Sphere-Gap Voltage Measurements.

By

A. J. Small, B.Sc., A.M.I.E.E.

A Thesis for the Degree of Ph.D.
in the Faculty of Engineering
of Glasgow University.

May, 1937.

CONTENTS.

Appendix I.

The Employment of Neon Lamps in Electrical Measurements.

-------o0o-------

INTRODUCTION.

The following is a description of the installation and testing of a 2 cm. sphere-gap as a standard of high-voltage measurement in the Electrical Engineering Department of the James Watt Laboratories of Glasgow University.

Particular study has been made of the procedure necessary to obtain the greatest possible consistency in the results, and to determine the factors which most affect this consistency. Experiments were continued until, by process of elimination, the only variable factors occurring appeared to be in the quantity measured.

E.R.A. Standard Values.

The values of the breakdown voltage relative to gap spacing recommended by the Electrical Research Association (E.R.A.) and adopted by the British Engineering Standards Association are given in Table 1 on the following page.

It is the purpose of the experiments described herein, to ascertain how nearly these values are approached by the apparatus available. The comparison of the experimental values with the E.R.A. values is carried out by inserting the experimental points on the standard curves Fig. I plotted from the values given in Table 1.

B.E.S.A. Specification Nº 358 – 1929.

Table 1.

Sparkover Voltage
for 2cm. Sphere Gap.

kV. (r.m.s.)	Gap mm.
10	3·85
11	4·35
12	4·85
13	5·35
14	5·83
15	6·32
16	6·84
17	7·38
18	7·92
19	8·45
20	9·00
21	9·60
22	10·25
23	11·00
24	11·75
25	12·55

Temperature 25°C.
Barometric Pressure } 760 mm.

Table 2.

Air Density
Correction Factors.

Relative Air Density	Factors
0·50	0·572
0·55	0·617
0·60	0·661
0·65	0·705
0·70	0·748
0·75	0·790
0·80	0·833
0·85	0·875
0·90	0·917
0·95	0·959
1·00	1·00
1·05	1·041
1·10	1·082

SPHERE-GAP VOLTAGE MEASUREMENT.

Curves for 2 cm. diameter Spheres.

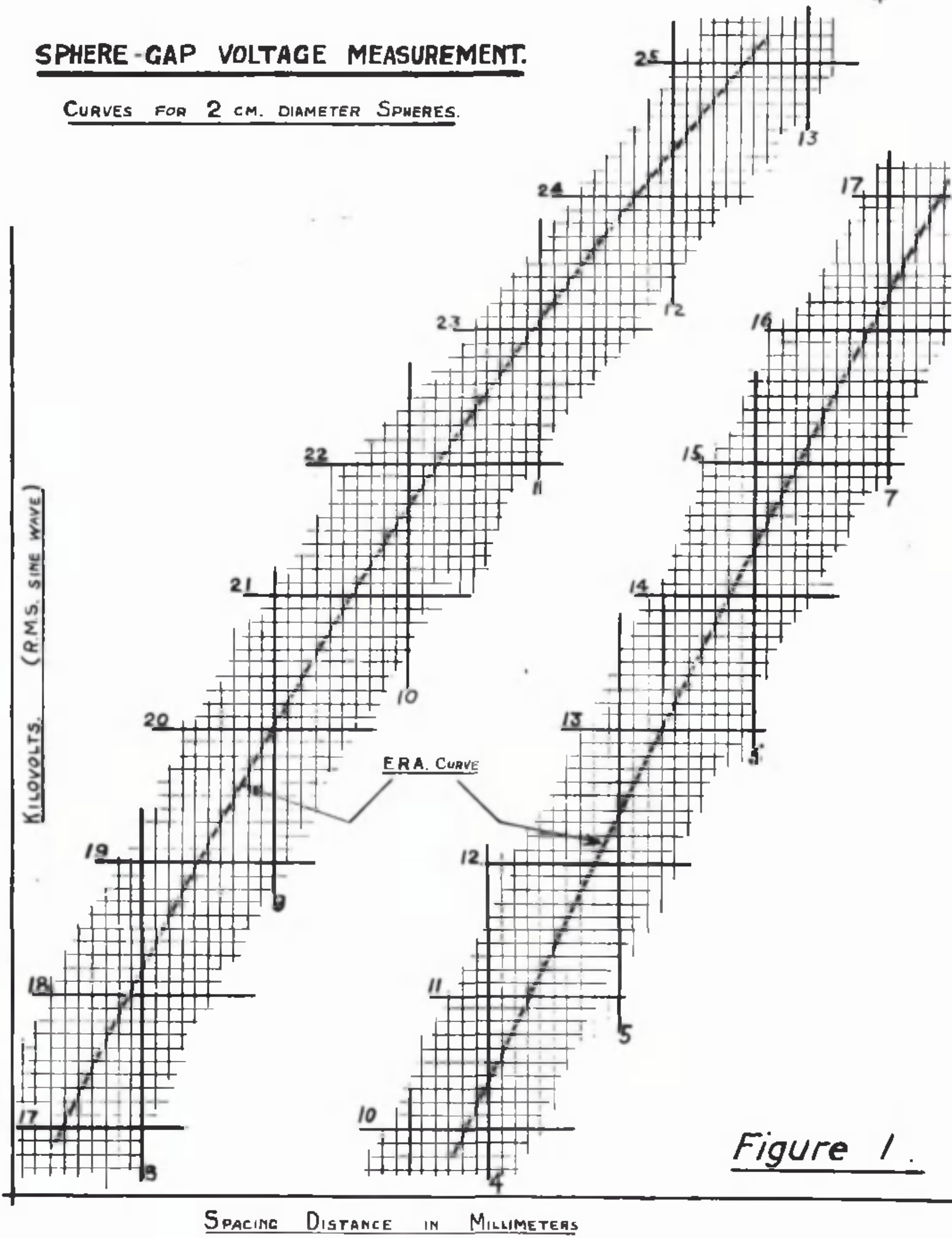


Figure 1.

Atmospheric Conditions.

For a given gap setting the spark-over voltage increases with increase of air density, that is, it increases with rise of barometric pressure and with fall of temperature.

The relative air density, δ is given by the expression

$$\delta = \frac{0.392 \times b}{273 + t}$$

where b = barometric pressure in mm.
and t = temperature in degrees centigrade

The correction factors corresponding to a given air density and unchanging humidity are given in Table 2 and apply if the variation from sea level is not great. For air densities above 0.9, the correction factor differs but slightly from the value of the air density. Consequently, the correction factor may be taken as equal to the air density.

"For a given gap spacing, the actual value of spark-over voltage is given by the product of the voltage obtained from Table 1 and the factor given in Table 2."

For a given voltage the gap setting is determined by dividing this voltage by the correction factor (Table 2) and reading off the corresponding spacing from Table 1.

The procedure adopted has been to measure the breakdown voltage for a given gap setting. For convenience in the comparison with the E.R.A. values all these experimental observations of breakdown voltage have been referred to the same standard values of temperature and pressure (25°C. and 760 mm.) by dividing them by the correction factor, which in all cases has been taken as equal to the relative air density.

The humidity of the atmosphere in the room in which the experiments were performed was considered to be of sufficient constancy that its effect on the breakdown strength of the gap was negligible. It is recognised that unusually low or high humidity may cause a loss of accuracy. Also if the humidity of the atmosphere is changing the results are expected to be erratic.

<u>High Voltage Supply</u>.

The 50-cycle supply was obtained from either

(a) 30 kVA, 400 V, 8-pole, 3 phase alternator,

or (b) 10 kVA, 600 V, 6-pole, 3 phase alternator.

The stator windings of both of these machines could be star or delta connected as desired, and in addition each phase was brought out in two halves for series or parallel connection. The fields were supplied through slip-rings from 125 and 250 volt batteries.

This a.c. supply was stepped up by a single phase, oil-immersed, 10 kVA transformer having a nominal ratio of 660 to 101,700 volts. The primary applied voltage could be varied continuously and conveniently by means of (a) resistance in the alternator field circuit, or (b) a single phase, 10 kVA induction regulator giving a voltage variation from zero to twice the alternator voltage.

The circuit is diagrammatically indicated in Fig. 2.

Three calibrated voltmeters were used at various times for measuring the primary voltage.

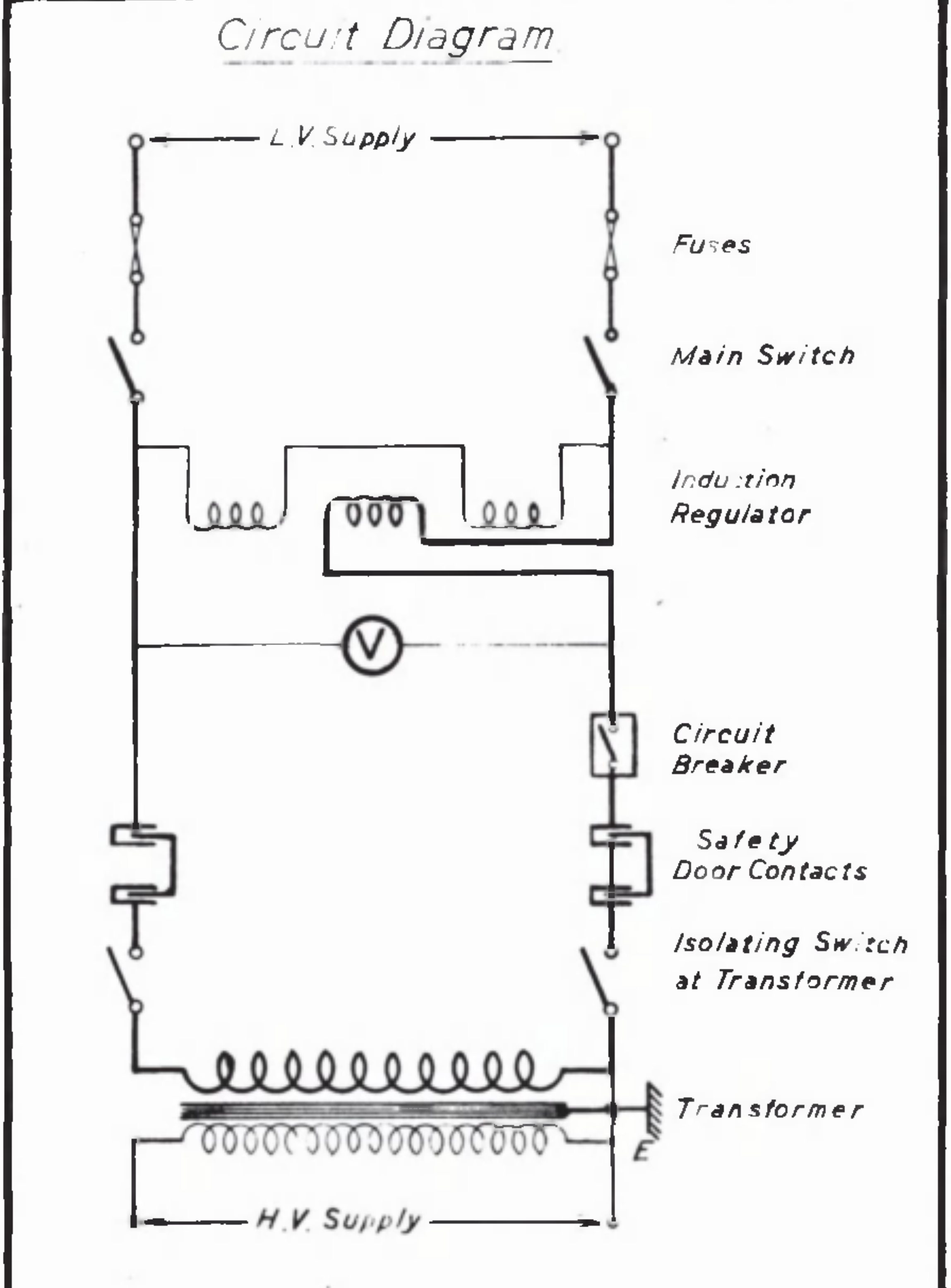

Circuit Diagram
L.V. Supply
Fuses
Main Switch
Induction
Regulator
V
Circuit
Breaker
Safety
Door Contacts
Isolating Switch
at Transformer
Transformer
E
H.V. Supply

Figure 2.

Sphere Gap Details.

The spheres were mounted on a wooden framework as shown in Fig. 3, the joints in the wood being secured with wooden pins. The only metal present therefore was that supporting the shanks carrying the spheres. The design of the gap was based on the proportions given by Farnsworth and Fortescue.* The clearances around the gap are in agreement with those recommended by the E.R.A.ø

The spheres were the standard 2 cm. diameter brass spheres supplied by Messrs. Baird & Tatlock by arrangement with the E.R.A. Six of these spheres were used in the course of the investigations.

The micrometer was fitted to the lower sphere which was earthed. Since this micrometer was scaled in inches it was considered more accurate to set the gap spacings in steps of twentieths of an inch instead of millimetres. This accounts for the gap lengths in the tables being stated in millimetres and fractions of millimetres. The corresponding lengths are:-

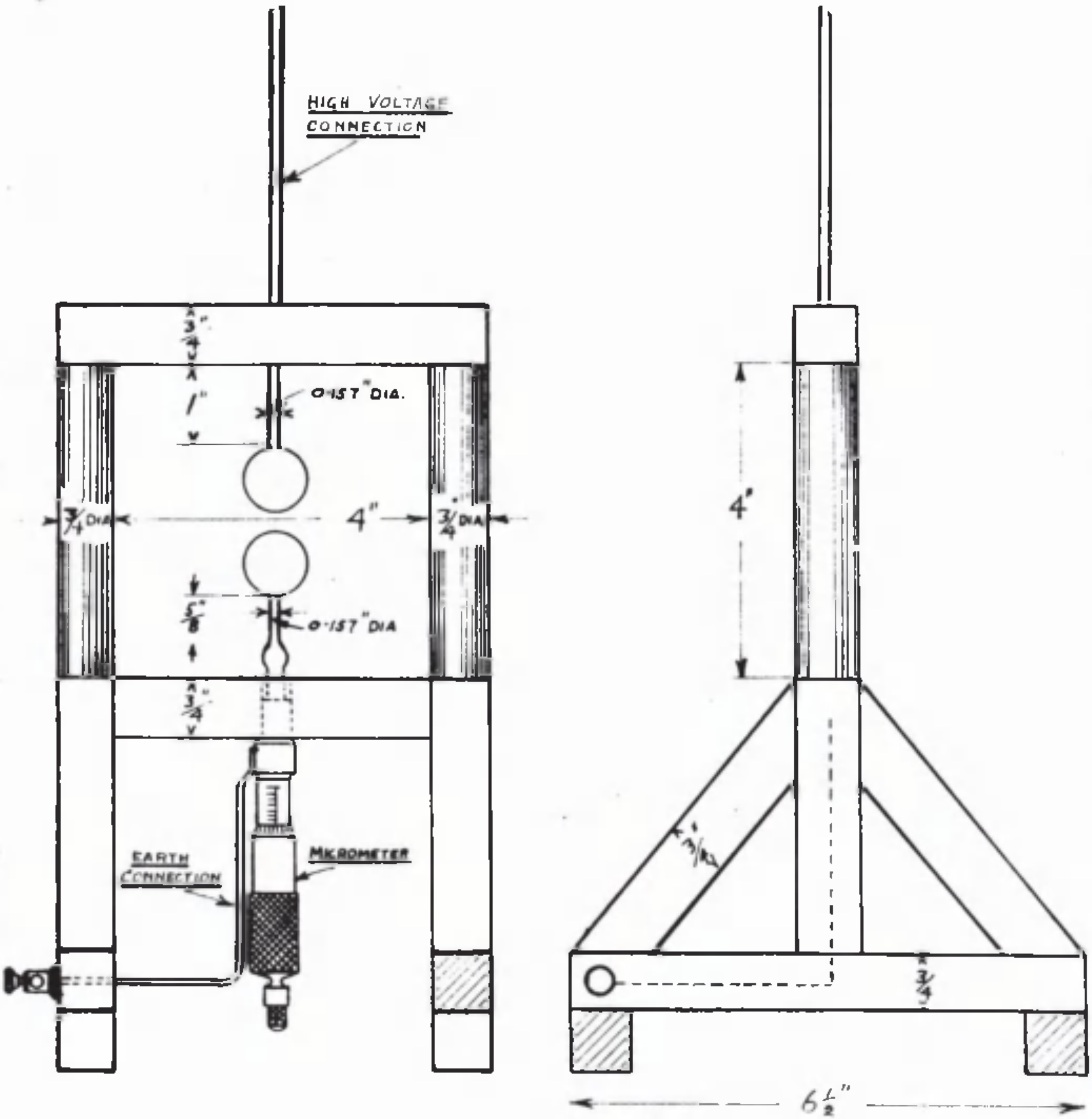
inches:	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
millimetres:	3.81	5.08	6.35	7.62	8.89	10.16	11.43	12.70

* S. W. Farnsworth and C. L. Fortescue, Elect. Eng., 32.1. pp. 733-737, 1913.

