SPARK POTENTIALS IN LIQUID DIELECTRICS.

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AN extensive literature exists on spark potentials. This is confined, for the most part, to a study of gaseous dielectrics.

In this paper spark potentials, for small distances, in liquid dielectrics are discussed. Extended experiments on the disruptive strength of various oils, used in the insulation of electrical machinery, have been made by several of the companies engaged in the manufacture of such apparatus. No doubt, much interesting matter, so secured, has not been published by the investigating parties.

In the recent publication, Turner and Hobart on the Insulation of Electrical Machinery, various sections deal with the disruptive strength of oils. For the most part, Mr. C. P. Steinmetz is quoted as authority. In the original paper of Mr. Steinmetz,¹ measurements on the potential required to cause a spark to pass between parallel plates are given. These measurements were made with a periodic P.D., an alternate current transformer being used to obtain the required P.D.

The results obtained by Mr. Steinmetz do not agree with those obtained by MacFarland and Pierce.² The last named investigators obtained their P. D. from a Toepler-Holtz machine. They experimented on a large number of oils and are the authorities quoted in the Smithsonian Tables edited by Dr. Thomas Gray. In a discussion of the various results obtained,³ Dr. MacFarland points out that the method employed by Mr. Steinmetz in measuring distances, interrupted the continuity of the liquid and explained the discrepancy on that ground. In the Steinmetz experiment, two plane electrodes were separated by a solid dielectric, of known thickness, containing a hole. This aperture contained the oil

¹ Proc. Am. Inst. E. E., 1893, p. 85.

² PHYSICAL REVIEW, Vol. I., p. 165.

³ Proc. Am. Inst. E. E., 1893, p. 109.

through which the spark passed. Mr. Steinmetz maintains that values of spark potentials obtained by the use of static machines do not afford data which the electrical engineer can accept. Both agree that the electrostatic potential gradient required to cause the passage of a spark between electrodes is constant, although they do not agree upon the value of this constant.

That this not true for air and other gases has long been known, the potential gradient decreasing with increase in distance. Mr. Steinmetz calls attention to the fact that if the curves showing the relation between potential and distance be plotted, an extrapolation of these for air and the various oils, would give a higher potential gradient for air if the distances were small. His computed value for air, at small distances, gives a gradient of 139 kilovolts per cm. and he calls attention to the fact that this is about the value obtained for red fiber and is higher than for any of the oils on which he operated.

The author has made a series of observations on spark potentials in air and CO_2 , for extremely short distances.¹ The results for air at atmospheric pressure are shown, for purpose of comparison in Plate II. The values obtained were for P.D.'s from a bank of storage cells. In a later paper,² similar and almost identical results were reported as secured from an A.C. source. The interesting part of this curve lies in the peculiar bend occurring at a distance of approximately 3 micra and for a potential of about 350 volts. This indicates a change in the law at this point and the value 350 volts corresponds with what is commonly termed the minimum spark potential of air.

Professor J. J. Thomson³ explains this turning point on the theory that for potentials less than this critical potential, the discharge is carried by free metal corpuscles projected from the electrodes; that for greater potentials both metal corpuscles and ions of the dielectric are the carriers.

In the present experiment, it is desired to extend spark potential curves over extremely small distances, using liquid dielectrics. The

¹ Phil. Mag., 1900, p. 147.

² PHYSICAL REVIEW, VOL. 15, p. 163.

³ Conduction of Electricity through Gases, p. 384.

distances cover a range from .118 mm. to .003 mm. and are thus comparable with previous measurements in air.

CONDITIONS WHICH AFFECT SPARK POTENTIALS.

In such measurements there are a number of variables which must be taken into consideration. The P.D. required to cause a spark between electrodes depends: (1) Upon the distance separating the electrodes, (2) upon the nature of the intervening medium, (3) upon the pressure, (4) upon the temperature, (5) upon the length of time of application of P.D., (6) upon the shape and size of the electrodes, (7) in case the electrodes are not of the same shape, upon which one is positive, (8) upon whether the intervening medium is ionized by the action of Roentgen rays or other means, (9) upon the material of which the electrodes is composed, (10) upon the strength of the magnetic field in which the discharge occurs.

