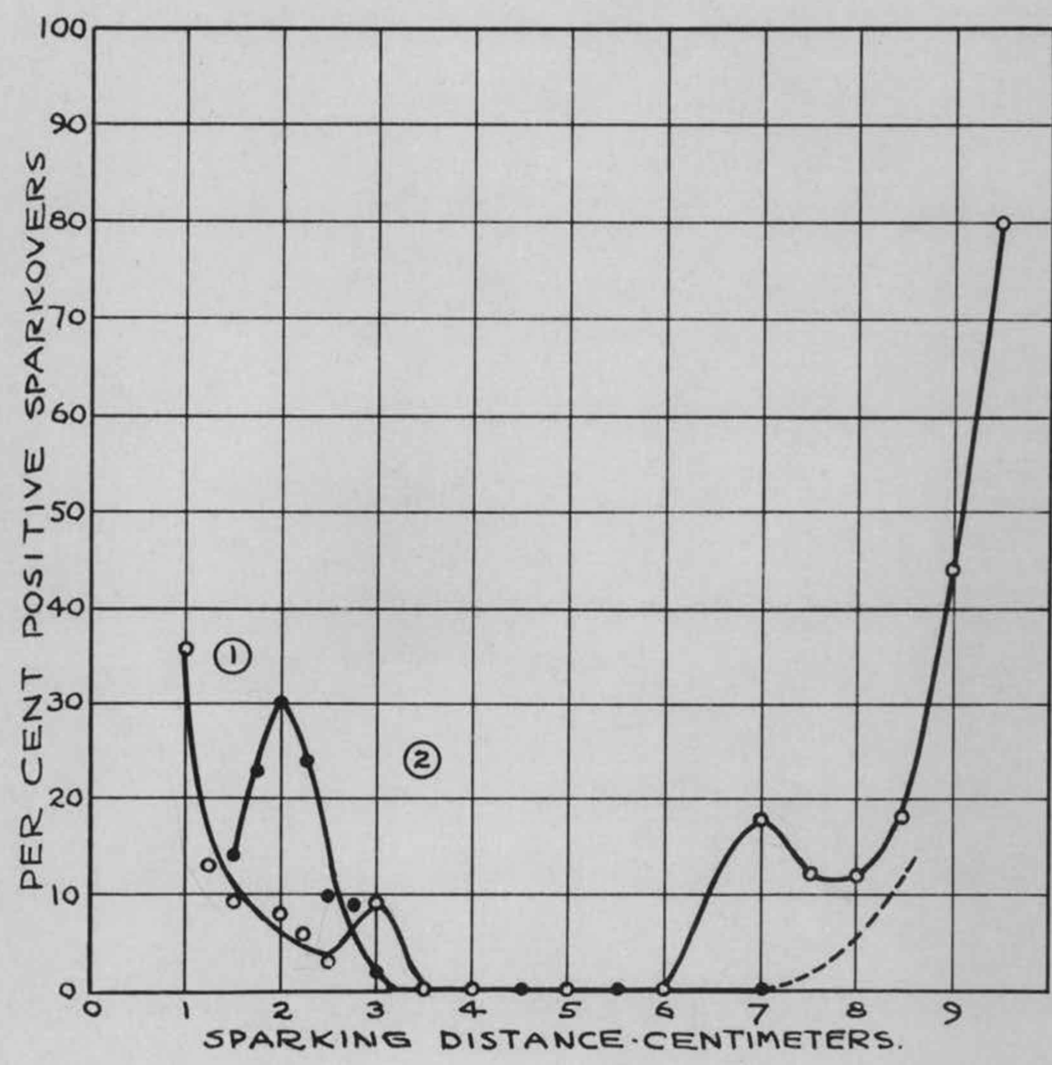
The polarity characteristic curves were determined for the unshielded sphere-gap as a control for the determination of the action of the shields. Figure 6 shows two curves obtained under different atmospheric conditions. The two curves are typical and are the same as have been obtained by McMillan and Starr and by the author on previous occasions. Curve 1 in the figure was obtained under conditions of comparatively low barometric pressure and of high temperature, both conditions being conducive to corona formation. This corona formation caused the typical "humps" on each side of the 100 per cent negative sparkover range. In the range of these "humps" the positive and negative sparkover voltage curves are very near to being together and so are very sensitive to any affect such as corona formation. The data for Curve 2 was taken under different air conditions; the barometric pressure being high and the temperature low. The result is a lenghening of the 100 per cent negative sparkover range and the apparent elimination of the "corona humps". The important point to be here considered is that the polarity characteristic curve is not an absolute definite thing for all conditions. However, in all cases there is a range of sparking distance over which all sparkovers are negative, showing the negative sparkover voltage to be lower than the positive.

FIGURE 6

POLARITY DISTRIBUTION CURVES FOR UNSHIELDED 6.25 CM. SPHERE-GAP.

4 DIAMETERS TO GROUND PLANE.

CURVE NO.	①	②
BAROMETER, m.m. Hg.	746.5	764.4
TEMPERATURE, °C	25	17
ABS. HUMIDITY, GRAMS/M³	8.8	8.2
RELATIVE AIR DENSITY	0.983	1.003



Both Spheres Shielded.

A series of tests were made with both spheres shielded to determine first, the influence of the shielding on the polarity characteristics of the gap and, second, the position of the shields relative to the spheres to obtain maximum control of the polarity characteristics. All tests were made on the 6.25-cm. sphere-gap with the lower sphere grounded and with the ground plane 4 sphere diameters from the gap.

