Second Series. *November, 1916* *Vol. VIII., No. 5*

THE

PHYSICAL REVIEW.

A COMPARISON OF ALTERNATING AND DIRECT SPARK POTENTIALS.

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THE potential required to produce a disruptive discharge across a spark gap has received the attention of many investigators. Until comparatively recent years these measurements have been chiefly concerned with direct current, the source of potential usually being a Holz or a Wimshurst machine. A fairly complete list of these contributions beginning with the work of Lord Kelvin in 1860 may be found in J. J. Thompson's "Conduction of Electricity through Gases."[1]

With the development of high-frequency oscillatory discharges such as are used in wireless telegraphy, and high tension alternating current for the transmission of power, the question of alternating spark potentials has received the attention of engineers and physicists because of the practical value attached to such information. Steinmetz[2] has measured the A.C. potential required to produce a spark in air at ordinary pressures and found a practically linear relation between potential and spark distance up to 110-$KV._{eff}$ with a commercial current of 125 cycles. Muller,[3] who used a different method, obtained similar results. Toepler[4] has collected tables from Freiberg, Jona, Steinmetz and others and attempted to reduce all to standard conditions for purposes of comparison, but with unsatisfactory results. Kowalski and Rappel[5] have made one of the most careful series of measurements and found their mean effective values for alternating potentials from 4 to 6 per cent. lower than those given by Toepler. Among others who have worked

[1] J. J. Thompson, Conduction of Elect. through Gases, p. 436.
[2] Steinmetz, Am. Inst. E. E. Trans., 15, p. 294.
[3] Muller, Ann. der Physik, 28, p. 585.
[4] Toepler, Electrotech. Zeitschr., 28, p. 1000.
Kowalski and Rappel, Phil. Mag., 18, p. 699.

in this field may be mentioned Weicher,[1] Reisenfeld,[2] Peek,[3] and Watson.[4]

While the relation of direct to alternating spark potentials has both theoretical and practical value, the difficulty in getting results capable of comparison has resulted from the fact that the measurements to be compared have been made under different conditions, by different methods, and different observers. Some hold that the alternating maximum potential for a given gap equals the direct, and others believe that the mean effective is more nearly the correct value. To settle this question by measuring first, say, the direct, and then the alternating potential under identical conditions of electrode material, spark distance, temperature, gas and pressure, was the purpose of the following work.

Apparatus.

A diagram of the apparatus used is shown in Fig. 1. The spark gap, S, is connected with a set of variable liquid resistances, R_3. Direct potential was supplied through the switch K_4, by four 1,000 volt generators connected in series, or alternating potential by an open-core transformer, Tr, excited by a 60-cycle, 220-volt power supply. The alternating potential was varied by a flexible lamp-bank resistance placed in the primary circuit of this transformer. The direct potential could be varied by the use of resistances placed in the field circuits of the generators. The current flowing through the gap at the moment of discharge was measured by a Weston A.C. voltmeter, calibrated to read in milliamperes. A high-resistance telephone receiver, P, shunted around a non-inductive resistance, R_2, served as a sensitive detector of oscillatory discharges and of the shorter sparks. Potentials were measured by a potentiometer system consisting of : — R, a specially constructed, non-inductive resistance of 600,000 ohms in steps of 20,000; R', a smaller resistance; the galvanometer, G; (all of Leeds & Northrup make); and the battery, B. The contactor or Joubert disk, C, was rotated by a synchronous motor connected in multiple with the alternating current supply. When making readings for comparison this contact was set for the peak of the alternating potential wave so that the readings indicated the maximum alternating potential. When measuring direct potential the Joubert disk was short-circuited by the switch, K_3. The Battery, B, had an E.M.F. of about 6 volts, checks being made from time to time against a Weston Normal cell. With the arrangement of

[1] Weicher, Electrotech. Zeitschr., 32, p. 463.

[2] Reisenfeld, Z. S. fur Elec. Chemie, 11, p. 725.

[3] Peek, Am. Inst. E. E. Proc., 33, p. 911.

[4] Watson, Jour. Inst. E. E., 43, p. 713.

the apparatus as shown the potential across the terminals of the potentiometer, hence also across the spark gap, is given by the equation,

$$\text{P.D.} = \frac{R + R'}{R'} E,$$

where E is the E.M.F. of the battery B.