The foregoing list may not be complete, but sufficient work has been done by various investigators to show that any of these causes may modify the values obtained. Some of these apply only to particular cases. The relation between distances and pressures for gaseous media is embodied in Paschen's law. This is fully discussed by Carr.¹ The fourth consideration, *viz.*, that of temperature, has never been fully investigated. Turner and Hobart² quote a series of measurements showing variations in the disruptive strength of some commercial insulators, due to temperature changes. Oiled linen, for example, was one of the insulators tested. The results show a decrease in the disruptive strength with increase in temperature. It seems probable that temperature effects would cause greater variations in liquid than in gaseous media.

The influence of time of application of the P.D. was first investigated by Warburg and is commonly known as the lag. The size and shape of the electrodes has been studied by Baille and others. The results obtained by a number of investigators are compared and discussed by J. J. Thomson.³ The effect of polarity of the electrode seems to be most important in the case of a point and plane.

¹ Proc. Roy. Soc., 1903, p. 374.

² Insulation of Electrical Machinery.

³ Conduction of Electricity Through Gases.

Change of the spark potential due to external ionization of the field appears to be confined to gaseous media and has the effect of diminishing the time of lag.¹ Dr. G. M. Hobbs² has investigated the effect of the material composing the electrode on spark potential. He has shown that at the elbow or turn of the potential distance curve in air, that this curve lies parallel to the *X*-axis for a certain distance and that this distance of parallelism depends on the kind of metal used as the electrode. For distances greater than those represented by the bend in the curve the nature of the electrode appears to have no effect.

The effect produced by a magnetic field is most pronounced in gaseous media under small pressures. Precht³ has investigated the case for atmospheric pressures under certain special conditions.

If periodic P.D.'s are applied, the introduction of capacity and inductance in the circuit containing the spark gap may introduce resonance conditions. This would greatly modify apparent values of the P.D. when measured by the usual method.

DESCRIPTION OF EXPERIMENT.

In this experiment the variation of spark potential with distance is treated. The dielectrics used were kerosene, paraffin oil, olive oil and a transformer oil purchased on the market. One surface consisted of a circular plate 3.80 cm. across the face; this was ground plane but not polished. The other surface consisted of a ball 2.54 cm. in diameter. Both surfaces were of steel. Changes in atmospheric pressure were regarded as unimportant within the limit of accuracy of the experiment. The temperature conditions were very favorable. The mean temperature was 21° C., with variations of not more than one degree. The apparatus was so constructed that only a small quantity of oil was used at one time. The oil was obtained in sufficient quantity and renewed after each discharge. It is believed that this precaution is unnecessary. This point will be discussed later. For measurements on potential through small distances, it is necessary to measure both distances and potentials ac-

¹ Warburg, Wied. Ann., lix., p. 1, 1896.

² Phil. Mag., December, 1905, p. 617.

³ Wied. Ann., 1896, p. 676.

curately. Distances were measured by attaching the plane surface to the movable arm of an interferometer from which it was insulated. The ball was insulated from and suitably mounted on the interferometer bed. The surfaces were then brought in contact and separated. The distance of separation could be determined by the number of light fringes, preferably circular, which crossed the interferometer field during separation of the surfaces. Sodium light was used, and from the known wave-length of the sodium radiation, distances were determined. The arrangement as indicated in Fig. 1 D and D' indicate the surfaces, M the mirror on the carriage of the interferometer. The vessel containing the liquid is designated V .

Fig. 1.

The ball and plate were so mounted that fresh portions of the surfaces could be brought into contact after each discharge. The point of contact was determined by a galvanometer and small E.M.F. No difficulty was

experienced in securing a positive and definite zero setting. P.D. was measured by means of a Weston A.C. voltmeter, properly calibrated, and reading directly to 120 volts. By means of suitable multipliers, potentials up to 1,500 volts could be measured. The result in root of mean square volts can be transformed into maximum volts by multiplying by the proper factor. If we assume a sine form wave this factor is 1.41. Oscillograph curves of the E.M.F. show that a sine form is only approximated. The departure of this curve from a true sine form is such that variations in the readings obtained will hardly justify a further refinement in the matter of correction.