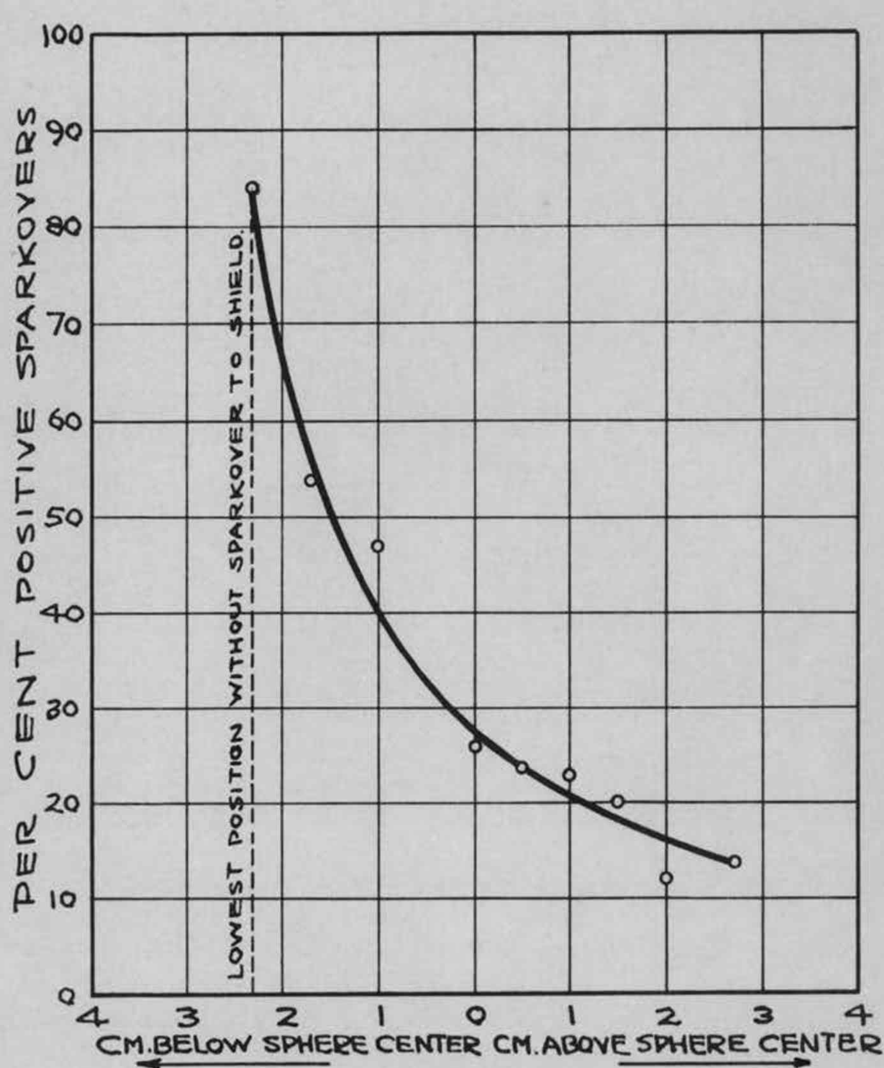
In Figure 7 data are shown giving the affect of the position of the upper shield with the lower shield centered on the lower sphere. The position of the upper shield is shown with reference to the upper sphere and the two reference planes are taken as the horizontal plane through the shield center and the horizontal plane through the sphere center. These planes will be used as reference throughout the discussion. In Figure 7 the gap spacing was constant at 4 cm. which is in the range of 100 per cent negative sparkover for the unshielded gap. (See Figure 6.) The data of Figure 7 show that with the upper shield placed near the gap the polarity characteristic was reversed from that of the unshielded gap and as the shield was raised from the gap there is a transition toward the high percentage of negative sparkovers which is characteristic of the unshielded gap at this sparking distance.

FIGURE 7

EFFECT OF POSITION OF UPPER SHIELD WITH LOWER SHIELD CENTERED ON LOWER SPHERE

SPARKING DISTANCE - 4 CM
4 DIAMETERS TO GROUND

BARGMETER m.m.Hg 749.1
TEMPERATURE °C 23
ABS. HUMIDITY, GRAMS/M³ 7.0



POSITION OF UPPER SHIELD PLANE.

Figure 8 shows polarity characteristic curves for the gap with both spheres shielded. Four curves are given showing the affect of the position of the shields. In all cases the two shields were placed symmetrically with respect to the gap. The four curves in the order of their number show the effect of moving the shields from the gap. For Curve 1 the shields were close enough together that sparkover to the shield began at a gap spacing of 3.5 cm. For all other positions of the shields no trouble was encountered in increasing the gap to diameter spacing. The family of curves shown in Figure 8 show that the 100 per cent negative sparkover range, characteristic of the unshielded gap has been eliminated by the use of the shields. In no case throughout the range of gap spacing from 1 to 7 cm. was there obtained a 100 per cent sparkover of either polarity. The polarity characteristic curves are not ideal in that the per cent positive sparkovers vary from 10 per cent to 85 per cent, but if sparkovers of both polarity can be obtained at any reasonable percentage then the positive and negative sparkover voltages must be very near the same. This is course is the fundamental objective.