ø S. Whitehead & A. P. Castellain, I.E.E.J. 69, pp. 898-921, 1931

Figure 3.

DETAILS OF 2 CM. SPHERE GAP.



SCALE :- HALF FULL SIZE.

Protective Resistance.

A water-tube resistance was used in series with the high voltage lead. This resistance was in the form of two glass U-tubes filled with weak brine and mounted side by side to enable them to be easily connected in series or parallel as required.

One of the electrodes in each of the tubes could be lowered to any desired extent into the electrolyte, thereby allowing the resistance to be varied over a wide range. This method of varying the resistance proved to be more convenient than altering the conductivity of the electrolyte.

Before taking observations at any gap setting the resistance was adjusted to approximately one ohm per volt by means of a Bridge-Megger.

As shown in Figure 4 the resistance is mounted on tall insulating supports thus removing all high voltage conductors from the immediate neighbourhood of the spark gap.

Position of Gap and Neighbouring Bodies.

The position of the gap with respect to other apparatus was kept constant throughout all the tests, as it was realised that the electric field distribution might otherwise be appreciably altered. All conductors, earthed or live, were kept as far as possible away from the gap. Figures 5 and 6 indicate the position of the various objects in the neighbourhood of the

Figure 4.

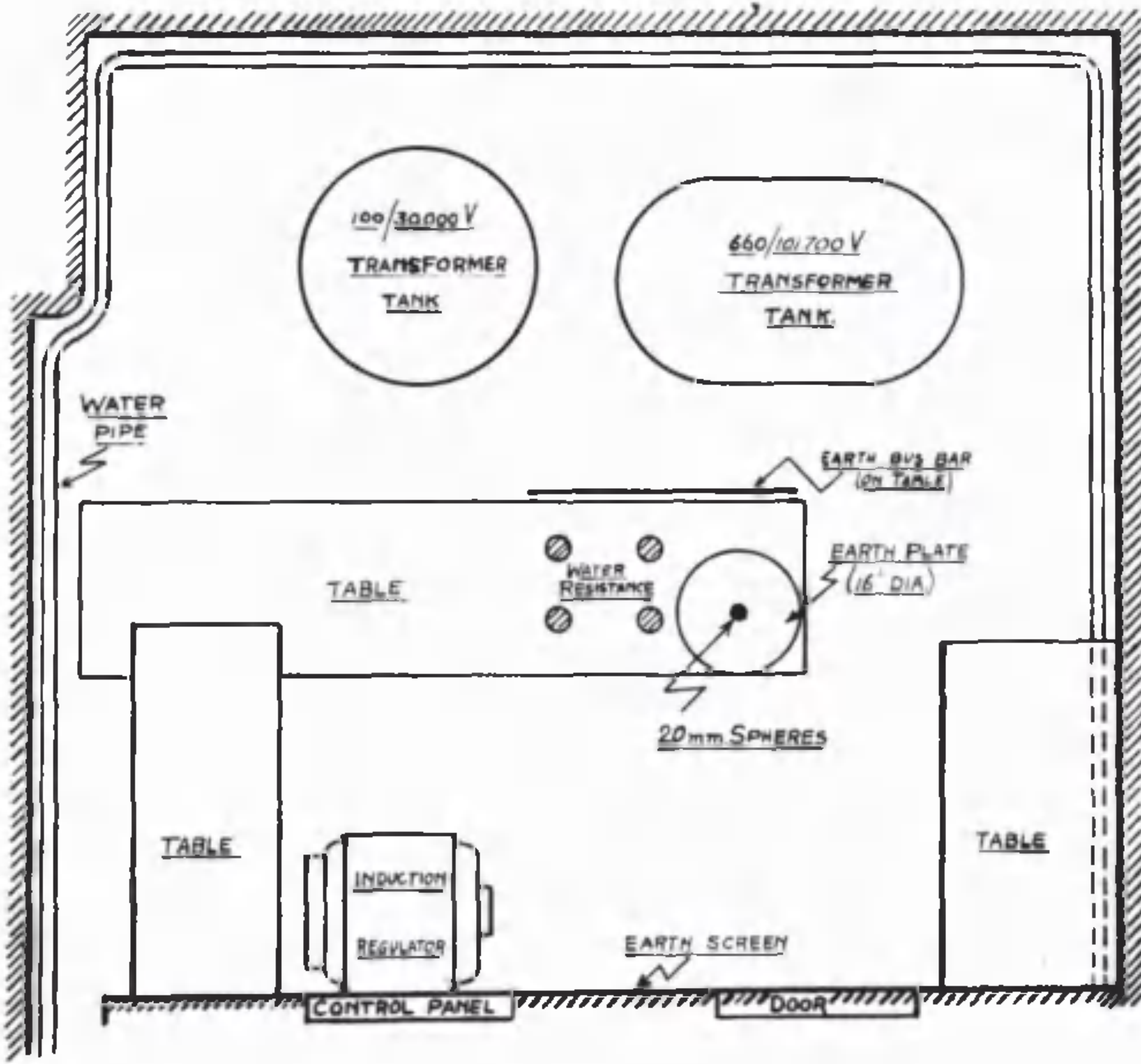


Figure 5.

PLAN OF
H.T. LABORATORY
Showing
layout of
apparatus
near
sphere-gap.

Scale: ½ inch = 1 ft.

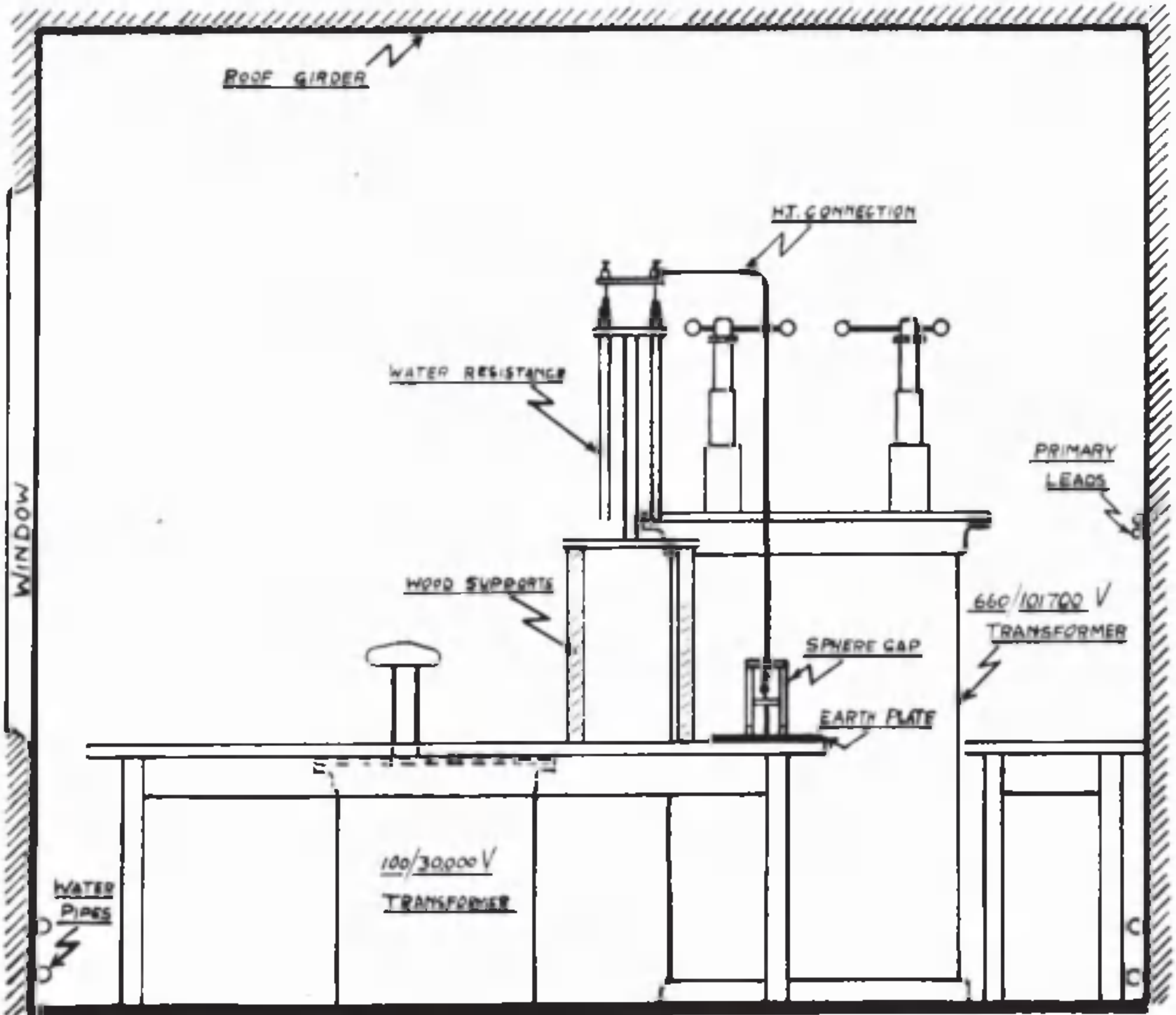


Figure 6.

Layout of apparatus near sphere gap.

Scale: ½ inch = 1 ft.

gap and from these figures it may be clearly seen that all earthed objects above the level of the earth plate are more than 30 inches from the gap. The earth plate, (see Fig. 4) consisted of a zinc plate 16 inches diameter.

To ensure further, that as many conditions as possible remained constant the experiments were carried out in a completely darkened room except for the lamp illuminating the voltmeter scale. The ionisation of the gap by sunlight was thus prevented and any ionising agents such as corona from h.t. leads, etc., if present, would be approximately constant from one experiment to another.

Numerous preliminary tests were carried out to establish a definite experimental procedure. In most cases these tests were followed by appropriate modifications to the apparatus. Only the more important of these modifications however are recorded. The test methods to be described will be seen to incorporate much of the experience gained in these earlier experiments.

Surface of Spheres.

The methods of preparing the spheres consisted in rubbing them in the lathe with oiled rouge emery (blue backed paper) until all marks of previous discharges were removed. After mounting in position the spheres were wiped with a chamois leather dipped in absolute alcohol, thus removing any oil or grease film. After about 20 repeated discharges the spheres were allowed to cool thoroughly and observations were commenced. Care was taken not to handle the spheres after mounting in position and wiping.

These preliminary discharges are now recommended for all small sphere gaps in order to remove dust or residues of polishing materials.* It would appear that any very slight differences in the polished surface are removed and the conditions standardised by the passage of the discharge. M. Toepler[x] goes as far as to say that, with newly polished spheres, a stable value is to be expected only after 100 discharges have passed.

<u>Effect of a Blast of Air</u>.

Fibres adhering to the sphere surface have been[ø] suggested as a possible cause of inconsistency in sphere gap observations, since they are capable of alignment and consequent reduction of breakdown voltage.

The Comité Electrotechnique Suisse recommend a blast of air through the gap but so far, this does not appear to have found sufficient favour in this country to be included in the standard recommendations.

To investigate this point a number of observations were taken with a fixed gap length and the sparkover voltage found

---

* S. Franck, Archiv. f. Elektrot., 8, pp. 485-486, 1934.

x M. Toepler, Archiv. f. Elektrot., 6, pp. 429-442, 1932.

ø E.R.A. Report L/T16, 1926.

with still air and then with air at various velocities blown across the gap by a fan about one yard distant.

An air velocity of about 100 ft. per minute at the gap was found convenient and did not cause any serious disturbance of dust, etc. in the room.

Readings representative of the behaviour under these conditions are given in Table 3 and are for a gap of 0.3 inch.

On comparison it is seen that the mean values of each set of ten readings agree very well, but there is less dispersion of the readings when a current of air is blown across the gap. Similar conditions were observed at other spacings.

During these experiments it was observed that immediately after breakdown occurred the arc was blown away from the shortest gap. On subsequent examination of the sphere surface the discolouration was found to be spread over a much greater area. Consequently it seems reasonable to assume that there is a considerable reduction in the "pitting" of the surface of the spheres in the active part of the gap.

In addition to the scavenging action of the air current across the gap there is also the improved cooling effect which may contribute to the decrease in the dispersion of the results.

The improvement observed with this air blast was considered of sufficient importance to warrant its employment in all succeeding observations. The possibility of dust being blown into the gap by the fan seems unlikely after air conditions had become steady in the relatively small room in which the

Table 3.

Gap Length 0·3 cm.

Still Air	Moving Air	
16·88	16·98	
17·01	16·95	
17·07	17·01	
17·01	17·04	
17·04	17·04	
16·92	17·04	
17·01	16·92	
17·04	16·92	
16·88	17·01	
17·07	16·98	
16·99	16·98	Mean
+0·08	+0·06	Dispersion
−0·11	−0·06	
+0·48	+0·35	Percentage Dispersion
−0·66	−0·35	

experiments were performed. In the event of any dust particles being blown into the gap there would have been such a great reduction in the breakdown voltage as to warrant that particular observation being ignored.

Application of the Voltage.

When the induction regulator was used the voltage was raised very gradually from zero to the breakdown value by slowly turning the regulator handle which was coupled to the rotor through a worm drive.

With the induction regulator cut out and the supply voltage regulated by means of the excitation of the alternator, not more than 30% of the sparkover voltage was switched in and thereafter the voltage gradually raised to the sparkover value by cutting out resistance in the field circuit. At first trouble was experienced with this method but was finally traced to a faulty sliding contact on the wire resistances. Redesigning the contact and replacing the slider by a screw feed the contact could be driven forward slowly and uniformly. This arrangement proved entirely satisfactory and was employed as the final critical adjustment of the excitation to produce sparkover. The total time required to raise the voltage to the breakdown value was from 15 to 20 seconds.

The circuit breaker was critically set so as to open the circuit as soon as possible after sparkover occurred, thus reducing the temperature rise and the pitting of the sphere surface to a minimum.

Sufficient time was allowed between successive discharges to prevent any temperature and/or ionising effects of a previous discharge affecting the results. The layer of air surrounding the spheres and in the gap might conceivably be ionised and thus cause a reduction in the sparkover voltage. The air blast across the gap ensures rapid removal of any such ionisation.

Table 4 demonstrates this effect. Readings "b" and "c" were taken as soon as possible after reading "a" in each set of three. Whereas after reading "c" of one set an interval of at least 90 seconds was allowed to elapse before reading "a" of the next set was taken. From these results the effects of the previous discharge can be taken as completely dispelled after this interval of time.

Since carrying out this investigation, very similar results have been published by J. Claussitzer.* To avoid surge effects he recommends that the initial applied voltage should not exceed 20% of the sparkover value and that 30 seconds should be taken to rise to the breakdown value if the voltage is raised in small steps. It is further recommended that at least one minute should elapse before the next discharge. These values are employed up to 700 kV.

In Table 5 is given a complete set of observations embodying the various points of procedure already discussed,

---

* J. Claussitzer, E.T.Z., 57, pp. 177-180, Feb. 13, 1936.

Table 4.

BREAKDOWN KILOVOLTS.