P.D.'s were obtained from a bank of incandescent lamps arranged in series. A General Electric transformer took current from a 110-volt 60-cycle circuit and stepped it up to 2,200 volts. This was passed through a bank of 44 incandescent lamps arranged in series. By introducing suitable lead wires, it was possible to utilize the fall in potential across one or more lamps. The transformer could be connected to give a total fall in potential of 550, 1,100 or 2,200 volts. Smaller steps than the direct drop across lamps could be

obtained by shortcircuiting lamps outside the lead wires or by throwing lamps in parallel inside the lead wires. The small capacity and induction of the lamp filaments makes this a desirable means of obtaining P.D.'s.

Fig. 2 shows the manner of applying the P.D. to the electrodes D, D' across which the voltmeter V was connected. A suitable double-throw switch was arranged so that the galvanometer G could be placed in circuit to test for contact, or a P.D. applied.

The method of procedure was to separate the surfaces a known distance and apply P.D.'s building up by small increments. The P.D. was applied for 5 seconds. If the medium did not break down

Fig. 2.

a higher P.D. was applied and so on until a spark passed. This would be indicated by the deflection of the voltmeter needle.

The tables indicate both the values which the dielectrics would withstand and those at which they broke down. These are indicated on the graphical representation by a cross and circle, respectively.

RESULTS.

Plate I. (Fig. 3) represents graphically the results obtained on a transformer oil. This was purchased from a local concern as a low grade transformer oil.

This shows a bend in the curve corresponding to approximately 350 volts and at a distance lying between 13 and 15 micra. For distances below this elbow, the passage of a spark always produced coherence between the surfaces. No matter for how brief a time the P.D. was applied, a test with the galvanometer showed metallic contact between the surfaces. For distances above this bend such was not the case. The appearance of the surfaces in the two cases was noticeably different. For potentials corresponding to the flat portion of the curve, no discoloration of the surfaces or carbonizing

TABLE I.
Transformer oil.

Distance in Wave-lengths Sodium Light.	P.D. which Medium Would Withstand.	P.D. at which Medium Broke.	Distance in Wave-lengths Sodium Light.	P.D. which Medium Would Withstand.	P.D. at which Medium Broke.
5	115	123	35	372	395
10	191	206	40	412	423
15	226	259	45	395	412
15	268	288	45	406	423
17.5	305	310	50	434	457
20	327	350	60	457	468
20	310	327	70	468	485
22.5	338	364	80	496	507
25	350	388	90	455	502
25	310	344	100	558	575
30	384	395	150	609	635
30	372	406	150	651	668
35	372	395	200	871	888

of the oil was observed, for distances greater than this critical distance both surfaces and oil were badly discolored and the surfaces pitted. This is characteristic of all the oils operated upon. Fresh oil was used after each discharge.

Fig. 3.

A series of readings was taken to determine if changes in the disruptive strength occurred after the passage of a spark. The results are shown in Table Ia.

In this case the surfaces were separated a distance of 40 wave-lengths (Na Light) or approximately 24 micra. The first reading was taken on a fresh oil, the second after a spark had passed during the time a switch could be closed and opened by the hand. This

TABLE IA.

P.D. which Medium Would Withstand.	P.D. at which Medium Broke Down.	Condition of Medium.
406	423	Fresh oil.
412	423	Quick spark.
406	420	Quick spark.
406	417	Spark had passed 30 sec.
406	429	Spark had passed 60 sec.

is designated as a quick spark. From the foregoing results, it would seem that the precaution of using a fresh oil after each discharge is unnecessary and that the oil is self-healing. The entire curve was repeated without renewal of the oil and practically the same results obtained. A second transformer oil sent out by one of the large electrical manufacturing companies gave the same result within the accuracy of the experiment.

Table II. gives the results secured with kerosene oil. This was a high grade resistance kerosene. The results are given graphically in Fig. 4. A similar curve for air at atmospheric pressure is also

TABLE II.

Kerosene.