The spark gap, S, is shown in detail in Fig. 2. Spark balls of Al and Cu, having 1 cm. radius, were used for most of the experiments. These balls could be easily removed from the tube for repolishing, which was done after each set of observations. The length of the gap could be

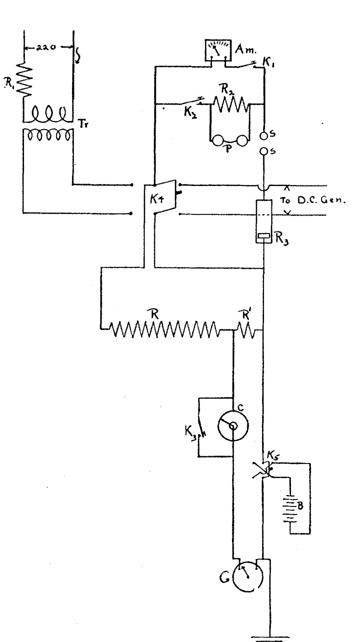

Fig. 1.

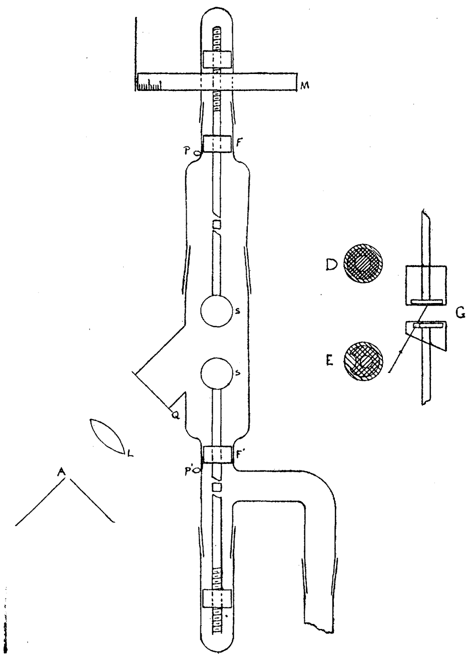

Fig. 2.

regulated by the micrometer drum, M, which had a circumference of 20 cm., making it possible to read within 1/200 of a thread on the screw, R. Platinum wires, P and P', connected respectively with the brass ferrules, F and F', through which the potential was applied to the balls. Initial ionization was furnished by the arc-lamp, A, whose ultra-violet light was focused on the upper electrode by the quartz lens, L, through the quartz window, Q. Plane electrodes of Cu and Al, constructed as shown in Fig. 2, D, E and G, were also used. The upper electrode, D (2 cm. in diameter), was covered by a piece of microscope cover glass (18 mm. in thickness), having a hole 1 cm. in diameter bored in the center.

This glass disk, which extended 2 mm. beyond the electrode on all sides, was cemented to a glass tube as shown at *G*. The glass hood was necessary in order to prevent a discharge from the edges of the electrode, and to make the field more nearly uniform. The lower electrode was similarly constructed except that a meniscus was cut from one side of it to permit of the passage of the ultra-violet light.

The gases used were air, N, H, and CO_2. These were carefully prepared and dried before using for from 12 to 24 hours in a chamber containing P_2O_5. In the case of the nitrogen (which was prepared by passing air over burning phosphorus to extract the O, and then removing any CO_2 present by leaving in contact with KOH) an unusual amount of ionization seemed present at times. This phenomenon was probably similar to that recorded by Schenck and Breuning[1] as the effect disappeared when the opening between the phosphorus tube and the drying chamber was kept closed and the gas stored for 24 hours or more before using.

Measurements.

The experimental difficulties connected with the making of measurements were not inconsiderable. The motors which drove the direct current generators are wound for 220 volts but it was found that the available direct current power was so fluctuating that it could not be used for purposes of research; fortunately, a set of 100 lead accumulators of size sufficient to drive the motors and excite the generator fields was at hand. The campus alternating current supply was generally quite steady, yet many readings were vitiated by the untimely advent of a motor load which caused momentary fluctuations. Moreover, the unusual atmospheric humidity during the time when most of the measurements were taken caused several breakdowns in the insulation of the armatures of the D. C. generators, with subsequent expense and delay.

In making a set of measurements the plan followed was to decrease the gap length slowly with the alternating potential applied, until a spark appeared. The distance taken was that given by the average of five readings of the micrometer, or more if the first five showed any appreciable variation. The corresponding potential was then observed, potentiometer settings being made both preceding and following those on the spark length. Immediately following this, direct potential measurements were made, the micrometer setting being that of the average of the five mentioned above, and the potential being gradually increased until the spark occurred. By taking these precautions results

[1] Schenck and Breuning, Deutsch. Chem. Gesell, Ber., 47, p. 2601.

were obtained which seldom varied as much as 1 per cent. in a set of five readings.[1]

For these direct potential measurements it was found that time could be saved by using a Weston voltmeter,—the voltmeter having been first checked with the potentiometer. The relative accuracy of the measurements can be judged by inspecting Tables I., II. and III. below,—the ± magnitudes indicating the mean variation observed.