2·54	3·81	5·08	6·35	7·62	8·89	10·16	11·43	12·70	Gap (mm) Length
7·01	9·64	12·26	14·41	17·14	19·14	21·28	22·95	24·35	a
6·85	9·54	12·16	14·19	16·46	19·14	21·04	22·95	24·19	b
6·85	9·54	12·10	14·19	16·76	18·93	20·97	22·79	24·19	c
7·01	9·79	12·38	14·72	17·27	19·40	21·22	22·95	24·19	a
6·85	9·67	12·16	14·50	17·06	18·93	20·97	22·95	24·19	b
6·76	9·64	12·16	14·35	16·84	18·93	21·04	22·73	24·04	c
6·76	9·89	12·22	14·69	17·06	19·31	21·22	23·04	24·04	a
6·53	9·64	12·07	14·60	16·90	18·93	21·13	22·95	24·04	b
6·57	9·64	12·07	14·50	16·74	18·93	21·13	22·73	24·04	c
6·98	9·86	12·54	14·69	16·96	19·24	21·22	23·26	24·19	a
6·79	9·82	12·16	14·60	16·83	19·09	21·13	23·04	24·13	b
6·79	9·64	12·16	14·50	16·74	18·93	21·04	23·04	24·04	c
6·94	9·79	12·35	14·63	17·11	19·30	21·24	22·79	24·19	Mean of "a" values.
	9·95	12·42	15·05	17·43	19·80	21·82	23·60		E.R.A. Value.

Table 5.

BREAKDOWN KILOVOLTS.

2·54	3·81	5·08	6·35	7·62	8·89	10·16	11·43	12·70	Gap (mm.) Length
7·03	9·08	12·31	14·68	17·00	19·03	21·27	22·83	22·70	
6·90	9·73	12·34	14·58	17·05	19·18	21·18	22·70	24·10	
6·84	9·67	12·22	14·70	17·10	19·15	21·27	22·77	24·07	
7·06	9·80	12·44	14·74	16·98	19·21	21·24	22·74	24·07	
6·84	9·73	12·53	14·74	17·05	19·18	21·09	22·80	24·10	
6·93	9·55	12·28	14·58	17·13	19·12	21·12	22·77	24·10	
6·84	9·70	12·28	14·74	16·98	19·24	21·18	22·77	24·07	
6·81	9·55	12·28	14·74	17·05	19·12	21·18	22·74	24·04	
7·06	9·64	12·25	14·70	17·05	19·21	21·27	22·77	24·07	
6·81	9·70	12·38	14·76	17·02	19·24	21·18	22·80	24·10	
6·91	9·69	12·33	14·70	17·05	19·17	21·20	22·77	24·08	Mean
	9·95	12·42	15·05	17·43	19·80	21·82	23·60		E.R.A. Value
+0·15	+0·11	+0·20	+0·06	+0·08	+0·07	+0·07	+0·06	+0·02	Dispersion
−0·10	−0·14	−0·11	−0·12	−0·07	−0·14	−0·11	−0·07	−0·04	
+2·17	+1·14	+1·60	+0·41	+0·47	+0·37	+0·33	+0·26	+0·08	Percentage Dispersion
−1·45	−1·44	−0·89	−0·82	−0·41	−0·73	−0·52	−0·31	−0·16	

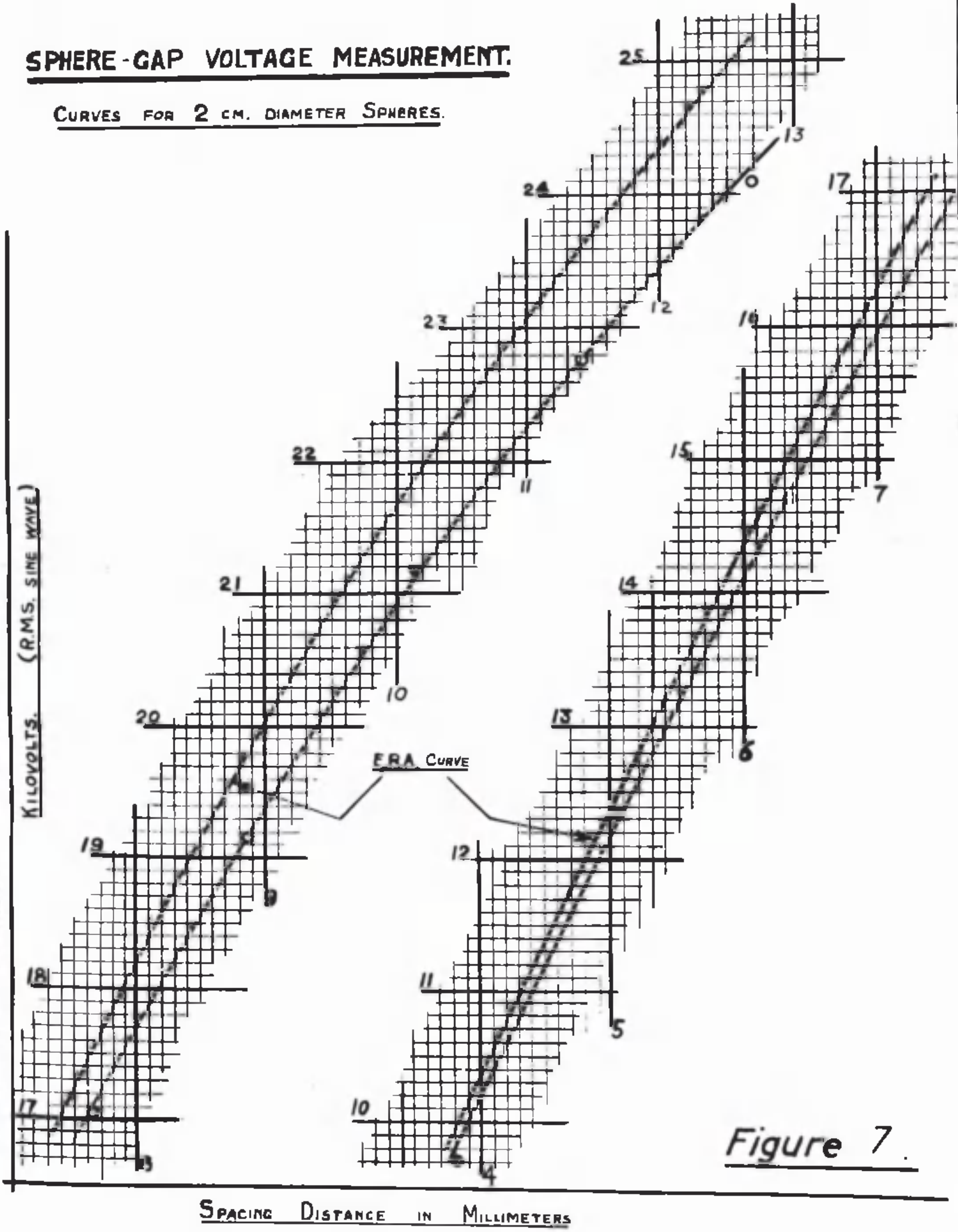

SPHERE-GAP VOLTAGE MEASUREMENT.
CURVES FOR 2 CM. DIAMETER SPHERES.
KILOVOLTS. (R.M.S. SINE WAVE)
E.R.A. CURVE
SPACING DISTANCE IN MILLIMETERS
17
18
19
20
21
22
23
24
25
3
9
10
11
12
13
4
5
6
7
12
13
14
15
16
17
10
11

Figure 7.

i.e. spheres cleaned immediately before test; at least 20 discharges occurred before readings started; air velocity at gap 100 ft. per minute; 90 seconds between each reading.

Ten readings were taken at each gap setting and the mean value plotted, Fig. 7, and compared with the E.R.A. value.

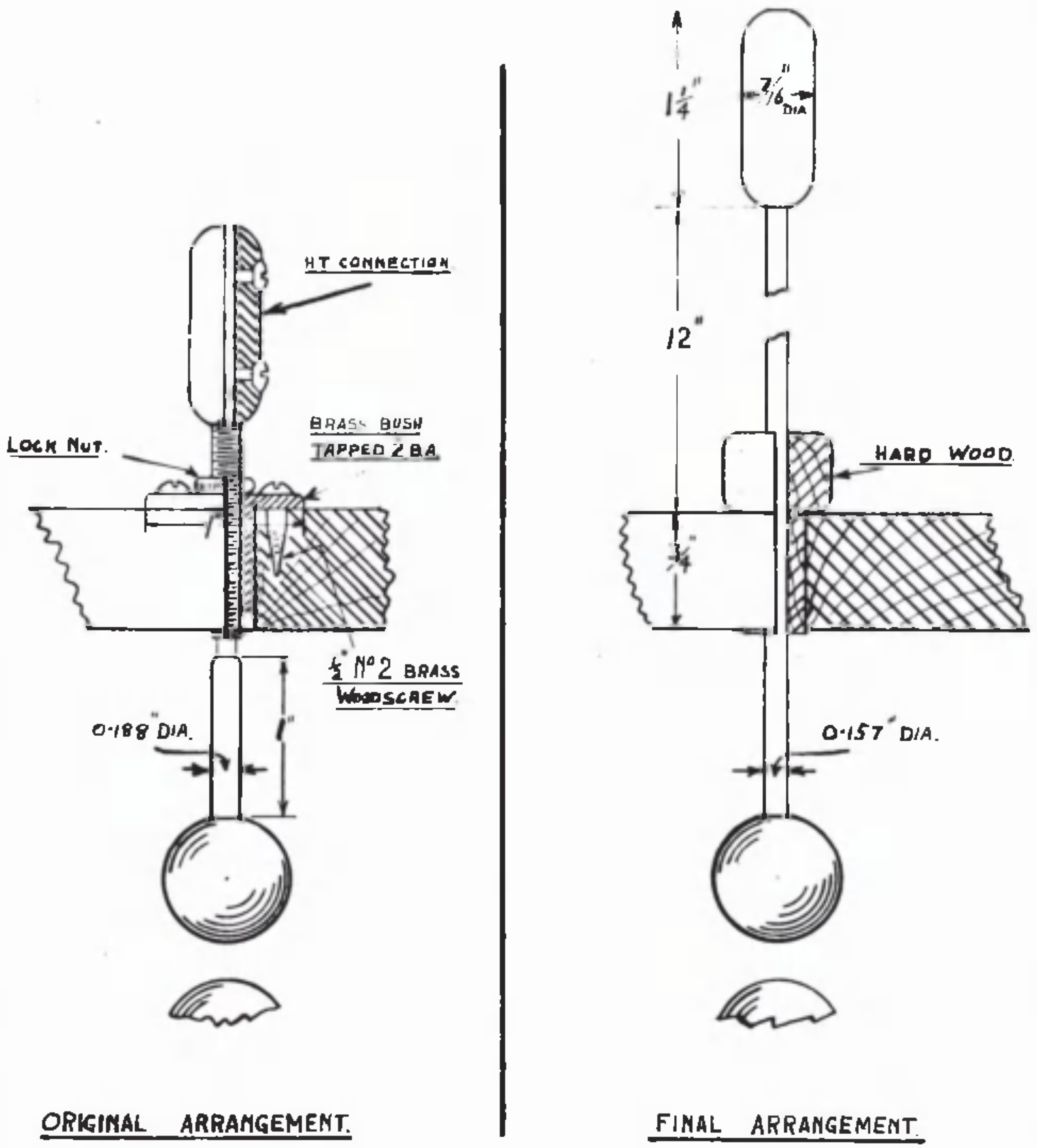
Included in the table are the dispersions of the readings above and below the mean value.

As the greatest difference between the observed and the E.R.A. values occur at the higher spacings it was thought that it might be attributable to some corona action taking place at these higher voltages. The nearest metal at which corona or other disturbing effect might take place was the h.t. lead to the upper sphere. The diameter of this lead was reduced from 0.188"(3/16") to the recommended value of one fifth of the sphere diameter, i.e. 4 mm. or 0.157". No appreciable change was observed in the calibration.

The brass mounting of the upper sphere was a more likely source of undesirable corona, particularly as the sharp points of the wood screws were distant only about 4 cm. from the sphere. The h.t. lead was lengthened and the brass mounting replaced by a hard-wood tapered plug, as shown in Fig. 8. This produced a slight general improvement in the calibration as seen by comparing Table 5 with Table 6 and Fig. 7 with Fig. 9.

The calibration was repeated a few days later to determine if the results obtained previously were reproducible.

Mounting of Upper Sphere.



Scale :- Full Size.

Figure 8.

Table 6.

BREAKDOWN KILOVOLTS.

2·54	3·81	5·08	6·35	7·62	8·89	10·16	11·43	12·70	Gap (mm.) Length
6·98	9·92	12·63	14·64	17·16	19·29	21·14	23·16	24·48	
6·98	10·01	12·44	14·74	17·16	19·38	21·17	23·32	24·38	
6·92	9·95	12·32	14·76	17·20	19·56	21·14	23·23	24·41	
7·01	10·01	12·42	14·74	17·25	19·32	21·08	23·32	24·53	
6·92	9·92	12·32	14·74	17·25	19·29	21·08	23·20	24·41	
6·92	9·82	12·51	14·70	17·16	19·48	21·23	23·32	24·38	
7·01	9·95	12·63	14·67	17·04	19·20	21·20	23·32	24·38	
7·04	10·04	10·32	14·79	17·29	19·45	21·23	23·32	24·44	
6·98	9·91	12·57	14·74	17·16	19·29	21·20	23·23	24·38	
6·98	9·98	12·35	14·70	17·41	19·35	21·11	23·29	24·53	
6·97	9·95	12·45	14·72	17·20	19·36	21·16	23·27	24·43	Mean
	9·95	12·42	15·05	17·43	19·80	21·82	23·60		E.R.A.Value
+0·07	+0·09	+0·18	+0·07	+0·21	+0·20	+0·07	+0·05	+0·10	Dispersion
−0·05	−0·04	−0·13	−0·08	−0·16	−0·16	−0·08	−0·11	−0·05	
+1·00	+0·90	+1·45	+0·47	+1·22	+1·03	+0·33	+0·21	+0·41	Percentage Dispersion
−0·72	−0·40	−1·04	−0·54	−0·93	−0·83	−0·38	−0·47	−0·20	

SPHERE-GAP VOLTAGE MEASUREMENT.

CURVES FOR 2 CM. DIAMETER SPHERES.

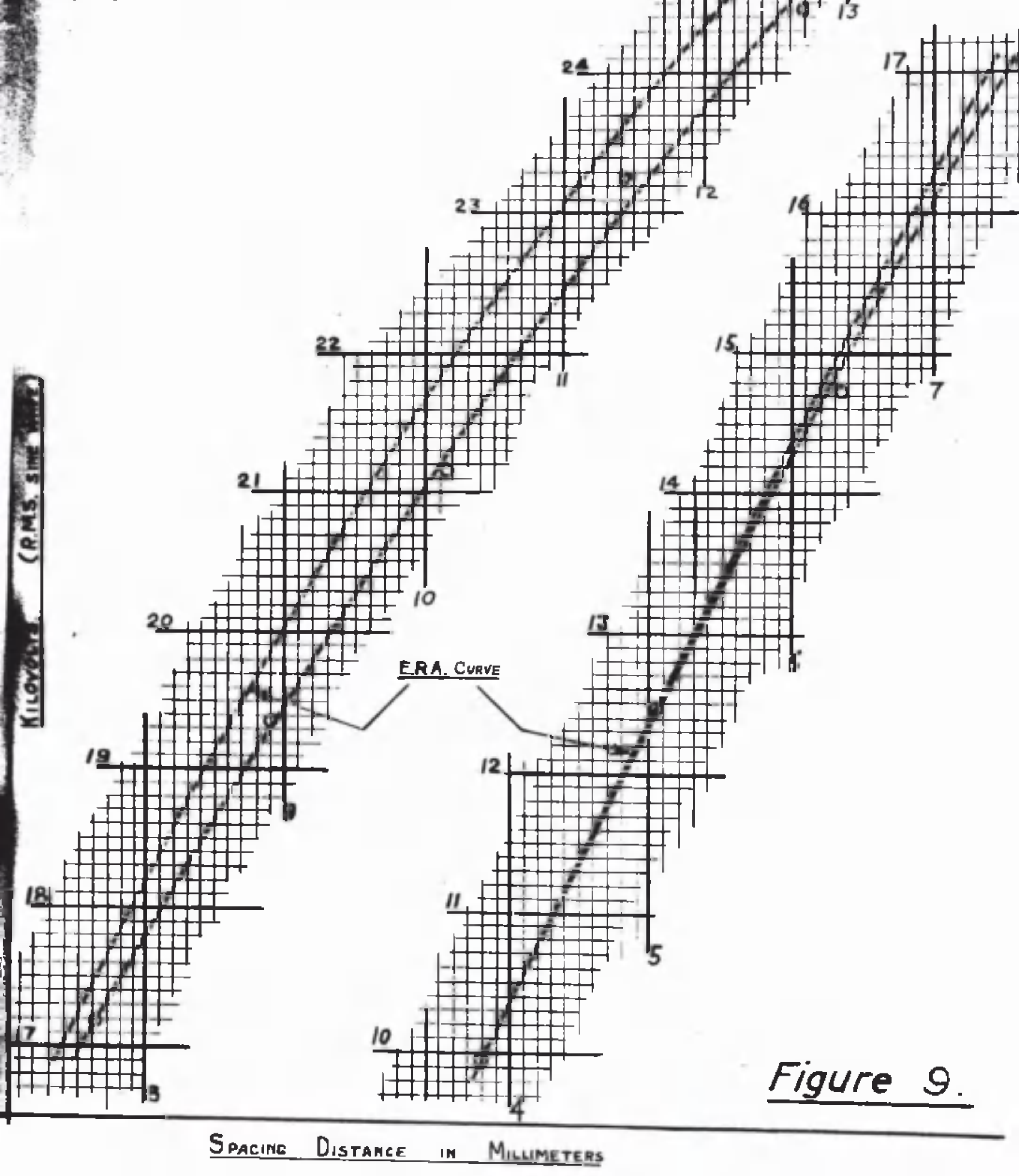


Figure 9.