From the series of tests with both spheres shielded the following conclusions are drawn:

1. The effectiveness of the shields is experimentally verified.

2. With the upper shield lowered around the gap there is

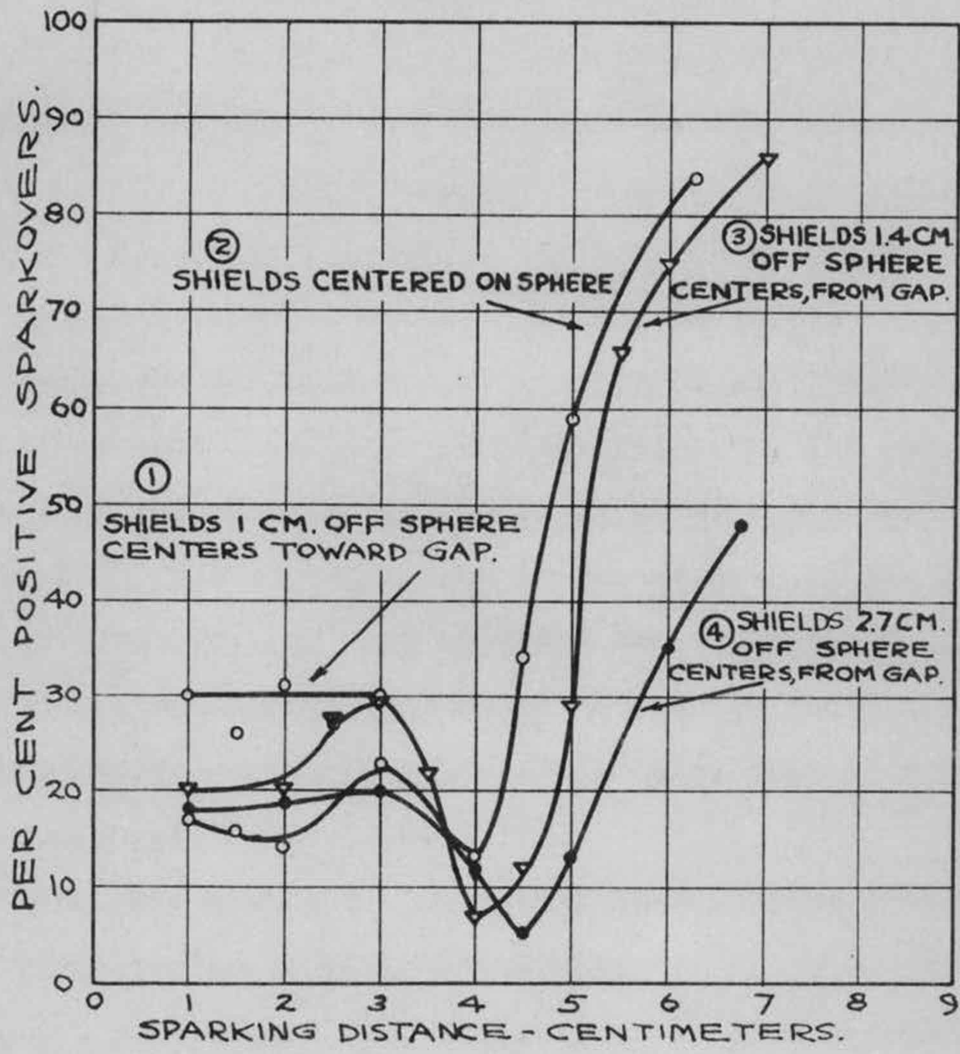
FIGURE 8

POLARITY DISTRIBUTION CURVES FOR SHIELDED 6.25 CM. SPHERE-GAP.

BOTH SPHERES SHIELDED

4 DIAMETERS TO GROUND PLANE

CURVE NO.	①	②	③	④
BAROMETER, m.m. Hg.	762.4	760.0	760.9	760.0
TEMPERATURE, °C	23	23	21	24
ABS. HUMIDITY, GRAMS/M^3	5.8	8.8	6.6	7.0



a reversal of the polarity distribution as obtained without the shields.

3. As the upper shield is moved upward from the gap with the lower shield centered on the lower sphere and with the gap spacing constant, there is a rapid transition in polarity distribution toward the condition obtaining without the shields.

4. From an examination of Figure 8 it is concluded that the most effective position of the shields is with them centered on the spheres.

Upper Sphere Only Shielded.

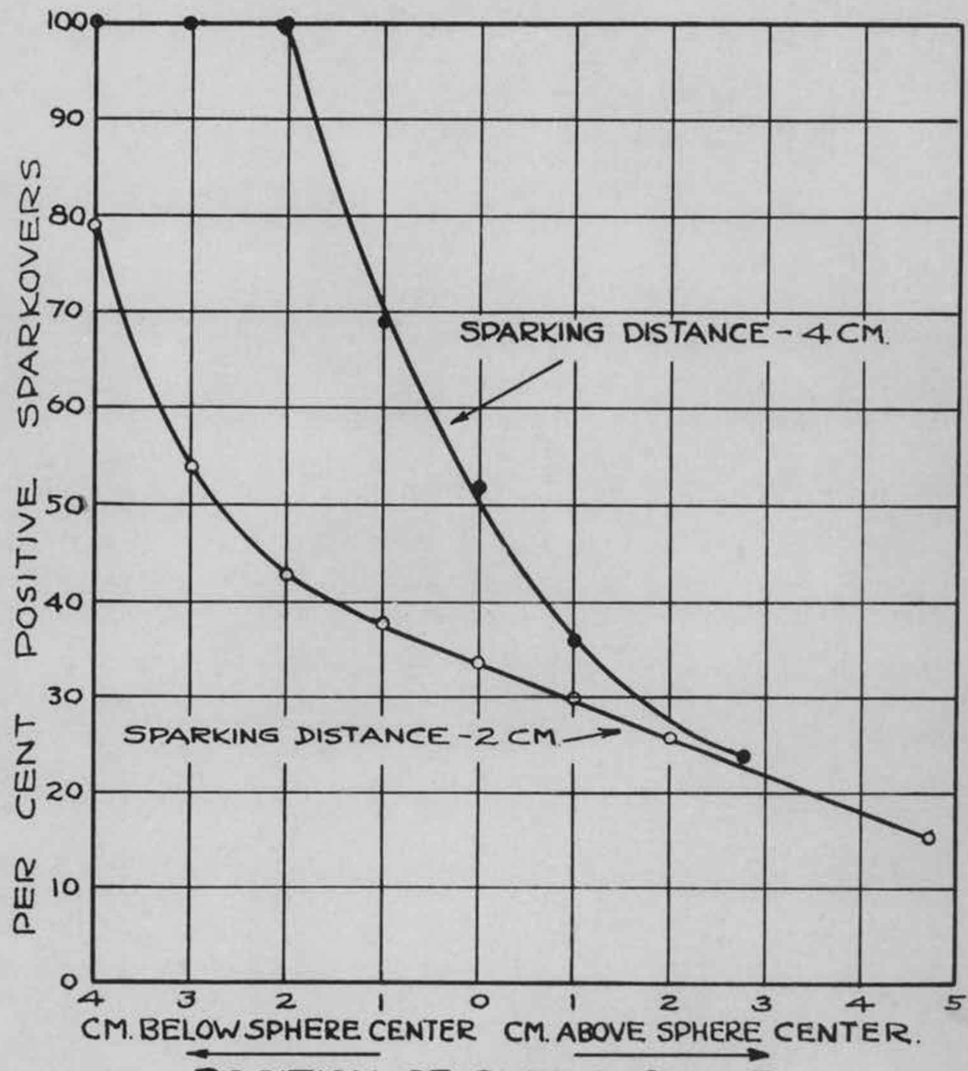
This series of tests was made to determine, first, if the dielectric field of the sphere-gap could be made symmetrical without the use of the lower shield, and second, the best position of the shield. Using the upper shield alone by far the major portion of the flux to ground is from the shield, very little of it being from the upper sphere. Theoretically then the potential gradients at the sparking surfaces of the spheres should be practically the same and there should be no polarity effect.