Distance in Wave-lengths Sodium Light.	P.D. which Medium Would Withstand.	P.D. at which Medium Broke Down.	Distance in Wave-lengths Sodium Light.	P.D. which Medium Would Withstand.	P.D. at which Medium Broke Down.
5	79	110	35	417	451
5	56	112	40	389	411
7.5	129	136	45	—	451
10	182	203	50	423	451
10	169	226	60	451	474
12.5	268	299	70	451	474
15	268	299	80	552	564
17.5	322	328	90	564	592
20	327	347	100	592	620
25	350	389	150	810	850
30	389	411	200	980	1,020

given. It is interesting to note that, for the distances taken, air is the better insulator. Mr. Steinmetz' prediction on this point has been noted previously. It is well known that the air curve bends toward the X -axis and it is presumed that the curve representing

Fig. 4.

the disruptive strength of a liquid is a straight line. At the point of intersection the spark-potentials would be equal. MacFarlane and Pierce¹ gave this as 1 mm. for air and kerosene.

If this curve for kerosene is interpolated the potential gradient at 1 cm. would give 55 kilo-volts per cm. This requires an extrapolation of the curve to something like 80 times its length and is unwarranted, however, it agrees well with the value obtained by MacFarlane, which was 50 kilo-volts per cm.

Plate III. (Fig. 5) represents the results obtained with paraffin oil. This shows a potential gradient somewhat less than that of kerosene and does not agree with MacFarlane's value of 87 kilo-volts per cm.

Paraffin oil, however, is a trade name applied to a number of the petroleum products. Oils sold under this name vary from heavy viscous oils to extremely limpid ones. The oil operated upon, in this case, was a clear limpid oil prepared by a drug firm and sold to the medical trade under the name of petrolatum oil. It may be observed that the curves representing the petroleum products show similar values and so far as their disruptive strength is concerned one is practically as good as another.

¹ PHYSICAL REVIEW, Vol. I., p. 165.

Fig. 5.

TABLE III.

Paraffin Oil.

Distance in Wave-lengths Sodium Light.	P.D. which Medium Would Withstand.	P.D. at which Medium Broke Down.	Distance in Wave-lengths Sodium Light.	P.D. which Medium Would Withstand.	P.D. at which Medium Broke Down.
5	92	110	35	434	451
7.5	127	135	40	412	446
10	265	282	40	485	508
10	164	188	45	451	462
12.5	226	254	45	462	474
12.5	234	245	50	412	440
15	327	350	60	479	508
15	311	344	70	479	508
17.5	271	282	70	423	440
17.5	377	389	70	547	609
20	333	344	80	508	547
20	344	361	90	540	558
25	310	338	90	620	661
25	355	378	90	863	884
30	400	411	100	558	630
30	—	406			

Plate IV. (Fig. 6) shows the results secured with olive oil, the only vegetable oil used in the test. It shows a higher potential gradient than any of the others. The bend in this curve is not so

TABLE IV.

Olive Oil.

Distance in Wave-lengths Sodium Light.	P.D. which Medium Would Withstand.	P.D. at which Medium Broke Down.	Distance in Wave-lengths Sodium Light.	P.D. which Medium Would Withstand.	P.D. at which Medium Broke Down.
5	59	94	30	384	390
5	55	94	35	406	429
7.5	113	118	35	406	446
10	149	164	40	440	457
10	164	169	40	448	468
12.5	175	186	45	491	513
15	175	223	45	505	513
15	155	178	50	550	592
17.5	223	240	60	584	626
20	271	293	70	546	626
22.5	288	310	70	632	643
25	342	388	80	685	711
25	372	384	90	744	792
27.5	388	416	100	792	843

Fig. 6.

apparent. There is some evidence of a turning point at a P.D. of 350 volts, at which coherence between the plates ceased.

An attempt was made to secure readings with water as a dielectric. Platinum electrodes were used in a high grade of ammonia-

free distilled water. This was a complete failure. The problem of securing a suitable water in the quantities desired seems very difficult, in the light of the Kohlrausch experiments on water. The conductivity of this water was not measured on account of the failure to obtain results.

CONCLUSIONS.

These experiments on the limited number of oils used would indicate :

1. That the potential gradient for very small distances is higher than for large ones.
2. That for small distances air is a better insulator than liquid dielectrics.
3. That the potential at which the bend in the potential-distance curve occurs is the same for air and liquid dielectrics.

If we accept Professor J. J. Thomson's explanation of the mechanism of spark discharge in gases for potentials less than the "minimum potential," *viz.*, that free metal corpuscles are the carriers of the discharge, and attach a similar meaning to the elbow occurring at the same voltage in liquids, it would follow that the corpuscles were able to travel further in liquids than in gases.

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