In this case the spheres were not cleaned prior to commencing observations. The results are given in Table 7 and are seen to agree closely with those of Table 6 (page 29).

Regarding the accuracy of sphere gap observations it is noteworthy that there is not complete agreement among experimenters. Just to quote two examples:-

(a) S. Whitehead* makes the following three statements:-

> "A single reading on a standard sphere-gap will be correct to at least 5 per cent without any particular precautions being taken beyond the removal of obvious impurities from the surface."
>
> "With special precautions a single reading will be correct to 1 per cent and the probable error can be reduced to about 0.5 per cent by taking the mean of 4 or 5 readings."
>
> "There still, however, remains the possibility of occasional individual variations up to 3 or 4 per cent which have not altogether been accounted for."

---

* S. Whitehead and A. P. Castellain, I.E.E.J., 69, pp. 898-921, 1931.

(b) P. L. Bellaschi,

> "With ordinary cleaning of the gap before use and after some preliminary sparkovers, and for openings not exceeding one-half diameter, successive measurements of the voltage seldom vary from each other more than 2 per cent."

To simplify the comparison of the tables and curves obtained in these experiments Fig. 11 shows the curves for 1% and 2% deviation from the standard E.R.A. values. These curves are plotted from the values in Table 8.

Table 7.

BREAKDOWN KILOVOLTS.

2·54	3·81	5·08	6·35	7·62	8·89	10·16	11·43	12·70	Gap (mm.) Length
6·98	9·87	12·33	15·04	17·11	19·48	21·57	23·37	25·18	
6·92	9·99	12·48	14·86	17·17	19·58	21·32	23·31	25·27	
6·83	10·17	12·26	14·80	17·14	19·55	21·35	23·25	25·21	
6·98	9·97	12·26	14·80	17·26	19·79	21·29	23·43	25·18	
6·86	10·11	12·60	14·92	17·32	19·61	21·38	23·19	25·24	
6·86	10·02	12·45	14·80	17·11	19·58	21·35	23·37	25·18	
6·83	9·87	12·42	14·89	17·14	19·49	21·44	23·25	25·24	
6·92	9·84	12·26	15·01	17·17	19·71	21·47	23·31	25·21	
6·98	9·87	12·54	14·89	17·23	19·51	21·32	23·41	25·27	
6·86	9·93	12·45	14·92	17·23	19·85	21·50	23·25	25·27	
6·90	9·96	12·41	14·89	17·19	19·61	21·40	23·31	25·23	Mean
	9·95	12·42	15·05	17·43	19·80	21·82	23·60		E.R.A.Value
+0·08	+0·21	+0·19	+0·15	+0·13	+0·24	+0·17	+0·12	+0·04	Dispersion
−0·07	−0·12	−0·15	−0·09	−0·08	−0·13	−0·11	−0·12	−0·05	
+1·16	+2·11	+1·53	+1·01	+0·76	+1·22	+0·89	+0·51	+0·15	Percentage Dispersion
−1·01	−1·20	−1·21	−0·60	−0·47	−0·66	−0·51	−0·51	−0·20	

SPHERE-GAP VOLTAGE MEASUREMENT.

CURVES FOR 2 CM. DIAMETER SPHERES.

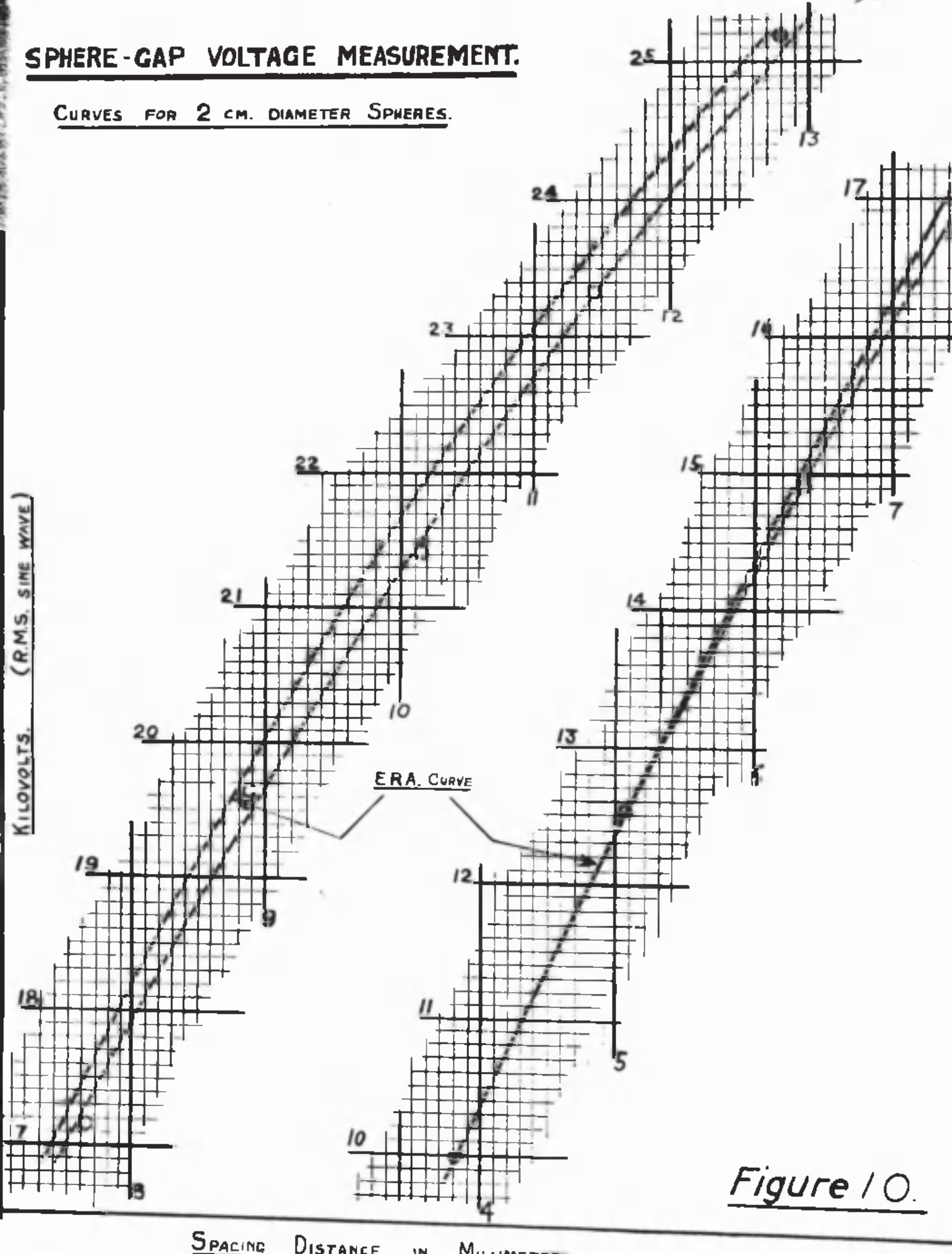


Figure 10.

Table 8.

BREAKDOWN KILOVOLTS.

3·81	5·08	6·35	7·62	8·89	10·16	11·43	Gap (mm) Length.
10·15	12·67	15·35	17·78	20·20	22·26	24·07	E.R.A. Value +2 %
10·05	12·54	15·20	17·60	20·00	22·04	23·84	" " +1 %
10·00	12·48	15·13	17·52	19·90	21·93	23·72	" " +½ %
9·95	12·42	15·05	17·43	19·80	21·82	23·60	E.R.A. Value
9·90	12·36	14·97	17·34	19·70	21·71	23·48	" " −½ %
9·85	12·30	14·90	17·26	19·60	21·60	23·36	" " −1 %
9·75	12·17	14·70	17·08	19·40	21·38	23·13	" " −2 %

SPHERE-GAP VOLTAGE MEASUREMENT.

CURVES FOR 2 CM. DIAMETER SPHERES.

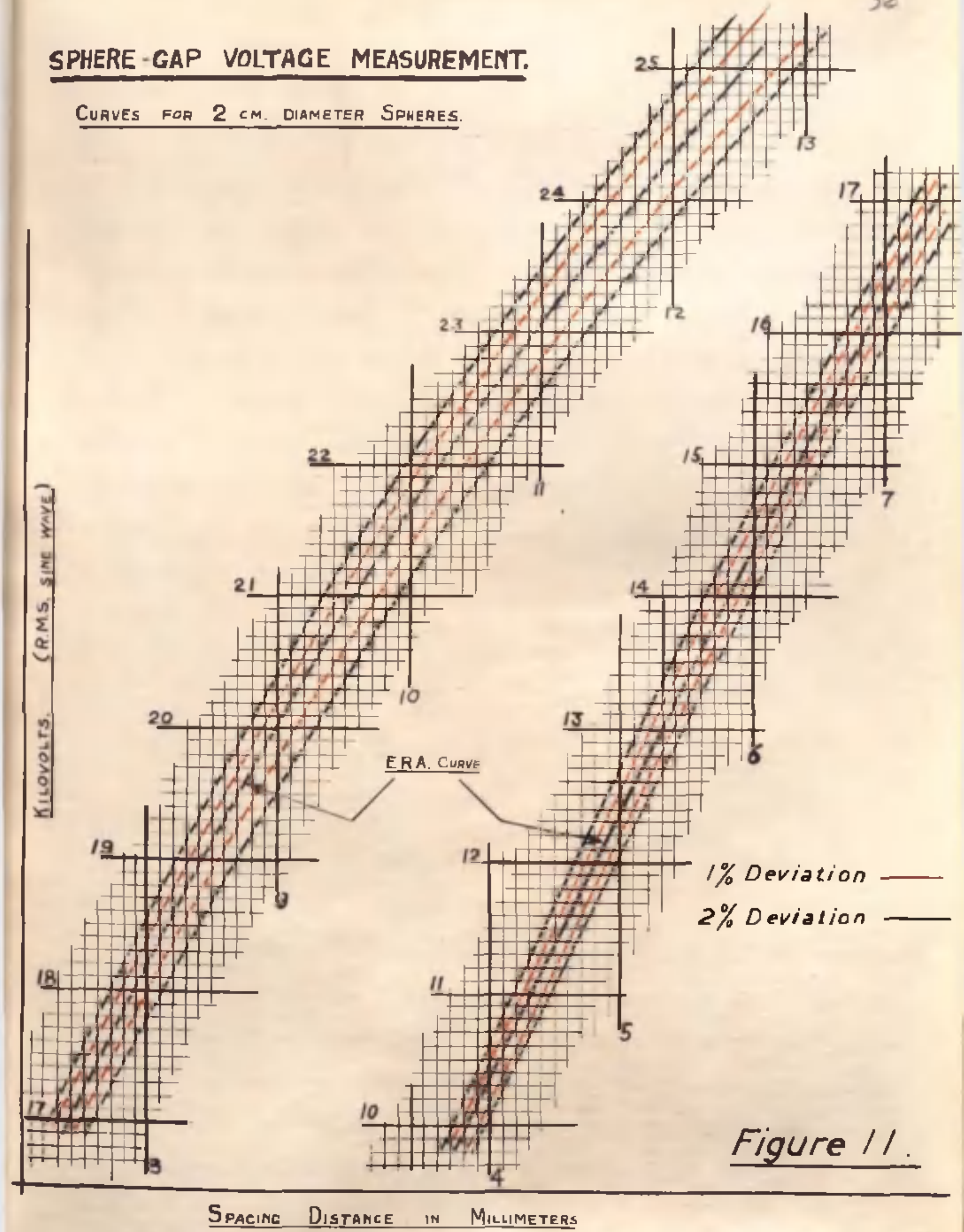


Figure 11.

Wave Form Investigations.

A series of observations was carried out to find if the same results were obtained when the induction regulator was employed to vary the primary voltage as when the alternator was connected directly across the transformer primary and the voltage varied by means of the alternator excitation.

A throw-over switch was arranged so that the transformer primary could be conveniently connected to either of the above sources of supply. To ensure that the same air conditions, sphere temperature, surface conditions, etc. were obtained, observations for a given gap setting were taken in the order indicated in Tables 9 and 10, viz.:-

A - five readings with induction regulator in circuit.

B - five readings with induction regulator cut out.

C - five readings as A.

D - five readings as B.

In Fig. 12 the mean values for the two arrangements are plotted with the standard curve.

The mean values of the ten readings for the two arrangements are seen to give fair agreement over the useful range of gap lengths, i.e. from 3.8 to 11 mm. It is to be noted however that the difference between the two sets of readings increases at the higher voltages. This could be due to the wave form of the applied voltage changing as the position of the rotor of the

Table 9.

BREAKDOWN KILOVOLTS.

3·81	5·08	6·35	7·62	8·89	10·16	11·42	12·70	Gap (mm.) Length.
9·90	12·75	15·01	17·56	19·84	21·88	23·28	24·89	A
9·90	12·67	14·92	17·56	19·81	21·57	23·21	25·04	A
9·87	12·75	14·89	17·62	19·78	21·66	23·21	25·01	A
9·74	12·79	14·92	17·53	19·72	21·75	23·28	25·04	A
9·84	12·73	15·01	17·59	19·84	21·66	23·28	25·04	A
9·90	12·65	15·01	17·56	19·75	21·79	23·36	24·98	C
9·93	12·56	15·05	17·62	19·72	21·88	23·36	24·95	C
9·74	12·53	15·01	17·62	19·70	21·85	23·36	24·95	C
9·90	12·59	15·05	17·56	19·78	21·75	23·40	25·01	C
9·78	12·65	15·08	17·59	19·84	21·85	23·36	24·98	C
9·85	12·67	15·00	17·58	19·79	21·76	23·31	24·99	Mean.
9·95	12·42	15·05	17·43	19·80	21·82	23·60		E.R.A. Value
+0·07	+0·12	+0·08	+0·04	+0·05	+0·12	+0·09	+0·05	Dispersion
−0·11	−0·14	−0·11	−0·05	−0·07	−0·19	−0·10	−0·10	Dispersion
+0·70	+0·94	+0·53	+0·23	+0·25	+0·55	+0·39	+0·20	Percentage Dispersion
−1·11	−1·09	−0·73	−0·28	−0·35	−0·87	−0·43	−0·40	Percentage Dispersion

Table 10.

BREAKDOWN KILOVOLTS.

3·81	5·08	6·35	7·62	8·89	10·16	11·42	12·70	Gap (mm) Length
9·83	12·73	14·92	17·56	19·87	21·66	22·96	24·67	B
9·93	12·82	15·05	17·56	19·75	21·72	23·03	24·61	B
9·90	12·70	15·08	17·65	19·81	21·66	22·96	24·61	B
9·87	12·88	14·89	17·53	19·62	21·57	22·90	24·61	B
9·87	12·82	15·02	17·56	19·75	21·63	22·93	24·61	B
9·83	12·85	15·02	17·53	19·69	21·66	23·37	24·61	D
9·83	12·76	15·05	17·53	19·78	21·57	23·37	24·64	D
9·81	12·73	14·92	17·56	19·81	21·57	23·24	24·61	D
9·99	12·79	15·05	17·53	19·84	21·48	23·31	24·58	D
9·93	12·85	15·08	17·62	19·75	21·54	23·31	24·61	D
9·88	12·79	15·00	17·56	19·77	21·61	23·14	24·62	Mean.
9·95	12·42	15·05	17·43	19·80	21·82	23·60		E.R.A. Value
+0·11	+0·09	+0·08	+0·09	+0·10	+0·11	+0·13	+0·05	Dispersion
−0·07	−0·09	−0·11	−0·03	−0·15	−0·13	−0·24	−0·04	Dispersion
+1·10	+0·70	+0·53	+0·51	+0·51	+0·51	+0·56	+0·20	Percentage Dispersion
−0·70	−0·70	−0·73	−0·17	−0·76	−0·60	−1·04	−0·16	Percentage Dispersion

SPHERE-GAP VOLTAGE MEASUREMENT.