In Figure 9 data are given showing the influence of the position of the upper shield for two gap spacings; 4 cm. which is in the range of 100 per cent negative sparkover, and 2 cm. which is about 20 per cent positive sparkovers for the unshielded gap. With the shield below the sphere

FIGURE 9

EFFECT OF POSITION OF UPPER SHIELD
WITH NO LOWER SHIELD

4 DIAMETERS TO GROUND PLANE.



center, that is, around the gap there is a complete reversal in both cases of the polarity characteristics obtained for the unshielded gap. As the shield is raised the transition toward the unshielded condition is quite rapid.

The influence of the position of the shield as a function of the sparking distance is shown in Figure 10. The result of raising the shield position is shown by the curves in the order of their number. Curve 1 shows one extreme, that of having the shield reference plane well below the sphere center, with the resultant tendency to high percentage of positive sparkovers and then the rapid change to 100 per cent negative sparkovers. The other extreme of shield position is the unshielded gap, which case it can be seen from Figure 6 is similar to Curve 1 of Figure 10 inverted.

Three polarity characteristic curves for the sphere-gap with one shield centered on the upper sphere are shown in Figure 11. The differences in the three curves are due to differences in atmospheric conditions. At a given point in each curve there is a rapid increase in positive sparkovers and there is a correlation between this point and the air conditions. With low air density due to the low barometric pressure, the temperature being essentially constant, corona forms on the circuit at a lower voltage and at this point the percentage of positive sparkovers becomes high. The corona was observed visually in each case and was found to be present at the spacing of high positive percentage of

FIGURE 10

POLARITY DISTRIBUTION CURVES AS AFFECTED BY POSITION OF THE UPPER SHIELD.

NO LOWER SHIELD.
4 DIAMETERS TO GROUND

① SHIELD PLANE 4 CM. BELOW SPHERE CENTER
② " 2 " " " "
③ " 0 " " " "
④ " 2.7 " ABOVE " "