TABLE I.

Cu Spheres, 1 cm. Radius in Hydrogen. Pressure 30 cm.

Spark Lengths, Mm.	Potentials.	
	D. C.	A. $C._{max.}$
3.175 ± .0025	2,915 ± 17.4	3,325
2.807 " .0013	2,672 " 3.6	3,070
2.413 " .0013	2,382 " 12.4	2,754
1.965 " .0013	2,060 " 6.0	2,363
1.575 " .0013	1,858 " 11.6	2,078
1.258 " .0013	1,596 " 4.4	1,763
.827 " .0013	1,245 " 2.6	1,464
.573 " .0013	1,046 " 4.0	1,133
.332 " .0013	769 " 4.0	891
.116 " .0013	538 " 3.0	661

TABLE II.

Cu Spheres, 1 cm. Radius in Hydrogen. 15 cm. Pressure.

Spark Lengths, Mm.	Potentials.	
	D. C.	A. $C._{max.}$
6.47 ± .0025	3,078 ± 12.0	3,341
5.886 " .0050	2,842 " 18.6	3,090
5.086 " .0038	2,500 " 3.6	2,755
4.185 " .0025	2,177 " 4.4	2,375
3.41 " .0013	1,842 " 4.0	2,052
2.776 " .0013	1,586 " 6.0	1,788
2.04 " .0013	1,283 " 3.0	1,395
1.39 " .0013	1,073 " 2.0	1,150
.91 " .0000	845 " 1.0	906
.45 " .0025	588 " 2.0	649

Since the investigations of Warburg[2] it has been generally agreed that in the case of direct potentials, the chief effect of illuminating a spark gap with ultra-violet light, X-rays, or cathode rays, is to diminish the " lag," and that the spark potential is but little affected. Investi-

[1] See Kemp & Stephens, Am. Inst. E. E. Proc., Jan., 1910.

[2] Warburg, Wied. Ann., 59, p. 1; 62, p. 385.

TABLE III.

Cu Spheres, 1 cm. Radius in N. Pressure 15 cm.

Spark Lengths, mm.	Potentials.	
	D. C.	A. $C_{max.}$
2.985 ± .0013		3,352
2.970 " .0013	2,975 ± 10.2	
2.833 " .0038	2,785 " 5.4	3,095
2.338 " .0013	2,423 " 13.2	2,720
1.907 " .0025	2,105 " 5.2	2,350
1.513 " .0013	1,763 " 5.2	1,990
1.208 " .0013	1,510 " 5.6	1,696
.916 " .0013	1,232 " 8.4	1,374
.637 " .0025	967 " 3.2	1,148
.485 " .0013	746 " 3.0	894
.241 " .0013	456 " 2.0	640

gators of alternating potentials are by no means unanimous on this point however. Kowalski and Rappel[1] contend that the relatively high results obtained by Steinmetz[2] are due to the fact that the latter provided no means for producing free ions in the spark gap. Weicher[3] found that illumination decreased the spark potentials, "Anfangsspannung," by several per cent., and Moreau[4] observed a similar effect. On the other hand, Kemp and Stephens[5] find this effect negligible; and Peek[6] after going over the whole field of evidence, comes to the same conclusion so far as ordinary frequencies and pressures are concerned. In the present experiment it was found that consistent results could not be obtained in a carefully dried gas without illumination, there being variations of as much as 20 per cent. in the potential obtained from setting to setting. It was observed further that after a discharge had taken place in a darkened room another discharge immediately afterwards would take place at a lower potential, but that a longer wait would eliminate this lowering. It was also found that, with the arc off, a given potential might be applied for five minutes or more without a spark, but that the spark would at once appear when the electrodes were illuminated. To test the effectiveness of the ultra-violet light as a producer of ions, a milligram of RaBr was put into the tube as a substitute, and readings taken. Curves 3, and 4, Fig. 3, show that the results were the same in both cases, so far as regularity of discharge is concerned.

[1] *Loc. cit.*

[2] *Loc. cit.*

[3] Weicher, Electrotech, Zeitschr., 32, p. 463.