CURVES FOR 2 CM. DIAMETER SPHERES.

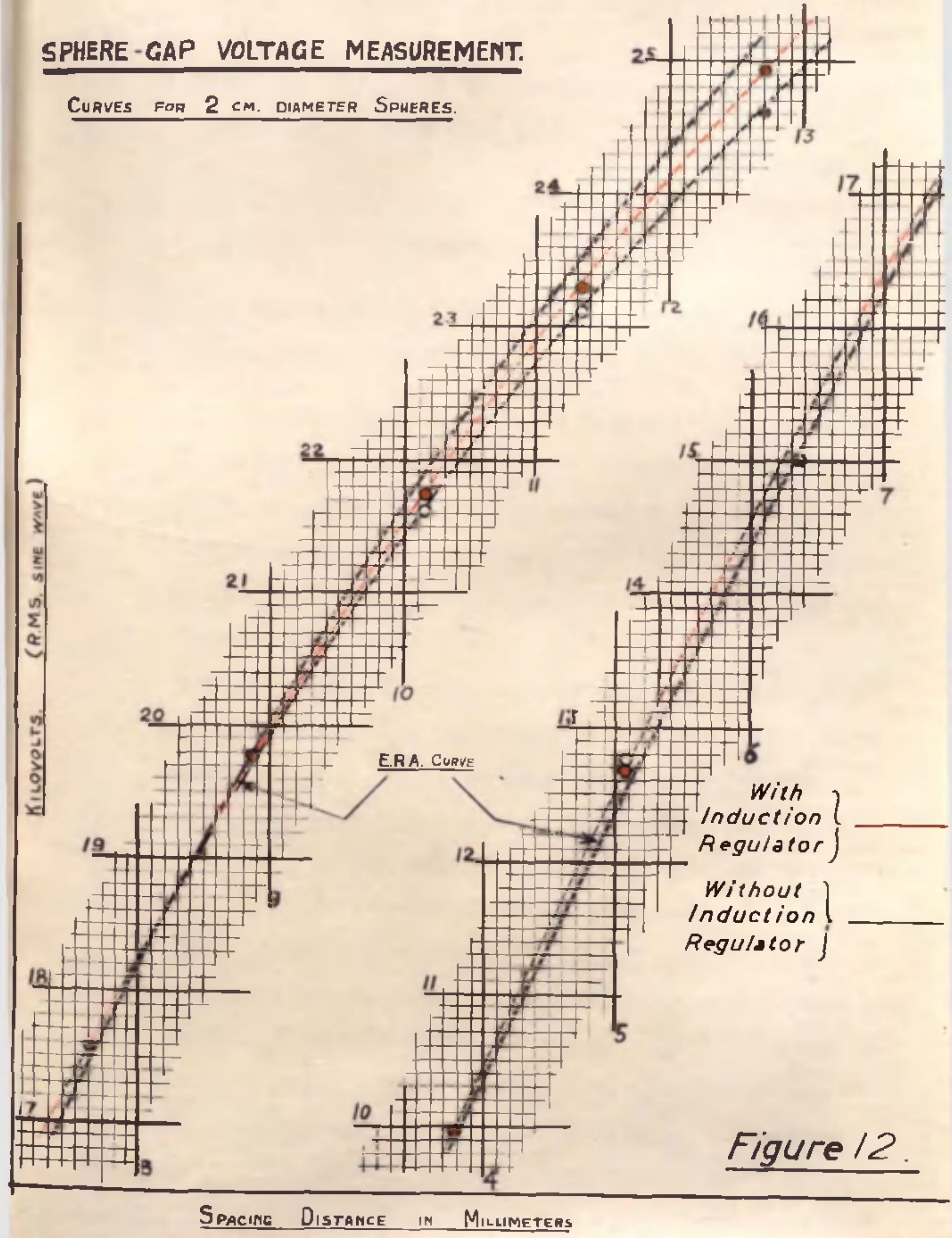


Figure 12.

induction regulator is altered. To investigate this point the following two tests were carried out:-

(a) With the induction regulator set to give a maximum voltage, i.e. doubling the alternator supply; and

(b) With the induction regulator set to give half of the maximum voltage, i.e. the same as the alternator voltage.

In both tests the voltage was raised to the breakdown value for the gap by adjustment of the alternator excitation.

Table 11 gives the readings obtained and with Fig. 13 clearly indicates that the induction regulator must be causing an appreciable change in the wave-form of the voltage applied to the transformer primary.

That the wave form of the applied voltage has a considerable influence on the values obtained for the breakdown field strength of the gap is further demonstrated by the following experiment which was suggested by the apparent discrepancy observed in the results, merely by altering the stator connections of the alternator from delta to star.

The procedure adopted was to adjust the gap length to a definite value and to determine the breakdown value with the stator of the alternator delta connected. Immediately thereafter, thus ensuring that the atmospheric conditions were unchanged, the stator connections were altered to the star arrangement and a set of readings of the breakdown value obtained for the same gap setting.

Table II.

BREAKDOWN KILOVOLTS.

Gap (mm) Length →	3·81	5·08	6·35	7·62	8·89	10·16	11·43	12·70
Induction-Regulator Doubling Machine Voltage.	10·13	12·81	15·77	17·98	20·39	22·34	23·73	25·27
	10·07	12·81	15·77	17·91	20·48	22·29	23·64	25·24
	10·25	12·88	15·68	18·04	20·51	22·40	23·64	25·27
	10·13	12·94	15·71	17·95	20·33	22·44	23·67	25·30
	10·13	12·94	15·62	17·98	20·39	22·32	23·73	25·27
Mean	10·14	12·88	15·91	17·97	20·42	22·36	23·68	25·27
Induction-Regulator Giving Machine Voltage.	9·94	12·57	15·21	17·24	19·29	21·49	22·94	24·36
	9·97	12·72	15·16	17·30	19·32	21·31	22·85	24·39
	9·94	12·51	15·19	17·36	19·50	21·46	22·97	24·30
	9·85	12·75	15·16	17·33	19·38	21·46	22·88	24·30
	9·97	12·54	15·19	17·36	19·44	21·49	22·97	24·36
Mean	9·94	12·62	15·19	17·32	19·39	21·44	22·92	24·34
E.R.A. Value	9·95	12·42	15·05	17·43	19·80	21·82	23·60	

SPHERE-GAP VOLTAGE MEASUREMENT.

CURVES FOR 2 CM. DIAMETER SPHERES.

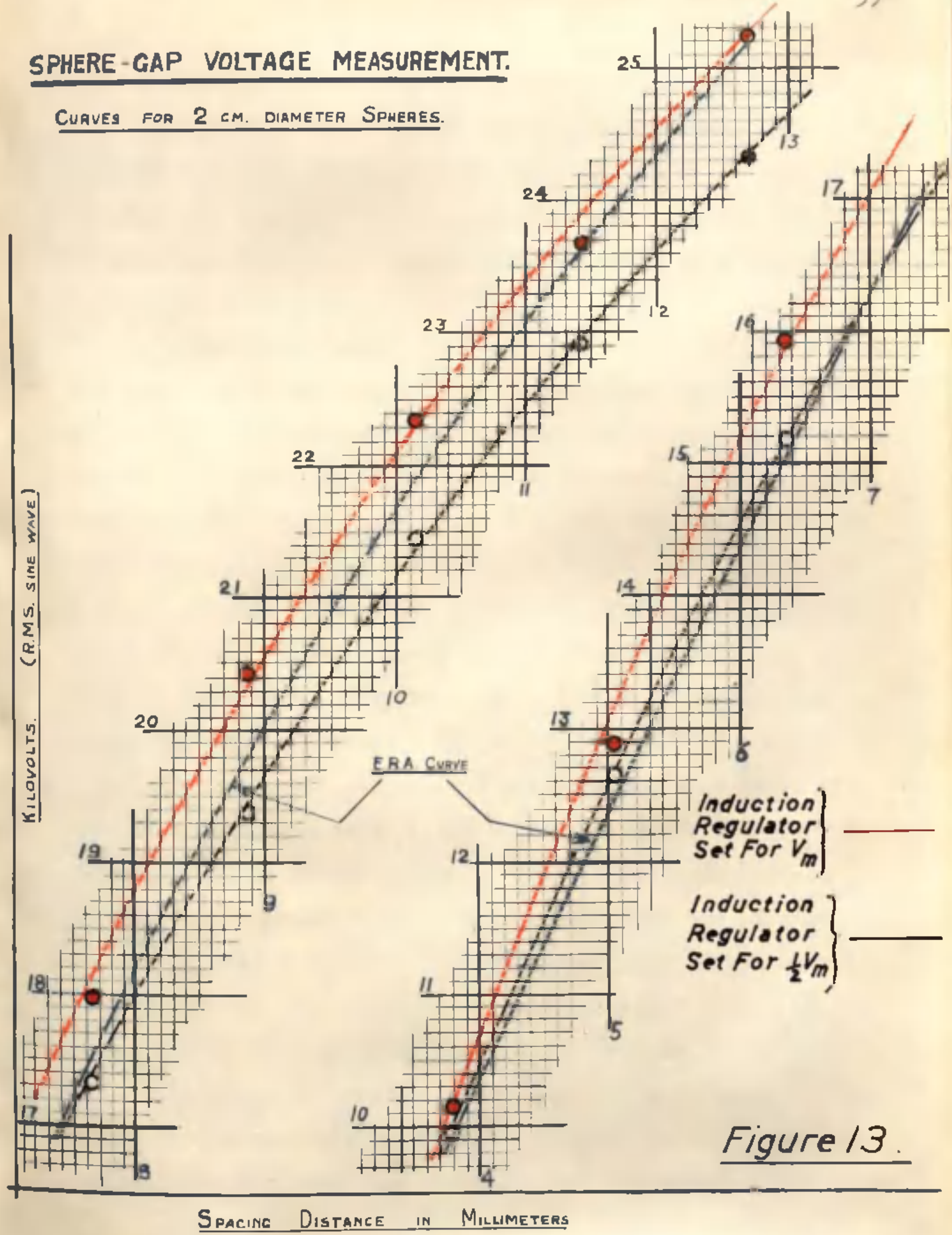


Figure 13.

The applied voltage was suitably controlled by means of the excitation of the alternator. After a set of ten readings had been taken for both arrangements of the stator winding, the gap length was adjusted to other values and the observations repeated. The results are shown in Tables 12 and 13 and Fig. 14a.

From these figures and curves it may be concluded that the root-mean-square value is not a satisfactory value in which to express the breakdown field strength of an air gap. A statement of the peak value would be preferable for practical purposes since it is seldom, if ever, that the voltage under test conditions follows the ideal of a sine curve. Moreover, stating the peak value would naturally infer that either the peak value was to be measured or that a knowledge of the wave-form of the voltage wave was necessary from which the peak value could be determined.

Accordingly, cathode-ray oscillograms were taken of the primary voltage wave of the h.t. transformer when supplied from the various sources used in these experiments. Since the transformer is practically on open circuit and the applied voltage is only a fraction (never greater than 25 per cent in these tests) of the normal value, the secondary wave form may be assumed to be similar to that of the primary.

It might be mentioned here that the oscillograms were obtained by photographing the waves on the screen of the cathode ray oscillograph which had recently been installed in the

Table 12.

Stator Delta Connected.

BREAKDOWN KILOVOLTS.

Gap (mm.) Length.	3·81	5·08	6·35	7·62	8·89	10·16	11·42	12·70
	9·56	12·04	14·49	16·66	19·23	21·00	22·54	24·07
	9·57	12·02	14·40	16·63	19·32	20·94	22·54	24·04
	9·59	12·02	14·52	16·60	19·05	20·94	22·63	24·07
	9·60	12·02	14·49	16·69	19·11	21·04	22·60	24·04
	9·62	12·04	14·49	16·72	19·08	21·04	22·60	24·07
	9·56	12·02	14·49	16·69	19·05	21·00	22·00	24·04
	9·62	11·98	14·49	16·69	19·23	21·00	22·56	24·04
	9·62	12·04	14·43	16·69	19·05	20·97	22·56	24·07
	9·59	11·93	14·49	16·66	19·02	20·97	22·63	24·04
	9·60	11·98	14·52	16·72	19·02	21·00	22·63	24·04
Mean.	9·59	11·98	14·48	16·68	19·12	20·99	22·59	24·05
E.R.A. Value	9·95	12·42	15·05	17·43	19·80	21·82	23·60	
Dispersion	+0·03	+0·04	+0·04	+0·04	+0·20	0·05	+0·04	+0·02
	−0·03	−0·07	−0·08	−0·08	−0·10	−0·02	−0·05	−0·01
Percentage Dispersion	+0·31	+0·32	+0·28	+0·24	+1·05	+0·24	+0·48	+0·08
	−0·31	−0·58	−0·55	−0·48	−0·53	−0·09	−0·22	−0·04

Table 13.

Stator Star Connected.

BREAKDOWN KILOVOLTS.

3·81	5·08	6·35	7·62	8·89	10·16	11·42	12·70	Gap (mm) Length.
10·28	12·88	15·47	17·85	20·27	22·19	23·86	25·45	
10·32	12·90	15·41	18·04	20·33	22·23	23·89	25·45	
10·34	12·93	15·44	17·98	20·36	22·19	23·86	25·42	
10·28	12·94	15·44	18·07	20·30	22·23	23·92	25·45	
10·34	12·90	15·59	18·04	20·24	22·26	23·92	25·45	
10·37	12·85	15·56	18·01	20·27	22·20	23·86	25·42	
10·32	12·93	15·50	18·10	20·18	22·14	23·83	25·42	
10·37	12·94	15·41	18·10	20·33	22·14	23·92	25·45	
10·37	12·90	15·44	18·07	20·24	22·29	23·86	25·39	
10·29	12·94	15·41	18·01	20·30	22·14	23·89	25·42	
10·33	12·91	15·47	18·03	20·28	22·20	23·89	25·44	Mean.
9·95	12·42	15·05	17·43	19·80	21·82	23·60		E.R.A. Value
+0·04	+0·03	+0·12	+0·07	+0·08	+0·09	+0·03	+0·01	Dispersion
−0·05	−0·06	−0·06	−0·18	−0·10	−0·06	−0·06	−0·05	
+0·39	+0·23	+0·78	+0·39	+0·40	+0·41	+0·12	+0·04	Percentage Dispersion
−0·48	−0·47	−0·39	−1·00	−0·49	−0·27	−0·24	−0·20	

SPHERE-GAP VOLTAGE MEASUREMENT.

CURVES FOR 2 CM. DIAMETER SPHERES.