CURVE NO.	①	②	③	④
BAROMETER mm. Hg.	754	754	755	753
TEMPERATURE °C.	18	19	24	19
ABS. HUMIDITY, GRAMS/M^3	6.5	6.4	5.7	5.9

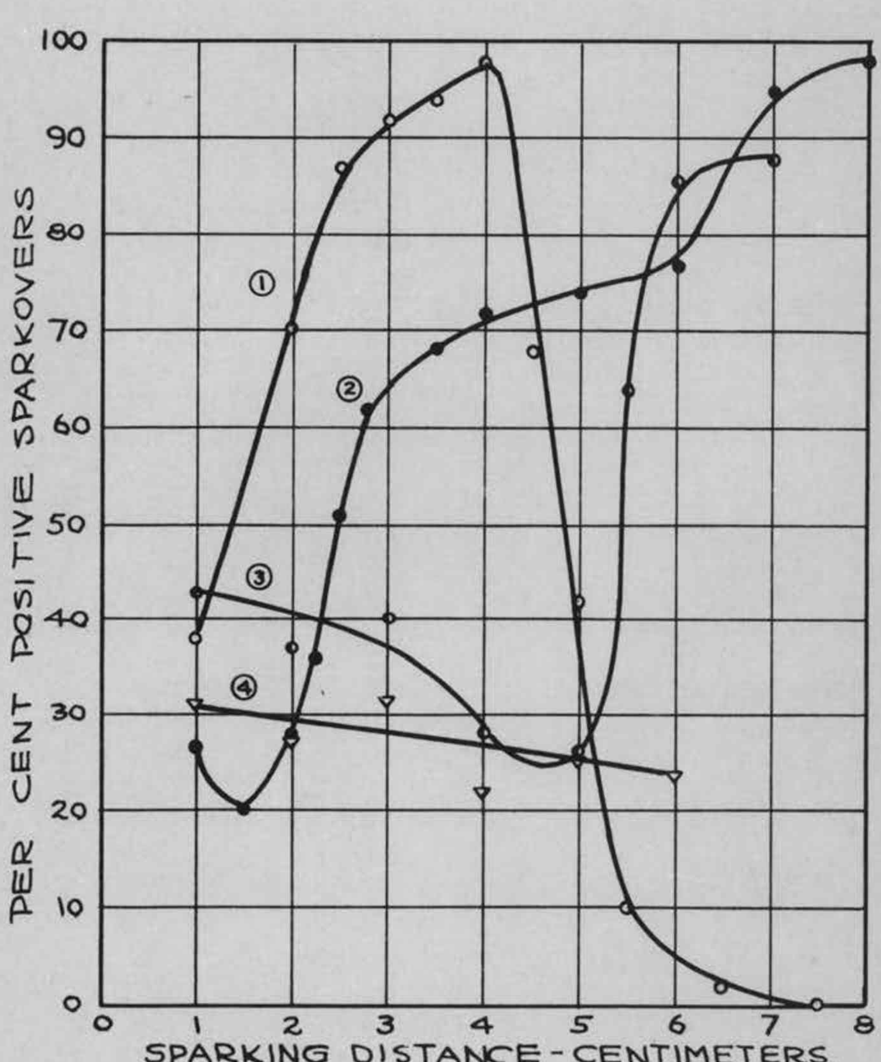
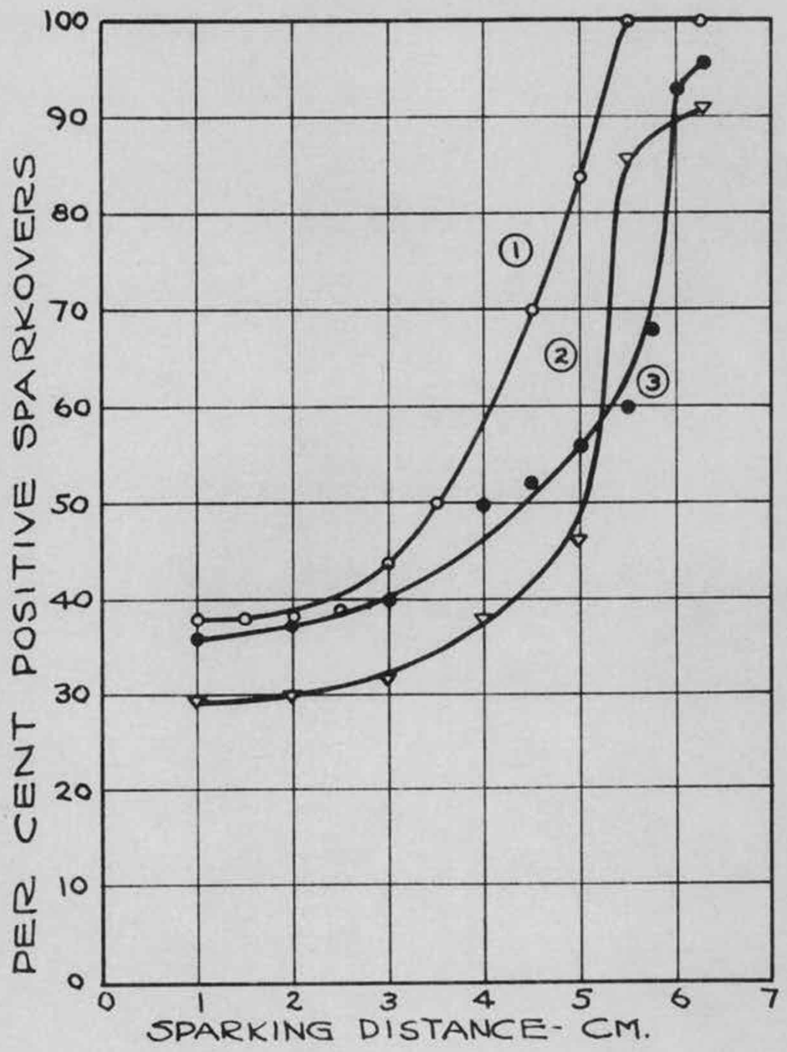


FIGURE 11

POLARITY DISTRIBUTION CURVES FOR 6.25 CM. SPHERE-GAP WITH ONE SHIELD CENTERED ON UPPER SPHERE.

4 DIAMETERS TO GROUND

CURVE NO.	①	②	③
BAROMETER, m.m. Hg.	748	756	762
TEMPERATURE, °C	22	21	22
RELATIVE HUMIDITY %	42	51	45
ABS. HUMIDITY, GRAMS/M³	8.2	9.4	8.8



sparkovers. The data indicate the increase in positive spark overs to be due to the corona formation on the circuit. This indication is not here determined to be fact. Further work on the sphere-gap with the use of apparatus such that the air conditions in the gap and the formation of corona could be controlled would determine these characteristics.

From the experimental work done with only the upper sphere shielded, and with this shield centered on the upper sphere it is concluded:

1. With the shield plane through the gap a complete reversal of the characteristics of the unshielded gap is obtained.

2. An ideal polarity distribution of 50 per cent sparkovers of each polarity can be obtained for any given gap spacing and for a given set of atmospheric conditions, by changing the shield position with respect to the sphere. Such refinements are not of practical necessity.

3. The lower shield is unnecessary.

4. With the upper shield centered on the upper sphere the characteristics of the gap show no marked polarity effects up to diameter spacing.

5. Corona formation on the circuit has a decided affect on the polarity characteristics of the shielded sphere-gap.

The Affect of Time Interval Between Sparkovers.

During a test on the shielded gap to determine the influence of the position of the upper shield using no lower shield a phenomemon was noticed which was investigated in a series of tests. In that test, see curve for 2 cm. sparking distance in Figure 9, the greater part of the sparkovers were positive at low positions of the shield, but it was found that when sparkover was resumed after a short interval during which voltage was off the gap, that the first sparkover was always negative. This appeared to be true only when the shield was placed very low on the sphere.