[4] Moreau, Jour. de Physique, 8, pp. 16 and 94.

[5] *Loc. cit.*

[6] Peek, Dielectric Phenomena in High-voltage Engineering, p. 198.

The difference in magnitude undoubtedly arises from other causes. It thus appears that Warburg's explanation holds equally well for both direct and alternating potentials as regards providing a source of ions.

With the potentials available, spark distances at atmospheric pressure would have been very small, hence most of the readings were taken at a

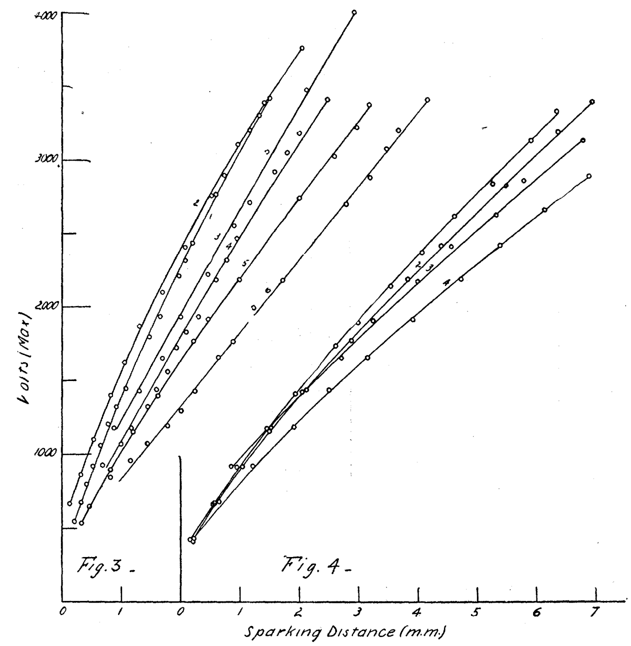

Fig. 3. Typical A.C. curves. 1. Al spheres (diam. 1 cm.) in air (press. 15 cm.). 2. Al spheres (diam. 1 cm.) in CO_2 (press. 15 cm.). 3. Al planes in air (press. 15 cm.). Ionizing agent: RaBr. 4. Al planes in air (press. 15 cm.). 5. Al spheres (diam. 1 cm.) in air (press. 10 cm.). 6. Al planes in air (press. 10 cm.).

Fig. 4. A.C. curves for hydrogen. 1. Al planes in H (press. 15 cm.). 2. Al spheres (diam. 1 cm.) in H (press. 15 cm.). 3. Cu spheres (diam. 2 cm.) in H (press. 15 cm.). 4. Al spheres (diam. 1 cm.) in H (press. 10 cm.).

pressure of 15 cm. Representative results are given in Tables I., II., and III., and in Figs. 3 to 9 inclusive.

A striking feature of all the curves is the increase in the potential gradient as the spark length decreases. Based on the work of Russell[1] and Dean,[2] Peek[3] gives the equation,

$$g_{\max} = Ef_0/X, \ KV/cm,$$

in which $g_{\max}$ is the gradient across a grounded sphere-gap in air, E the

[1] Russell, Phil. Mag., 11, p. 237.

[2] Dean, Phys. Rev., 35, p. 468.

[3] Peek, Dielectric Phenomena, p. 30.

applied potential, X the shortest distance between the electrodes and f_0 a function of the spark distance and the radius of the spheres. For ungrounded spheres,

$$f = \frac{X/R + 1 + \sqrt{(X/R + 1)^2 + 8}}{4},$$

and Peek shows that this holds approximately for grounded gaps also. Table IV. shows the result of a few calculations made on this basis from experimental data.

TABLE IV.

Potential.	Distance.	Gradient.	Data.
3,295 A.C.	2.949 mm.	12,290 volts/cm.	Cu Sph. in CO_2
2,939 D.C.	3.000	10,950	" " "
2,665 D.C.	2.708	10,800	" " "
3,030 A.C.	2.708	12,280	" " "
2,752 A.C.	2.378	12,540	" " "
2,482 D.C.	2.378	11,310	" " "
1,221 D.C.	.754	16,630	" " "
1,389 A.C.	.754	18,880	" " "
3,310 A.C.	3.360	11,060	" " air
2,400 A.C.	2.110	12,200	" " "
1,914 A.C.	1.470	13,680	" " "
1,420 A.C.	.890	16,450	" " "