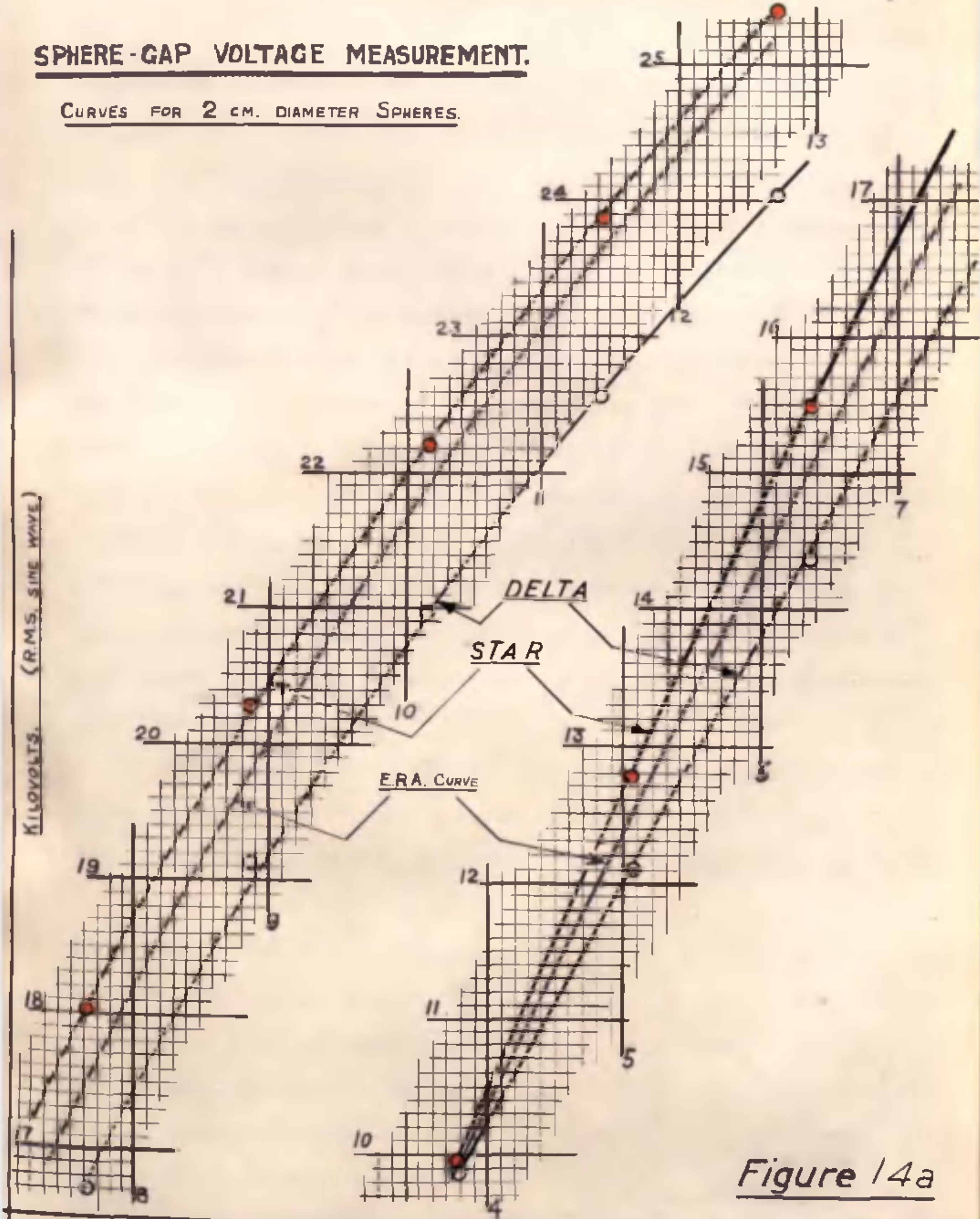


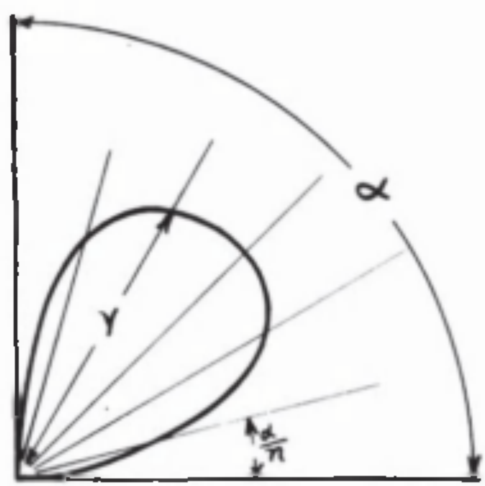
Figure 14a

laboratory. A rigid base and fixing was arranged for the camera so that it could be dropped into place and would require the minimum of adjustments.

A suitable lens (+4 diopters or 10" focal length) was fitted to a quarter plate camera to form a "portrait attachment" which focussed about 10 inches from the oscillograph screen. This strength of lens was chosen from two considerations, (a) that, at a distance of 10 inches from the oscillograph screen, the camera distortion was negligible, and (b) since only one half of a plate was required for each oscillogram, suitable masking and raising of the camera head enabled two oscillograms to be recorded on each quarter plate. From the negatives, enlargements were taken of a size which allowed the peak value to be measured and the r.m.s. value to be determined with reasonable accuracy.

Fleming's Method of deriving the r.m.s. value of the waves obtained was considered the least laborious since it does not necessitate squaring the ordinates. Briefly it is as follows:

The given curve is replotted in polar co-ordinates, so that equal polar angles, $\frac{\alpha}{n}$ correspond to equal distances $\frac{\pi}{n}$ on the abscissae. (α may be of any value whatever). If y is any polar radius then the area of an infinitesimal triangle



subtended by a polar angle $d\alpha$ is $\frac{1}{2}\,y.^2 d\alpha$ (since y is the altitude of the triangle on base $y.d\alpha$).

$$\therefore \text{ Area within polar curve } = A = \frac{1}{2}\int_0^{\alpha} y.^2 d\alpha$$

Since y is also an ordinate of the given curve on base θ

$$\text{Mean square value of given curve } = \frac{1}{\pi}\int_0^{\pi} y.^2 d\theta$$

$$= \frac{1}{\alpha}\int_0^{\alpha} y.^2 d\alpha \quad \text{since } \alpha \text{ propl. to } \theta$$

$$= \frac{2A}{\alpha}$$

$\therefore$ <u>Root Mean Square Value</u> $= \sqrt{\dfrac{2A}{\alpha}}$

Since A, the area within the polar curve, can be found by a planimeter, the effective value can be determined without squaring the ordinates.

In the curves considered, $\frac{\alpha}{n}$ is taken as 5° and n as 18

hence $\alpha = 5 \times 18 = 90^{\circ} = \frac{\pi}{2}$ radians.

$$\therefore \text{ R.M.S. value } = \sqrt{\frac{2A}{\pi/2}} = \sqrt{\frac{4 \times \text{area of polar curve}}{\pi}}$$

To facilitate the comparison of experimental observations with the standard E.R.A. values, which are given as R.M.S. kilovolts for sine wave form, suitable conversion factors are now determined.

Thus,

Observed r.m.s. kV x peak factor = observed peak kV.

$\therefore$ Equivalent r.m.s. sine wave kV $= \dfrac{\text{observed peak kV}}{1.414}$

$= \text{observed r.m.s. kV} \times \dfrac{\text{peak factor}}{1.414}$

$=$ observed r.m.s. kV x conversion factor.

Hence Conversion Factor $= \dfrac{\text{peak factor}}{1.414}$

This Conversion Factor may thus be defined as the factor by which the observed r.m.s. kV must be multiplied to give the r.m.s. value of the sine wave which would have the same peak value as the wave used in the observations - or briefly to give the "equivalent r.m.s. sine kV."

The calculations of the conversion factors corresponding to the various voltage wave forms employed are shown with the respective oscillograms, Fig. 27, etc.

In Table 14 these conversion factors are applied to the observations previously obtained with the alternator (a) delta- and (b) star-connected. The observed kV, taken from Tables 12 and 13 and the E.R.A. values are tabulated for comparison.

The agreement with the E.R.A. values is now seen to be extremely close for both methods of connection, and amply justifies the contention that peak values rather than r.m.s. values are to be preferred as reference standards.

Incidentally many of the troubles and discrepancies, to say nothing of the harassing disappointments with many of the earlier observations would not have arisen had this dependence of the breakdown strength on waveform been fully appreciated.

Column F in Table 14 gives the error in the observations as a percentage of the E.R.A. values. With the stator delta connected the error is less than 1 per cent. The larger error with the stator star connected may possibly be attributed to some slight fault in the wave form obtained with this connection.

On the whole, the accuracy of these sphere gap observations can be taken as about 2 per cent. with respect to the E.R.A. values and about 1 per cent among themselves.

A	3.81		5.08		6.35		7.62		8.89		10.16		11.43		12.70	
B	Δ	Y	Δ	Y	Δ	Y	Δ	Y	Δ	Y	Δ	Y	Δ	Y	Δ	Y
C	9.59	10.33	12.00	12.91	14.48	15.47	16.68	18.03	19.13	20.28	20.99	22.20	22.59	23.89	24.05	25.44
D	9.97	10.18	12.48	12.71	15.07	15.24	17.32	17.76	19.88	19.98	21.80	21.87	23.60	23.53	25.0	25.05
E	9.95		12.42		15.05		17.43		19.80		21.82		23.60			
F	+0.20	+2.31	+0.48	+2.33	+0.13	+1.26	-0.57	+1.72	+0.40	+0.91	-0.09	+0.23	0.00	-0.29		

A Gap length (mm.)

B Stator connection of 10 KVA. Alternator.

C Observed r.m.s. kilovolts.

D Equivalent r.m.s. sine kilovolts.

E E.R.A. r.m.s. kilovolts.

F Percentage error.

TABLE 14.

SPHERE-GAP VOLTAGE MEASUREMENT.

CURVES FOR 2 CM. DIAMETER SPHERES.

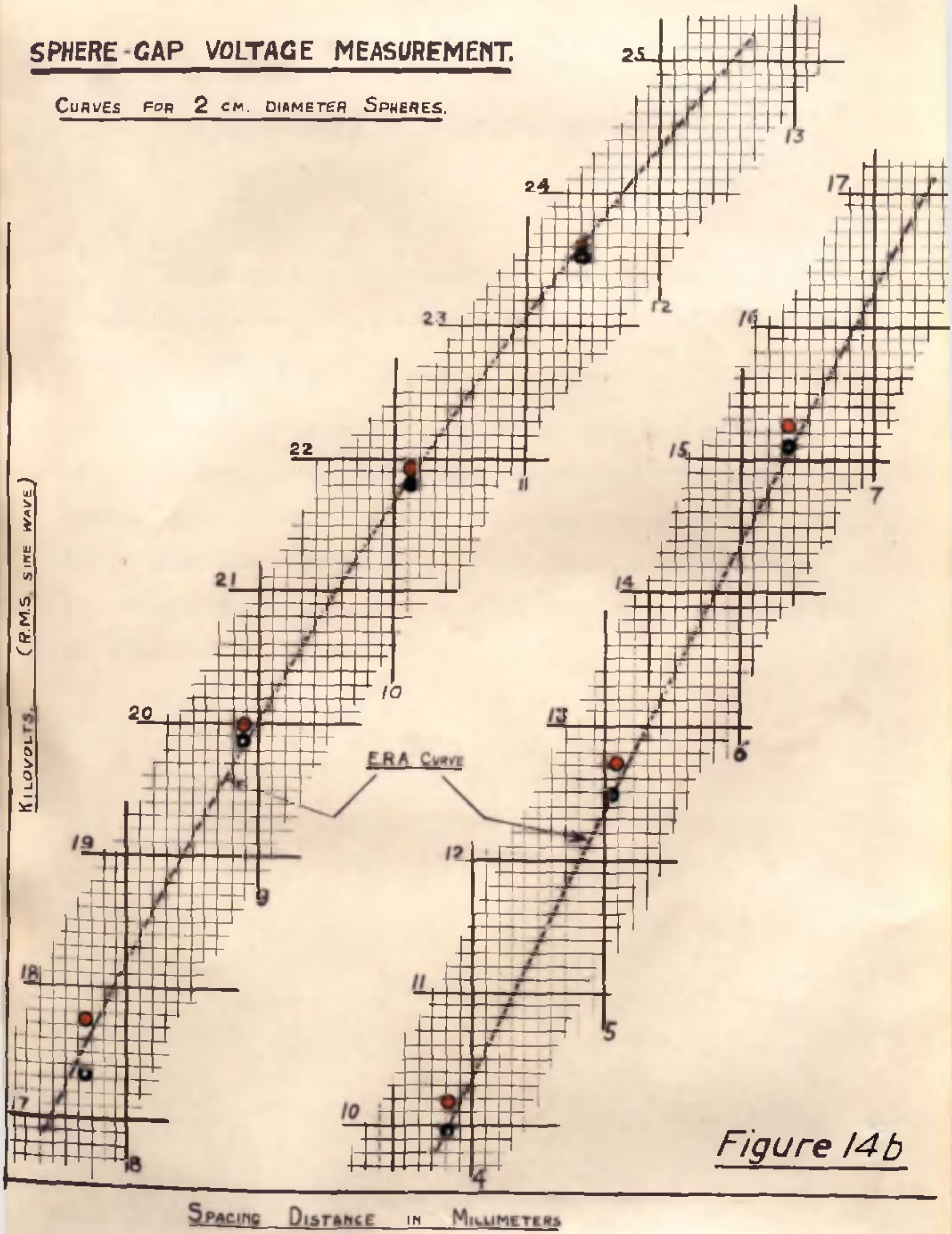


Figure 14b

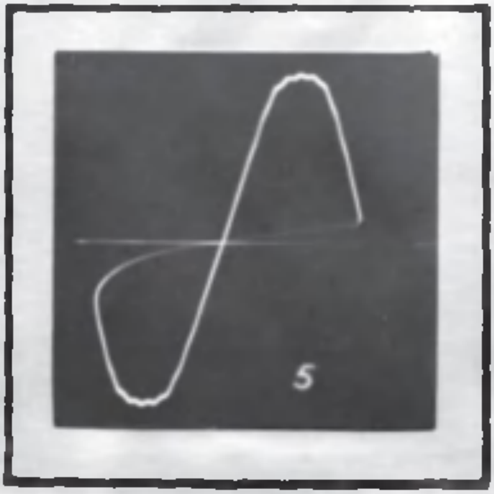
Oscillograms of 10 kVA Alternator.

Inspection of the following oscillograms of the 10 kVA alternator verify the conclusions deduced from the foregoing observations.

With both star and delta connection the wave form of the alternator voltage, which obviously is not a sine wave on open circuit, is seen to change even with the h.v. transformer alone as load. With the induction regulator in circuit the wave form is clearly seen to be dependent on the position of the rotor.

10 kVA. Alternator.

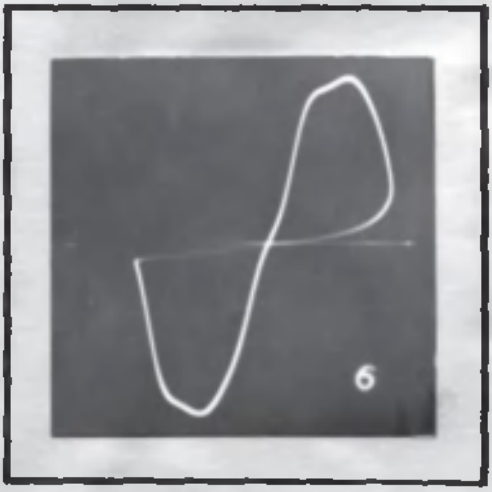
Connection :- Series-Star.



OPEN CIRCUIT VOLTAGE.

Terminal P.D. = 140 Volts.
Excitation = 1·1 Amps.

Figure 15 .



LOAD – H.T. TRANSFORMER

Terminal P.D. = 140 Volts.
Excitation = 1·1 Amps.

Figure 16.

10 KVA Alternator.

Connection :- Series – Star.

Oscillograms of transformer primary P.D. when supplied through induction regulator.

Alternator P.D. = 140 Volts.
Transformer P.D. = 140 Volts.

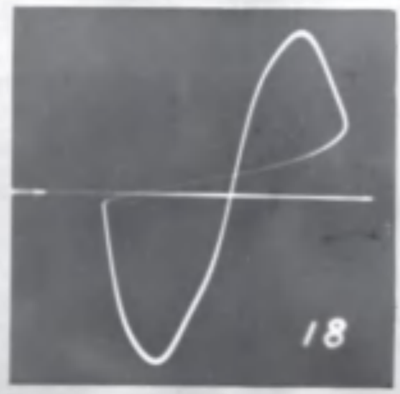


Fig. 17.

Alternator P.D. = 70 Volts.
Transformer P.D. = 140 Volts.
(i.e. regulator doubling supply voltage.)

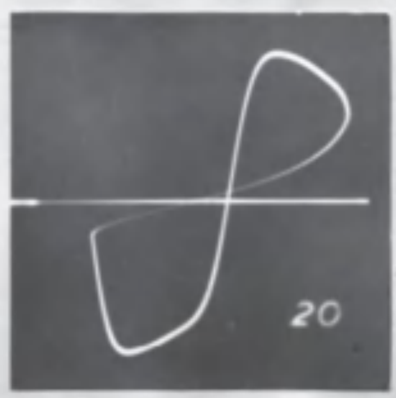


Fig. 18.