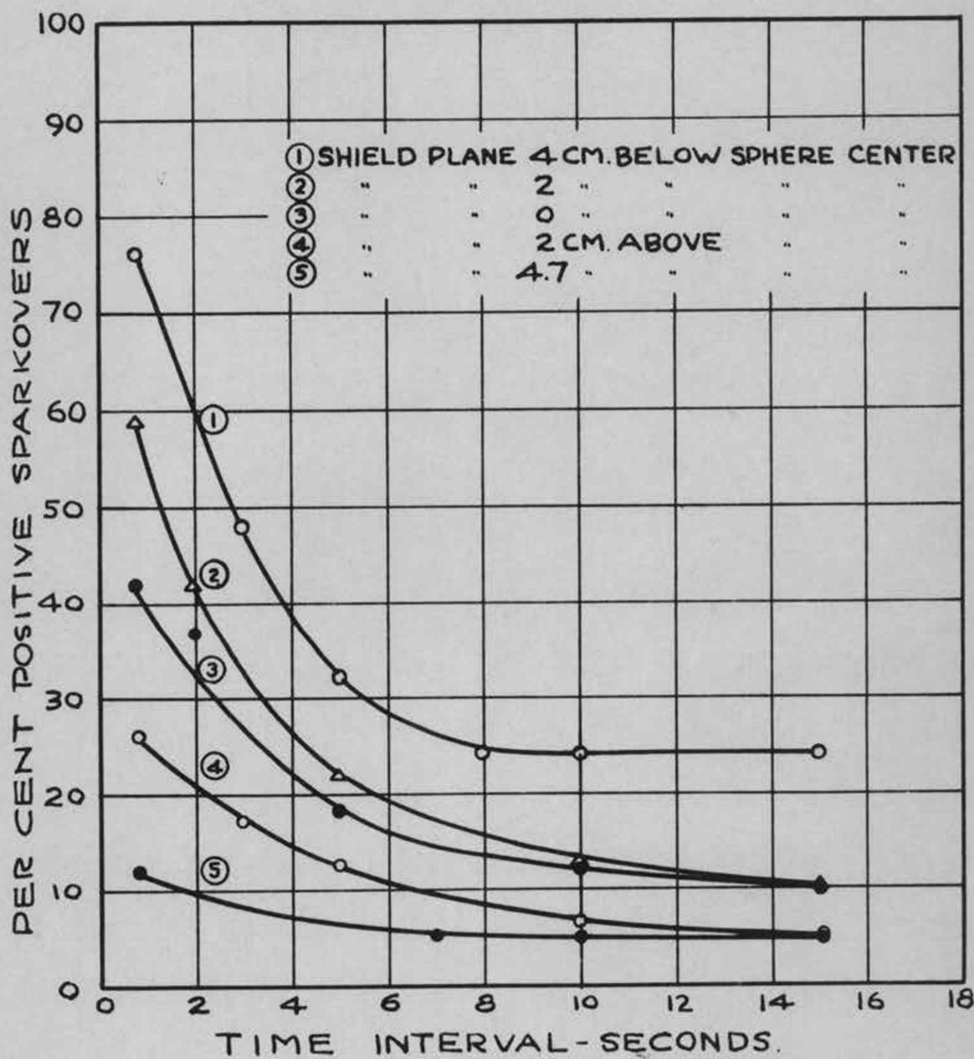
A series of tests was made to investigate this phenomenon and the results are shown in Figure 12. The time interval measured and shown in the figure is the interval between the opening and the closing of the circuit breaker in the low-voltage side of the transformer. The interval then is the time during which the voltage was off the gap. A period of from 2 to 5 seconds was required for the voltage to build up to sparkover after the breaker was closed, the exact time required being dependent upon the spacing of the gap. It will be noted from Figure 12 that the increase in per cent positive sparkovers due to a rapid rate of sparkover is greatest when the shield is low on the sphere. For all positions of the shield the percentage of positive

FIGURE 12

POLARITY DISTRIBUTION AS AFFECTED BY TIME INTERVAL BETWEEN SPARKOVERS FOR VARIOUS POSITIONS OF UPPER SHIELD.

SPARKING DISTANCE 2 CM.
4 DIAMETERS TO GROUND
LOWER SPHERE UNSHIELDED

CURVE NO.	①	②	③	④	⑤
BAROMETER m.m. Hg.	756	761	761	756	756
TEMPERATURE, °C	24	24	25	25	25
ABS. HUMIDITY, GRAMS/m^3	8.5	8.5	9.0	7.9	7.9



sparkovers becomes constant at a time interval of about 10 seconds, and would therefore not have to be taken into consideration for a rate of sparkover less rapid than 1 in 10 seconds.

To determine the influence of the shield on this interval effect, a test was made with the shield removed. Polarity was determined and found to be essentially constant over the entire range of time intervals. It is evident then that the interval effect is caused by the shield, and is due to a mechanical or electrical interference or both, which prevents the free scattering of the space charge formed in the gap on sparkover. That this interference is not entirely mechanical is shown by Curves 4 and 5 of Figure 12. For both of these curves the shield center plane was above the center of the sphere. It is probable that this electrical influence is due to the fact that the shield has an affect on a greater volume of air space than does the sphere. When the voltage is applied to the upper sphere and shield a large volume of air containing the ionized particles is drawn under the influence of the voltage. The dielectric field of the upper shield tends to converge into the lower sphere, and the charged particles are drawn into the gap by the voltage. Due to the convergent rather than divergent field and to the increased air volume affected, a greater number of ionized particles are retained in the gap. The mechanical interference of the shield to the scattering of the charged particles by air currents is also a factor. A test was made with the shield 1 cm. below being centered on the sphere, playing an electric fan on the gap during the interval between sparkovers. The sparkover polarity was 50 per cent over almost the entire range of time interval with a slight upturn to 69 per cent positive for the rapid rate of sparkover. A test was also made to determine the interval effect using both shields. The shields were placed symmetrically with respect to the gap and as close together as possible without having sparkover to a shield. The gap spacing was constant at 2 cm., and each shield was 1 cm. off the sphere center toward the gap. The per cent positive sparkover was found to be essentially constant over the interval range. The test was repeated with the gap spacing set at 4 cm., and with the shields moved to a position 0.8 cm. off the sphere centers toward the gap. The result was the same; the percentage sparkover being essentially constant at about 30 per cent positive. The reason for the absence of the interval effect when using two shields is that when both shields are used and placed symmetrically with respect to the gap, neither shield can be placed over the gap or even very near to the gap without having sparkover to a shield. Consequently the scattering of the ionized air is not materially impeded. The electrical interference of the shields remains present however, but in these tests it was found to be of minor importance. The electrical interference is probably reduced in this case since the field between the two shields is made more uniform than in the case when using only one shield.