Peek[1] accounts for this increased gradient with decreasing spark length on the ground that the conductors are so close together that the ion accelerating or energy storage distance is interfered with, requiring an increased gradient to produce sufficient ionic density. Almy[2] has shown that with direct current, a discharge does not occur under 340 volts in air. Values of the same magnitude were obtained with both Cu and Al spheres in H with alternating potential in the present experiment. Russell[3] objects to the energy storage view and accounts for the potential gradient as being caused by this minimum sparking potential. It does not, however, seem from the form of the curves, that this explanation is sufficient, for, on Russell's theory the curves could then as well be straight lines. Hayden and Steinmetz[4] give another explanation, namely; that when the available energy is limited the striking distance becomes a function of the energy rather than of the potential, the expression given being,

$$W = .3d_0^{1.5},$$

[1] Peek, Am. Inst. E. E. Proc., 32 (2), p. 1774.

[2] J. E. Almy, Phil. Mag. (6), 16, p. 456.

[3] Russell, Electrician, 62, p. 894.

[4] Hayden and Steinmetz, Am. Inst. E. E. Proc., 29, p. 1151.

for 3.8 cm. spheres in air, where W is the energy of the discharge in joules and d_0 the distance in cm.

It will be noted that all of the graphs given here show (Figs. 5–8) that the alternating maximum potential is higher than the direct, and that the relative differences are the same for all gases investigated, and also for the different electrode materials. Whitehead[1] explains this difference as due to a cumulative energy effect in producing ionization while Hubbard[2] believes that the lag interval is the time required to convert a gas from an insulator into a conductor. Peek[3] states that there is a given minimum time in which the rupturing energy must be applied to the dielectric, and that a steep wave front requires a higher potential than a flat one. Fig. 10 shows the wave form at different

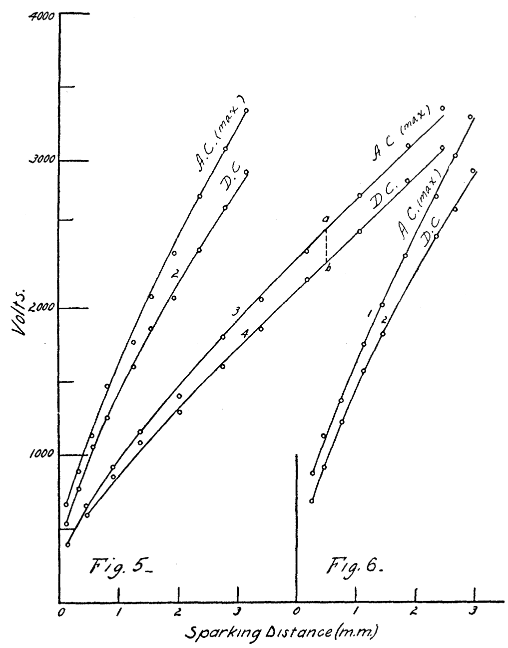

Fig. 5. A.C. and D.C. curves for H. 1. Cu spheres (diam. 2 cm.) (press. 30 cm.) A.C. 2. Cu spheres (diam. 2 cm.) (press. 30 cm.) D.C. 3. Cu spheres (diam. 2 cm.) (press. 15 cm.) A.C. 4. Cu spheres (diam. 2 cm.) (press. 15 cm.) D.C.

Fig. 6. A.C. and D.C. curves for CO_2. 1. Cu spheres (diam. 2 cm.) (press. 15 cm.) A.C. 2. Cu spheres (diam. 2 cm.) (press. 15 cm.) D.C.

amplitudes for the potentials used in this work. These curves were obtained by measuring the potential at points 5° apart on the circular scale attached to the Joubert disk for different values of the maximum

[1] Whitehead, Am. Inst. E. E. Proc., 29 (2), p. 1185.

[2] Hubbard, Phys. Rev., 32, p. 565.

[3] Peek, Dielectric Phenomena, p. 108.

potential, — 180° on the disk representing one cycle. The disk was mounted on a synchronous motor making 1800 R.P.M. This method of measuring the applied potentials has a distinct advantage over that used by some other observers, viz., multiplying the amplitude of the