Alternator P.D. = 140 Volts.
Transformer P.D. = 70 Volts.
(i.e. regulator halving supply voltage)

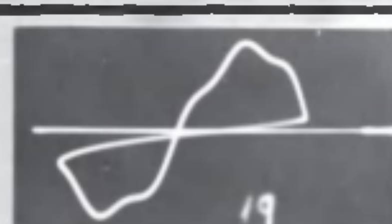


Fig. 19.

Alternator P.D. = 70 Volts.
Transformer P.D. = 70 Volts.

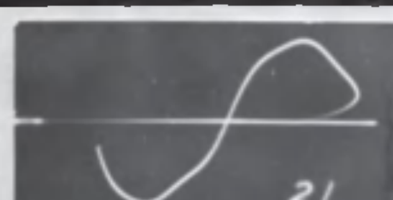


Fig. 20.

10 kVA. Alternator.

Connection :- Series-Delta.

OPEN CIRCUIT VOLTAGE.

Terminal P.D. = 140 Volts.
Excitation = 1·9 Amps.

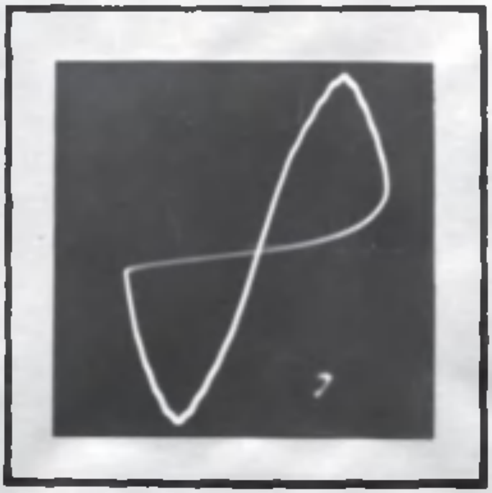


Figure 21.

LOAD - H.T. TRANSFORMER

Terminal P.D. = 140 Volts.
Excitation = 1·9 Amps.

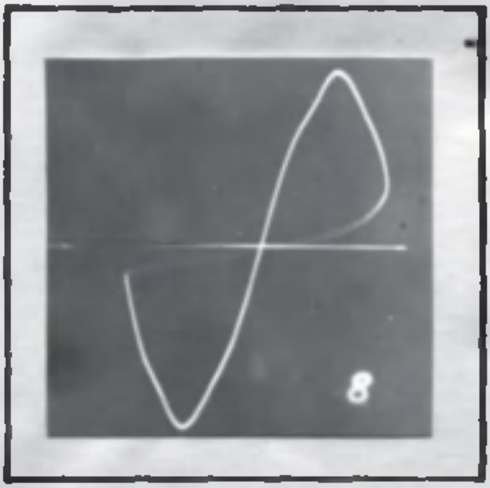


Figure 22.

IO KVA Alternator.

Connection :- Series – Delta

Oscillograms of transformer primary P.D. when supplied through induction regulator.

Alternator P.D. = 140 Volts.
Transformer P.D. = 140 Volts.

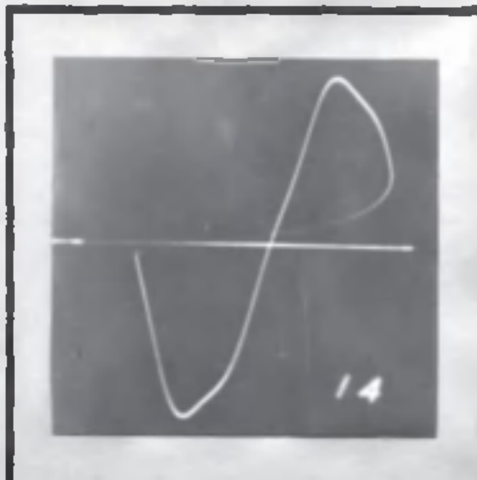


Fig. 23.

Alternator P.D. = 70 Volts.
Transformer P.D. = 140 Volts.
(i.e. regulator doubling supply voltage.)

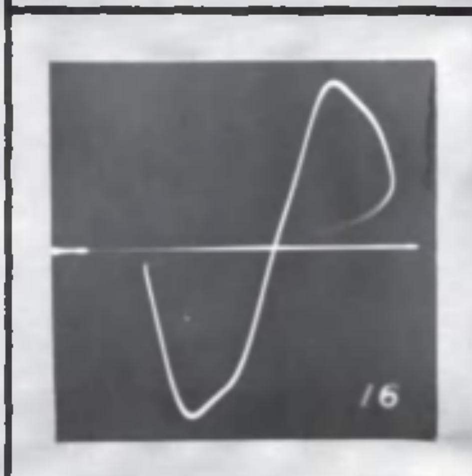


Fig. 24.

Alternator P.D. = 140 Volts.
Transformer P.D. = 70 Volts.
(i.e. regulator halving supply voltage)

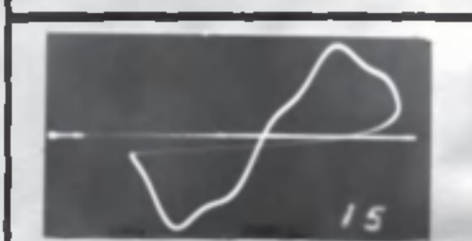


Fig. 25.

Alternator P.D. = 70 Volts.
Transformer P.D. = 70 Volts.

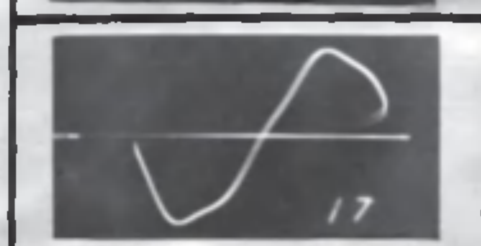
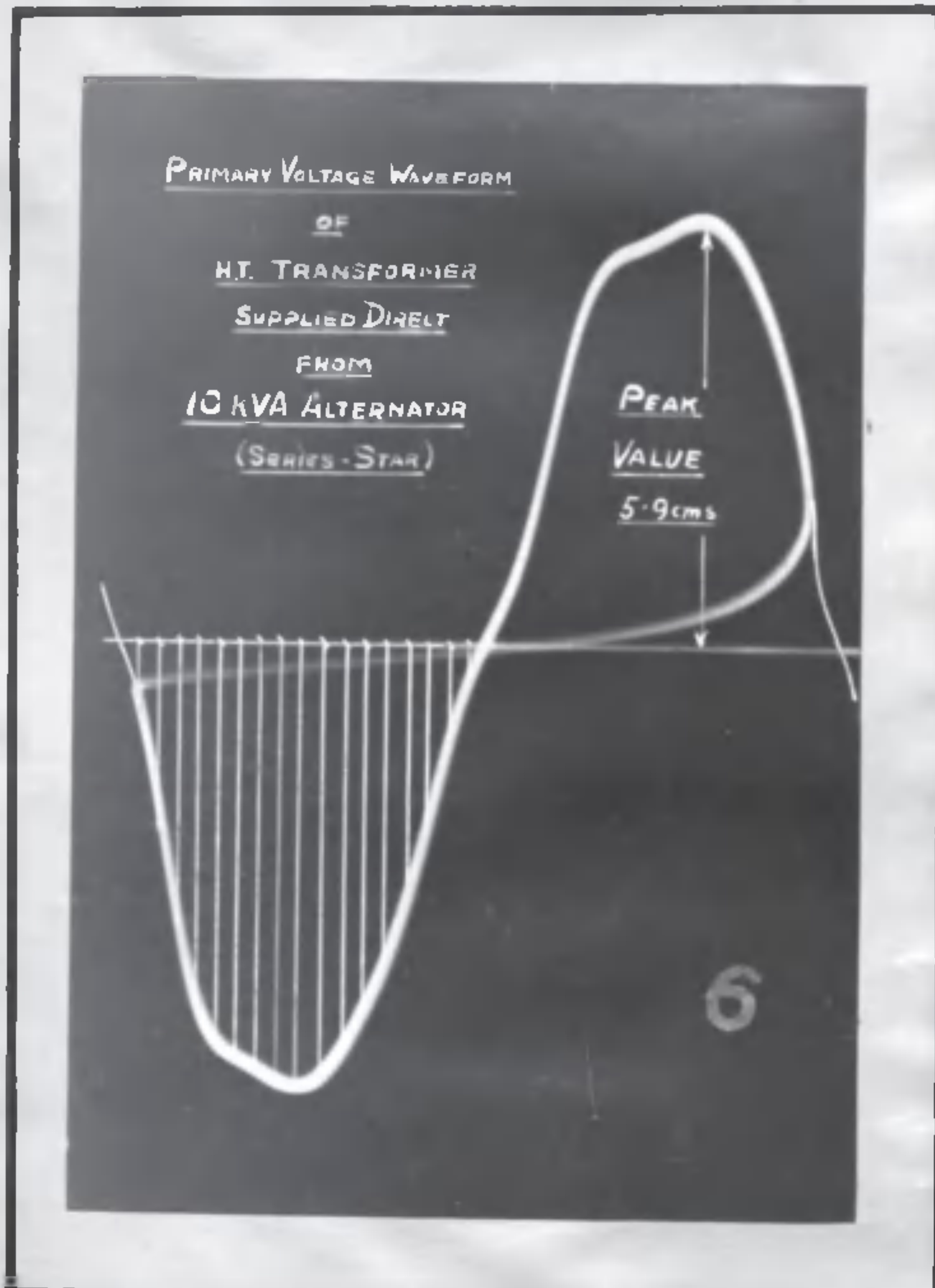
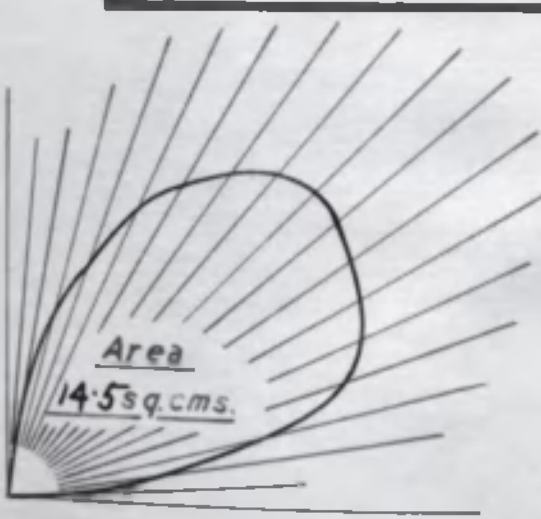


Fig. 26.



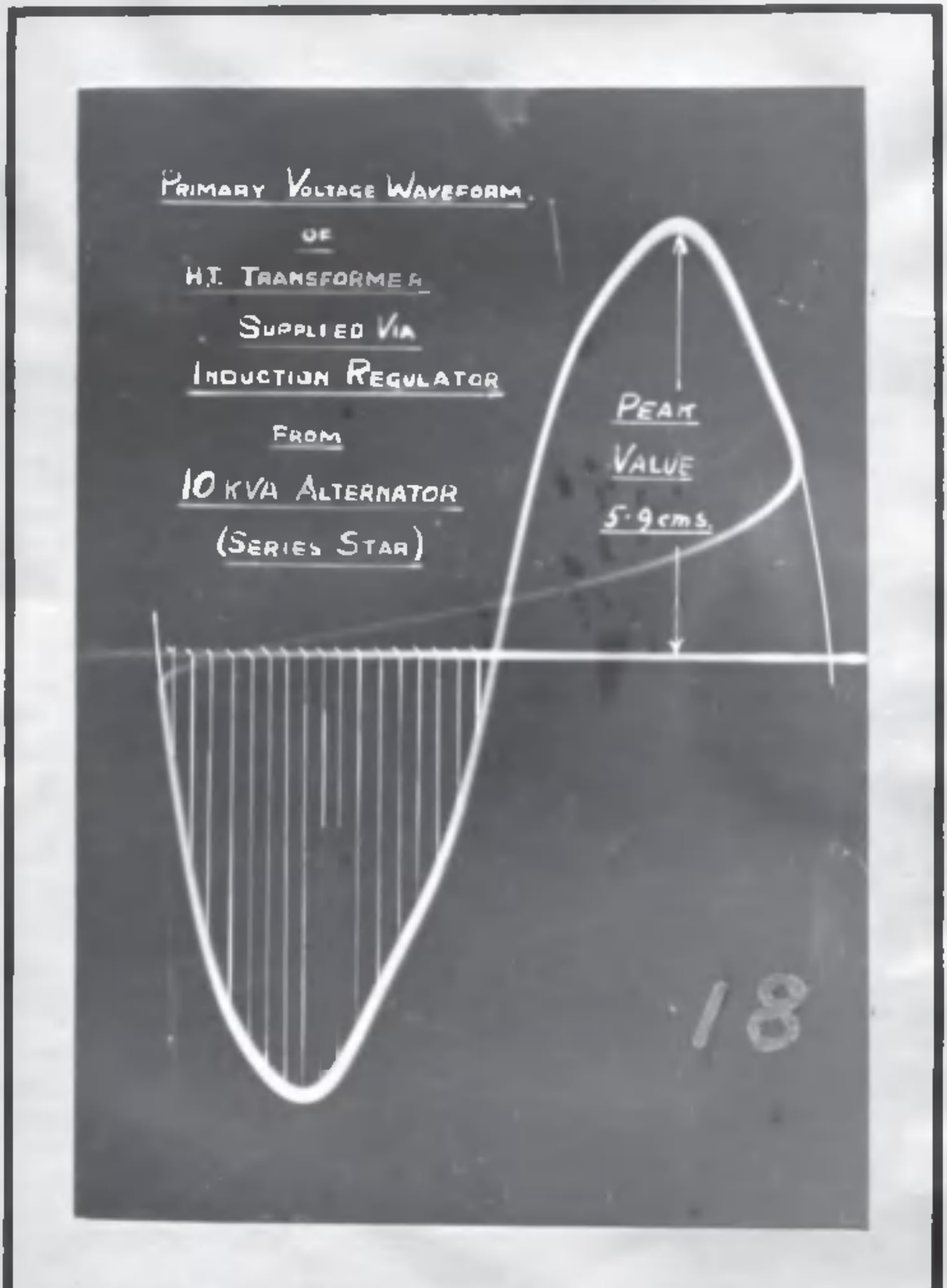


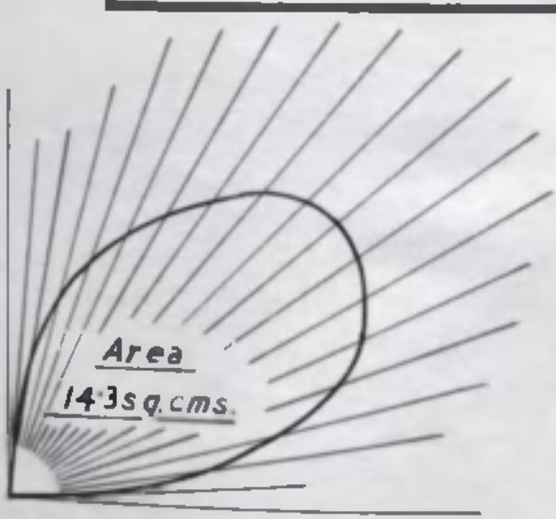
$$\text{R.M.S. Value} = \sqrt{\frac{4 \times 14 \cdot 5}{\pi}} = 4 \cdot 27$$

$$\text{Peak Factor} = \frac{5 \cdot 9}{4 \cdot 27} = 1 \cdot 38$$

$$\text{Conversion Factor} = \frac{1 \cdot 38}{1 \cdot 414} = \underline{\underline{0 \cdot 98}}$$

Figure 27.