From the work done in investigation of the interval effect it is concluded:

1. The shield, when shielding one sphere only, causes an interference to the scattering of the ionized air in the gap.

2. This interference is a combination of a mechanical and an electrical influence.

3. For any given shield position, the shorter the interval between sparkovers the greater is the percentage of positive sparkovers.

4. The farther the shield from the gap, the less is the affect of a short time interval in increasing the per cent positive sparkovers.

5. No interval effect was found with the unshielded gap, nor for the gap with both spheres shielded.

6. The interval effect vanishes for all positions of the shield, if approximately 10 seconds is allowed between sparkovers with voltage off the gap.

Calibration of the Shielded Sphere-Gap.

The shielded sphere-gap was calibrated for 60 cycle voltage using a 12.5-cm. sphere-gap in parallel for voltage measurement. The calibration curve for the shielded gap together with the standard calibration curve for the 6.25-cm. sphere-gap with one sphere grounded is shown in Figure 13. The calibration of the shielded gap was made with the shield in the recommended position, that is, with one shield centered on the upper sphere.

The sphere-gap shielded in the recommended manner was calibrated for impulse voltages of both polarities. For this calibration an impulse generator was built to generate a 1-5 impulse wave. The 12.5-cm. sphere-gap was connected in parallel with the test gap for voltage measurement. The impulse calibration curves for both polarities are shown in Figure 14. It can beeseen that the positive and negative sparkover voltage curves are identical throughout the range of sphere-gap spacings tested. This range extends well into the region where the polarity effect had its influence in the unshielded gap.

Calibration data for the shielded gap, both for the 60 cycle test and for the impulse voltages are included in Appendix A.

IV Summary

It has been shown that the accurate measurement of the dielectric strengthhs of insulating materials is an essential part in the design of electrical equipment of all kinds. The importance of the sphere-gap as a high-voltage measuring device for the determination of these