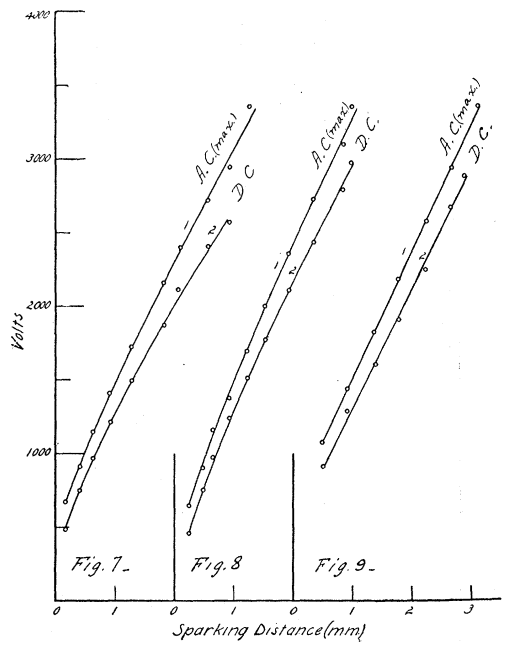

Fig. 7. In air. Cu spheres (diam. 2 cm.) (press. 15 cm.).
Fig. 8. In nitrogen. Cu spheres (diam. 2 cm.) (press. 15 cm.).
Fig. 9. In hydrogen. Al spheres (diam. 2 cm.) (press. 30 cm.).

primary potential by the ratio of transformation, in that it gives values directly and with a high degree of accuracy.

The curves show the presence of two principal secondary harmonics, and show that the wave form is practically constant for all potentials.

If, in any set of curves as shown in Figs. 5–8, the alternating and direct potentials corresponding to a given spark length be compared, and the time calculated from the wave form during which the alternating potential is above the value required to produce a spark of the same length with direct potential, the interval required to supply ionizing energy to the dielectric is obtained. For example the maximum potential shown by Curve 2, Fig. 10, is 2,550 volts. Referring to (*a*), (*b*), Fig. 5, we find that the D.C. spark potential corresponding to an A.C. spark potential of 2,550 volts is 2,300 volts. The time interval between the points (*c*), (*d*), Fig. 10, during which the A.C. potential is above 2,300 volts is found to be 23.5°, which corresponds to .00218 sec. Table V. shows a series of such computations. It is evident that the variation from the

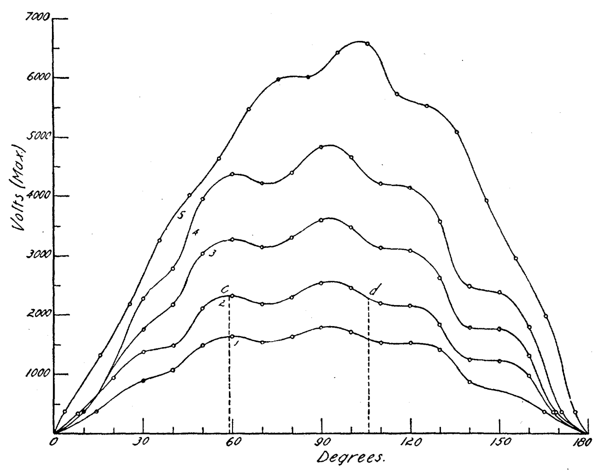

Fig. 10.

Wave forms. 1, 2, 3, 4. Open core transformer. 5. Potential transformer.

mean is small considering the difficulties connected with the method used for its determination.

TABLE V.

Data.	Pressure.	Potential.	Interval.	
Cu Sph.	Air 15 cm.	2,520 A.C.$_{max.}$	2,220 D.C.	.00245 sec.
" "	" "	1,760	1,520	.00263
" "	N "	2,550	2,280	.00231
" "	" "	1,760	1,560	.00245
" "	H 30	2,550	2,200	.00259
" "	" "	1,760	1,600	.00241
" "	" 15	2,550	2,335	.00208
" "	" "	1,760	1,590	.00231
" "	CO_2 "	2,550	2,280	.00231
" "	" "	1,760	1,570	.00241
Al Sph.	H "	2,550	2,300	.00199
" "	" "	1,750	1,630	.00221
" "	" 30	2,550	2,260	.00236
" "	" "	1,750	1,510	.00268
" "	N 15	1,750	1,530	.00264
" "	Air "	2,550	2,340	.00213
" "	" "	1,750	1,520	.00263
			Mean = .0024	

If the time required for energy absorption is the correct explanation of the relation of alternating to direct spark potentials, then all maximum potentials should lie above the direct, and mean effective values would be significant only when they include a reference to the wave form. Warburg[1] by suddenly applying direct potentials, was able to obtain a spark from an illuminated electrode in .0012 sec., or about one half the time interval of Table V. This is not necessarily contradictory evidence, however, for it is well known[2] that the sudden application of a potential has the effect of increasing the striking distance because of the large transient voltages produced. This fact was repeatedly observed in the present experiments, both with direct and alternating potentials. In fact modifications had to be made in the method of procedure in order to avoid these high, transient voltages. Kowalski and Rappel[3] give mean effective values which, if multiplied by the usual amplitude factor, 1.414, would lie considerably above corresponding direct potentials, but here again the real value of the comparison depends on the wave form.

If, however, the essential difference between alternating and direct spark potentials, as above stated, lies in the time required to transmit an amount of energy to the gas sufficient to produce sufficiently great ionization, the frequency of alternation should affect the maximum potential value. But Toepler[4] found no appreciable variation with frequency up to 10^6 cycles per second and irregular values above that number; and Whitehead and Gorton[5] observed only a 3 to 4 per cent. increase in corona voltages at 200 cycles as compared with 60 cycles. Yet in such cases and in all experiments with oscillatory potentials, the conditions approximate those of sudden impulse with high maximum gradient, while with a broad wave such as the one here used they are more nearly those of a gradually increasing electric force. Further investigations of this point are contemplated.

While this work was in progress E. Merkel[6] published an article covering to some extent the same ground. This investigator so regulated his power supply that he could produce discharges of large current density in the secondary circuit, one of those recorded being 1.45 Amp. $_{\text{eff.}}$ Because of the peculiar form of his curves (see Fig. 11) an effort was made to duplicate his results. Observations were made with different gases, at various pressures, and with both plane and spherical electrodes. The curves in Figs. 3 and 4 represent a few of the results obtained and are typical of them all. In these investigations the reactance and

[1] Warburg, Sitz. Akad. der Wissenschaften, XII., p. 223.
[2] Kemp and Stephens, Am. Inst. E. E. Jour., Jan., 1910.
[3] *Loc. cit.*
[4] *Loc. cit.*
[5] Whitehead and Gorton, Am. Inst. E. E. Proc., 33, p. 934.
[6] E. Merkel, Ann. der Physik, 43 (5), p. 725.

resistance in the spark circuit were such that the current for the highest potentials was about .007 ampere. For lower potentials the current following the advent of the spark became less and less until too small for accurate determination with the milliammeter used. In all of these cases the relation of potential to spark length was nearly linear, and in no case was there any suggestion of the anomaly as shown by Merkel. The steadying effect of illumination by ultra-violet was used in both cases.

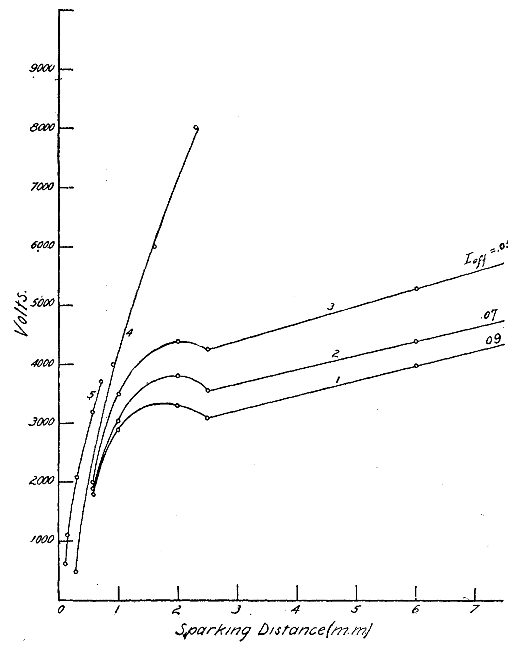

Fig. 11.

Air at normal pressure. 1. Cu electrodes—A.C. (effective), .09 amp. (eff.). Merkel. 2. Cu electrodes—A.C. (effective), .07 amp. (eff.). Merkel. 3. Cu electrodes—A.C. (effective), .05 amp. (eff.). Merkel. 4. Cu electrodes—D.C. Merkel. 5. Al electrodes—A.C. (max.), pressure, 73.9 cm. Jensen.

The only differences in our conditions of operation appear to be in the current density of discharge for various potentials—his being much larger than mine and constant throughout a set of potential-spark length determinations.

In order to obtain greater current densities than were possible with the open-core transformer used for the results so far given, two potential transformers of the closed-core type were used. These were so arranged that their secondaries could be connected either in series or in multiple, making possible secondary currents up to .1 ampere. The wave form of this combination is shown in graph number 5, Fig. 10. It having been found impracticable to duplicate Merkel's curves—(1, 2, 3, Fig. 11) with respect to constant current densities over their entire range, the problem was attacked from a different angle. Reference to these curves shows that for a 1.5 mm. spark in air at atmospheric pressure the potential should vary by 15 to 20 per cent. if the current density of the discharge be doubled. In Table VI., is shown a series of results obtained

TABLE VI.