FIGURE 13

60-CYCLE CALIBRATION CURVE FOR SHIELDED 6.25 CM. SPHERE-GAP

USING UPPER SHIELD ONLY, CENTERED ON UPPER SPHERE

4 DIAMETERS TO GROUND
LOWER SPHERE GROUNDED

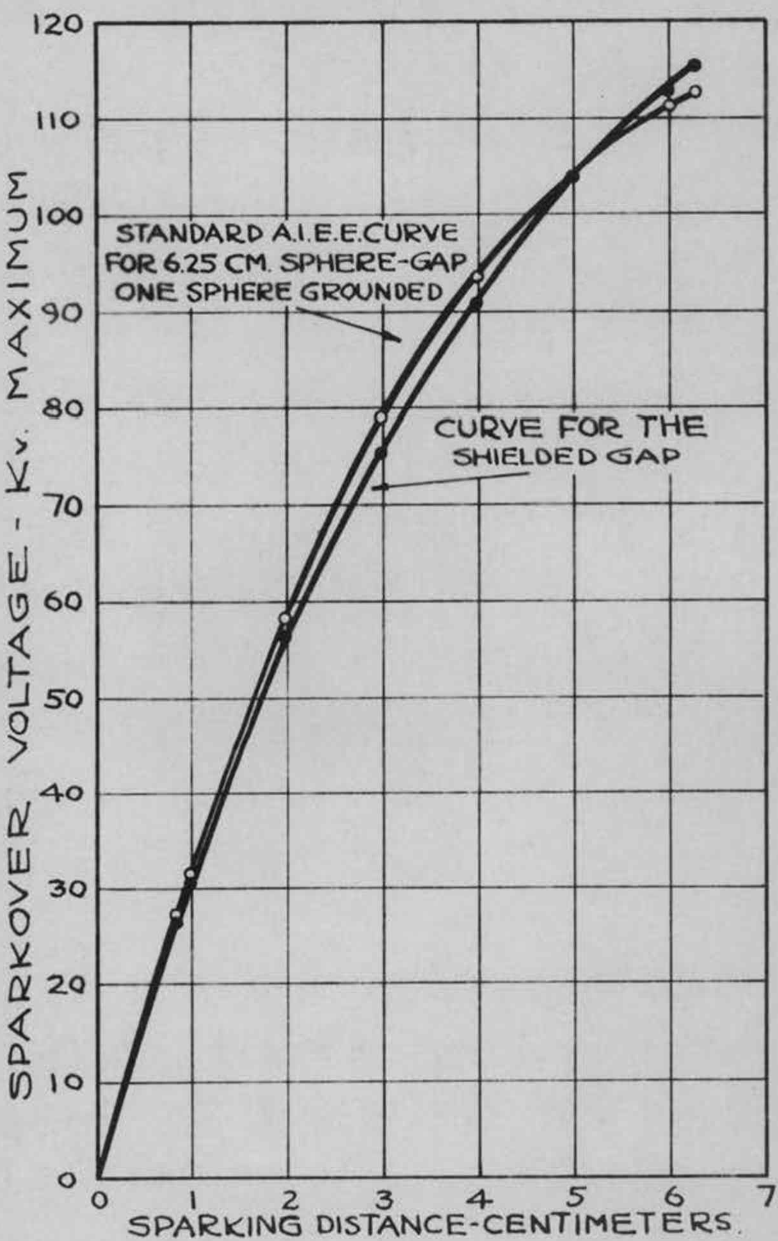
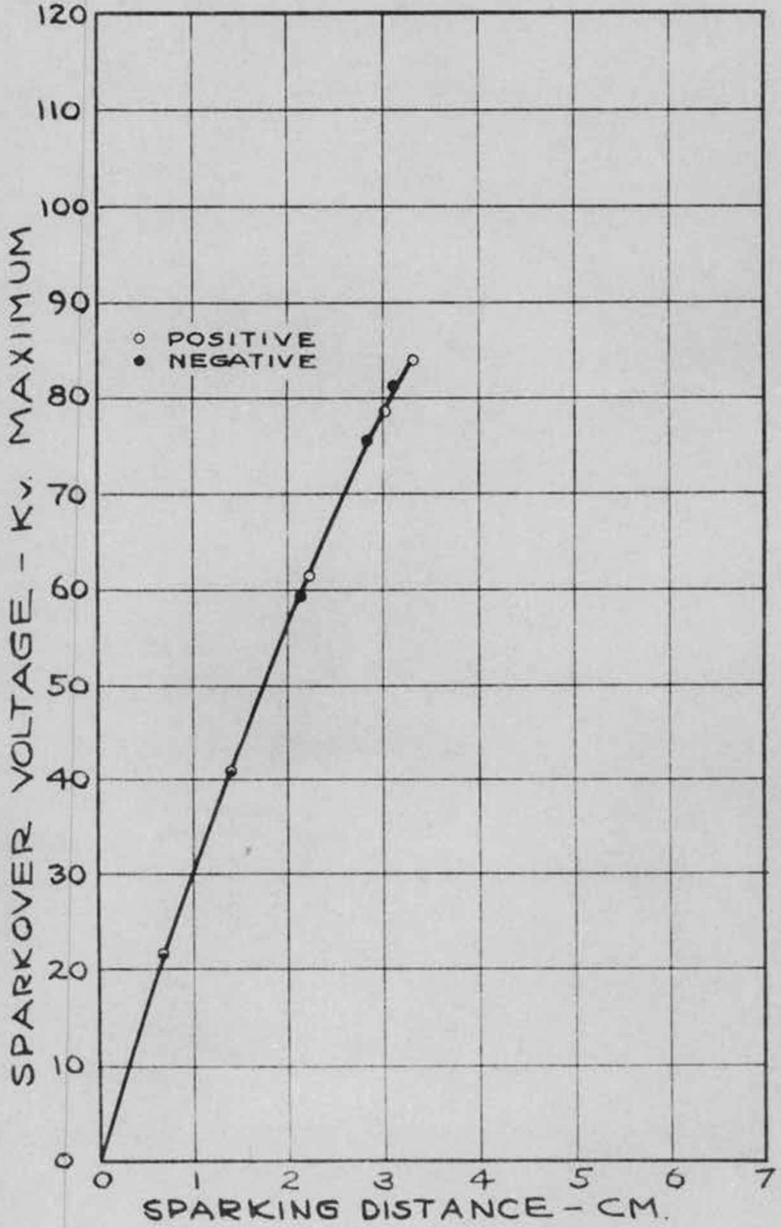


FIGURE 14

IMPULSE CALIBRATION CURVE
FOR SHIELDED 6.25 CM. SPHERE-GAP

USING UPPER SHIELD ONLY
CENTERED ON UPPER SPHERE
4 DIAMETERS TO GROUND
LOWER SPHERE GROUNDED

TESTING WITH 1-5 WAVE



dielectric strengths has been stressed.

It has been pointed out that the inaccuracies of high-voltage measurement are of such a magnitude as to cause serious errors in insulation design, and furthermore that the polarity effect in sphere-gaps is a factor causing these inaccuracies.

The idea of a shielded sphere-gap for the control of the polarity effect has been developed and tested. This shielded sphere-gap possesses the following properties:

1. Polarity effect can be controlled to the end that it is eliminated.

2. The shielding apparatus is simple, consisting of a metallic toroid placed in a centered position around the upper ungrounded sphere. No adjustment of the shield is necessary.

3. The polarity characteristic curves for the gap shielded in the devised manner do not reach 100 per cent sparkover of either polarity throughout the spacing range to diameter spacing.

4. The positive and negative impulse sparkover curves for the gap shielded in the recommended manner are the same throughout the range of gap spacing tested. (See Figure 14)

The influence of shield size has not been determined. Further work would determine the optimum shield dimensions.

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APPENDIX A.

60-CYCLE CALIBRATION DATA FOR 6.25-Cm. SHIELDED SPHERE-GAP.

Using 1 shield; centered on the upper sphere.

Gap Spacing cm.	Sparkover Kv. Maximum.
0.852	26.4
1.000	30.8
2.000	56.9
3.000	75.5
4.000	90.8
5.000	104.0
6.000	112.9
6.250	115.1

IMPULSE CALIBRATION DATA FOR 6.25-Cm. SHIELDED SPHERE-GAP.

Using 1 shield; centered on the upper sphere.

Gap Spacing cm.	Polarity	Sparkover Kv. Maximum
0.704	Positive	21.8
0.704	Negative	21.8
1.450	Positive	40.8
1.450	Negative	40.8
2.280	Positive	61.4
2.195	Negative	59.1
3.050	Positive	78.4
2.880	Negative	75.6
3.350	Positive	83.8
3.150	Negative	81.5