Al Spheres. 1 cm. Radius in Air. Pressure 73.5 cm.

Potential.	Spark Length.	Current.
6,810 A. $C._{max.}$	1.390 mm.	.0275 I_{eff}
6,810	1.410	.1030
6,810	1.340	.0424
6,810	1.365	.0280
5,380	1.067	.0280
5,380	1.030	.0080
5,230	1.015	.0370
5,230	1.080	.0120
4,190	.940	.0125
4,190	.990	.0070

with air at atmospheric pressure, the currents and spark lengths being of the order of those involved in the portion of Merkel's curves under discussion. Observations were readily reproducible, the values given being in most cases averages of five sets of readings. In each pair of observations the conditions as to temperature, polish of electrodes, etc., were as nearly identical as possible.

One of the characteristics of Merkel's observed anomaly is that with increasing current density of discharge, the necessary potential decreases. Referring to Table VI., it will be noted that for a given potential the spark length remained practically constant even for a range of current densities from one to four times the lower value, the gas, electrodes, and pressure remaining unchanged. Since Merkel's observed variation was through only half this range, the explanation for the hump in his curves must be sought in another direction.

Merkel states that Guye and Monasch,[1] who had performed experiments in this field, explained this "critical zone" comprising the hump as due to resonance phenomena, a condition which he sought to obviate by the method he used to measure potentials. But a careful study of

[1] Guye and Monasch, L'Eclairage Elec., 34, p. 305; 35, p. 18.

his apparatus does not seem to substantiate this contention, for the capacity of the spark gap he used would be appreciable and would vary with the spark length, and the inductance introduced into the oscillatory circuit by his electrodynamometer must also be accounted for. Whitehead and Gorton[1] observed a resonance condition which persisted over a wide range, and Peek[2] called attention to the necessity of using a series resistance in the spark circuit to prevent irregular effects due to high, transient voltages. The writer found evidence of such disturbances in a few instances only, when working at the lower pressures and greater spark lengths; also with the higher potentials when using the larger transformers. This would seem to indicate that the capacity here used was smaller than Merkel's. The disturbance caused by the static spark mentioned by Peek was also noticed, particularly when the liquid resistance in the circuit was much reduced in order to make observations with large current density. In the intensely lighted gap it was often impossible to see these minute sparks, but by the use of the telephones they could be easily heard, a considerable number of them sometimes passing before the true disruptive spark, capable of affecting the ammeter, was heard. That these were not point discharges due to an electrode surface roughened by repeated heavy sparks is shown by the fact that the phenomenon also occurred before the first disruptive discharge while the surfaces were still highly polished. In fact, the electrodes were not permitted to become appreciably disfigured, and an examination of the planes showed that the discharge took place fully as much in the center of the exposed circle as at the edges of the glass cover.

Oscillatory conditions such as those above mentioned were probably present in the apparatus used by Merkel, a conclusion which is fully justified by a study of his oscillograph curves. Inasmuch as the anomalous condition he observed is contrary to generally accepted principles, this explanation seems at least a plausible one.

Summary.

1. In the present investigation alternating and direct spark potentials have been measured under exactly the same conditions—the gas, electrodes, and pressure being identical throughout.

2. It has been shown that the effect of illumination by ultra-violet light of a gap supplied with alternating potential is essentially the same as that observed by Warburg for direct potential; and, in addition, that the presence of an abundance of ions lessens the irregular influence of transient voltages due to static and resonance phenomena.

[1] Whitehead and Gorton, Am. Inst. E. E. Proc., 33, p. 934.

[2] Peek, Am. Inst. E. E. Proc., 33, p. 911.

3. The time interval during which the alternating potential must be above that necessary to produce a spark by direct potential was found to be practically the same for all conditions as regards gases, electrodes, and pressures, the alternating maximum potential always lying above the corresponding direct one.

4. An attempt to reproduce evidence that, with an increase of current density of discharge, there is a corresponding decrease of spark potential, gave negative results, all indications tending to show that such an effect must be due to resonance in the discharge circuit.

In conclusion, the writer wishes to express his thanks to Professor Skinner for suggesting this investigation and for his continued interest in its progress; and to Professor Almy and Dr. Tate for valuable suggestions in overcoming experimental difficulties.

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LINCOLN, NEB.,
April 1, 1916.