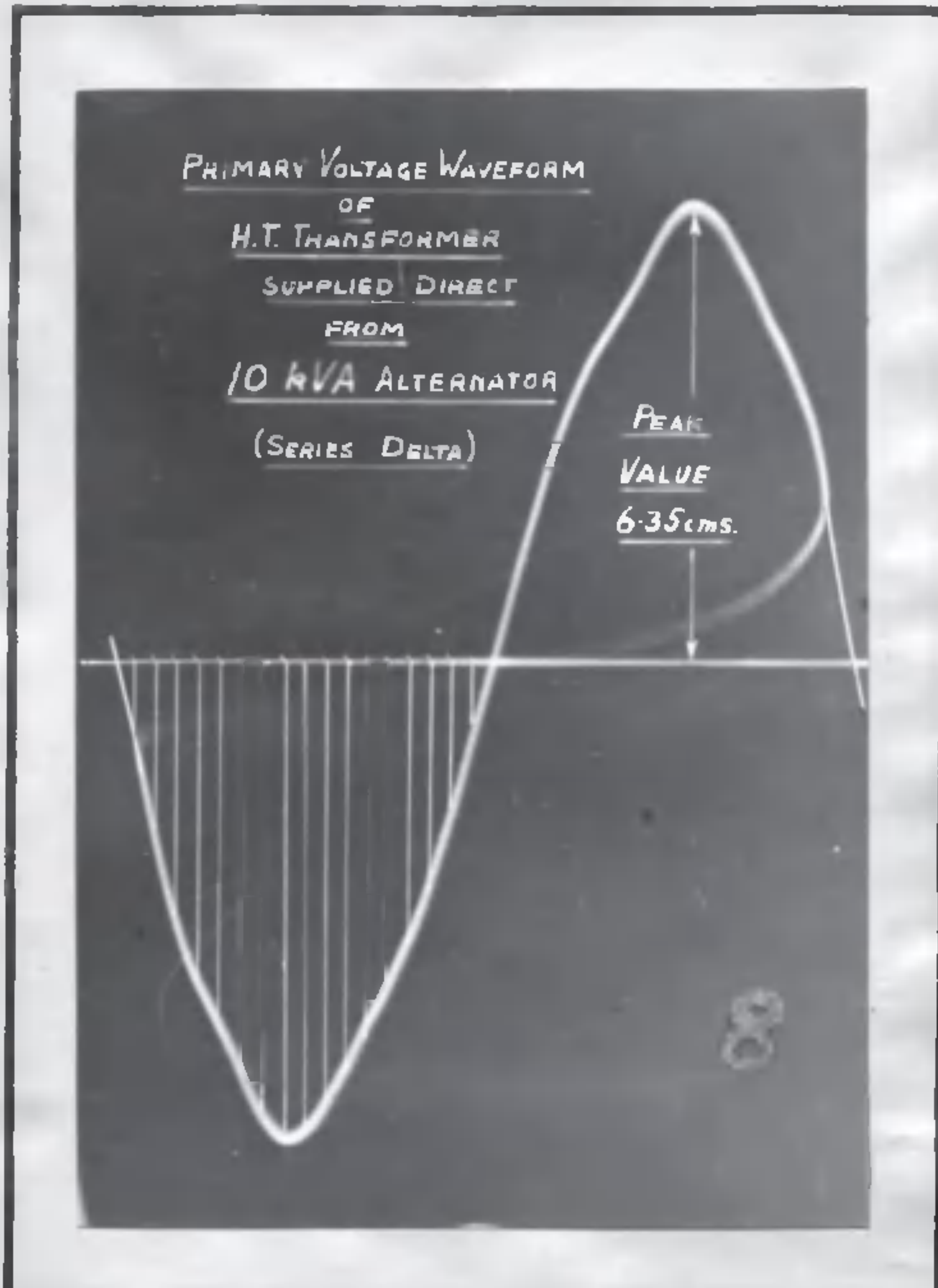


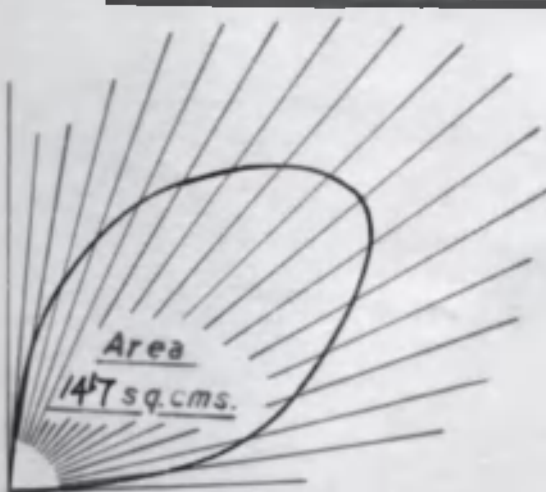
$$\text{R.M.S. Value} = \sqrt{\frac{4 \times 14{\cdot}3}{\pi}} = 4{\cdot}27$$

$$\text{Peak Factor} = \frac{5{\cdot}9}{4{\cdot}27} = 1{\cdot}39$$

$$\left.\begin{array}{l}\text{Conversion}\\ \text{Factor}\end{array}\right\} = \frac{1{\cdot}39}{1{\cdot}414} = \underline{0{\cdot}985}$$

Figure 28.



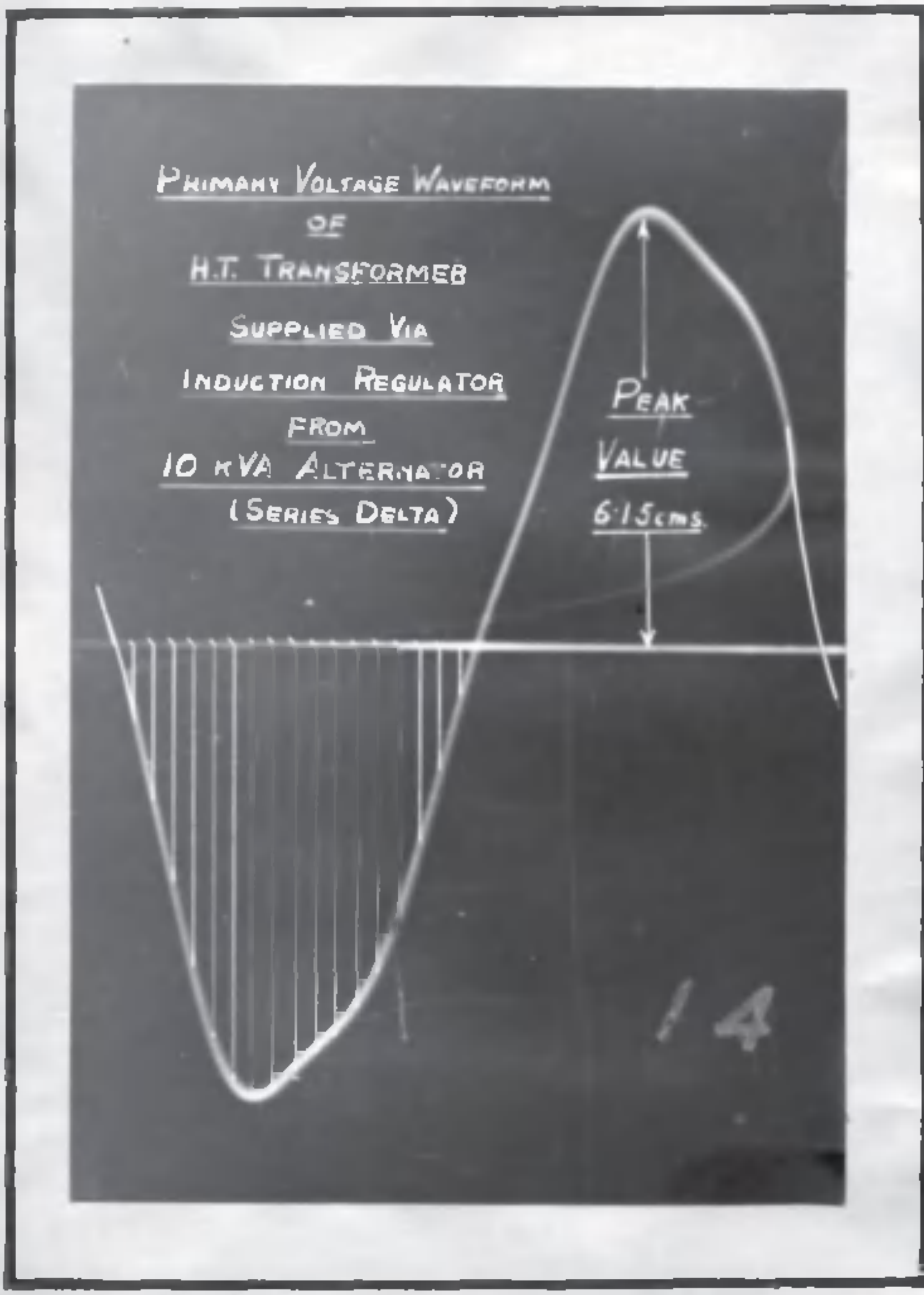


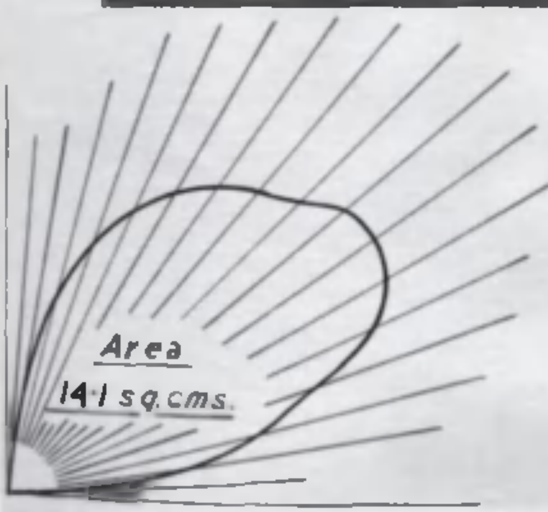
$$\text{R.M.S. Value} = \sqrt{\frac{4 \times 14{\cdot}7}{\pi}} = 4{\cdot}33$$

$$\text{Peak Factor} = \frac{6{\cdot}35}{4{\cdot}33} = 1{\cdot}47$$

$$\left.\begin{array}{l}\text{Conversion}\\ \text{Factor}\end{array}\right\} = \frac{1{\cdot}47}{1{\cdot}414} = \underline{\underline{1{\cdot}04}}$$

Figure 29.





$$\text{R.M.S. Value} = \sqrt{\frac{4 \times 14{\cdot}1}{\pi}} = 4{\cdot}23$$

$$\text{Peak Factor} = \frac{6{\cdot}15}{4{\cdot}23} = 1{\cdot}46$$

$$\text{Conversion Factor} = \frac{1{\cdot}46}{1{\cdot}414} = 1{\cdot}03.$$

Figure 30.

Oscillograms of 30 kVA Alternator.

A similar procedure was carried out with the oscillograms of the 30 kVA alternator to determine the conversion factors which would apply in this case for the star and delta connection of the stator winding.

30 kVA. Alternator.

Connection :- Series-Star.

OPEN CIRCUIT VOLTAGE.

Terminal P.D. = 140 Volts.
Excitation = 1·0 Amps.

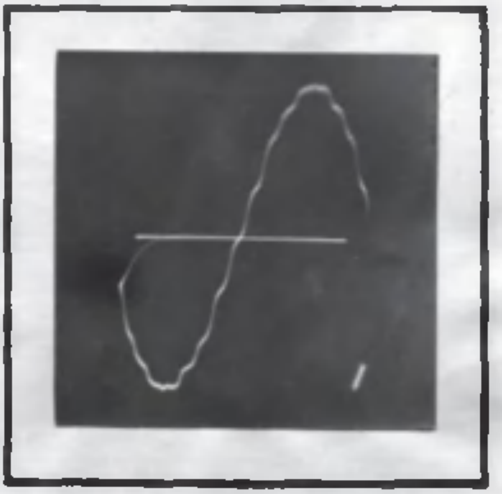


Figure 31.

LOAD – H.T. TRANSFORMER

Terminal P.D. = 140 Volts.
Excitation = 1·0 Amps.

Figure 32.

30 KVA Alternator.

Connection :- Series – Star.

Oscillograms of transformer primary P.D. when supplied through induction regulator.

Alternator P.D. = 140 Volts.
Transformer P.D. = 140 Volts.

Fig. 33.

Alternator P.D. = 70 Volts.
Transformer P.D. = 140 Volts.
(i.e. regulator doubling supply voltage.)

Fig. 34.

Alternator P.D. = 140 Volts.
Transformer P.D. = 70 Volts.
(i.e. regulator halving supply voltage)

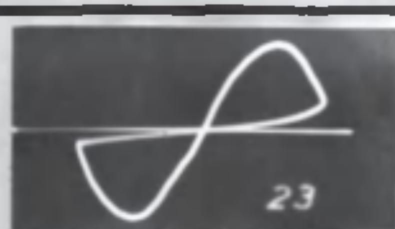


Fig. 35.

Alternator P.D. = 70 Volts.
Transformer P.D. = 70 Volts.

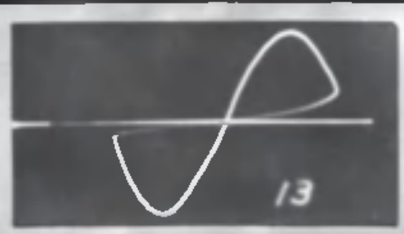
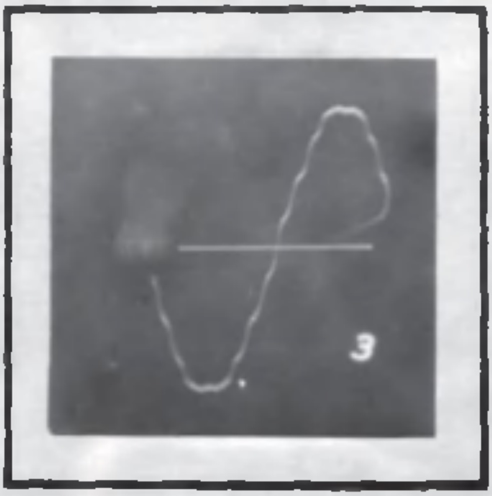


Fig. 36.

30 kVA. Alternator.

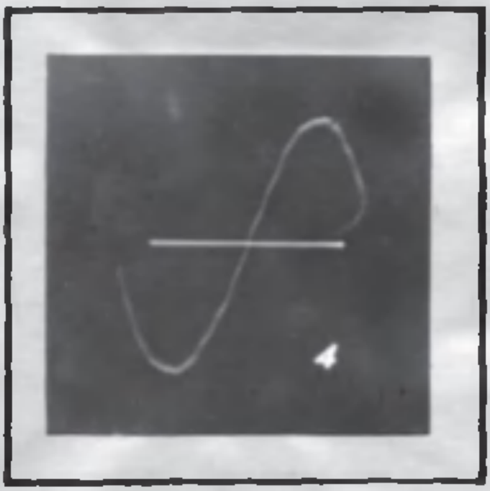
Connection :- Series-Delta.



OPEN CIRCUIT VOLTAGE.

Terminal P.D. = 140 Volts.
Excitation = 1·7 Amps.

Figure 37.



LOAD – H.T. TRANSFORMER

Terminal P.D. = 140 Volts.
Excitation = 1·7 Amps.

Figure 38.

30 KVA Alternator.

Connection :- Series – Delta

Oscillograms of transformer primary P.D. when supplied through induction regulator.

Alternator P.D. = 140 Volts.
Transformer P.D. = 140 Volts.

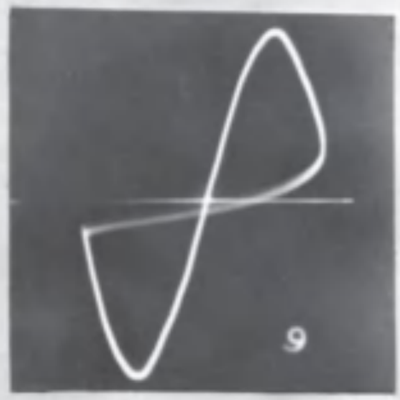


Fig. 39.

Alternator P.D. = 70 Volts.
Transformer P.D. = 140 Volts.
(i.e. regulator doubling supply voltage.)

Fig. 40.

Alternator P.D. = 140 Volts.
Transformer P.D. = 70 Volts.
(i.e. regulator halving supply voltage)

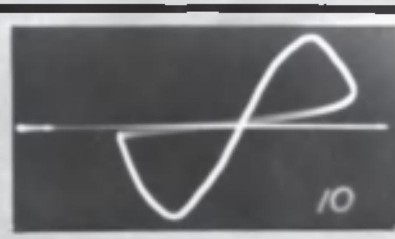


Fig. 41.

Alternator P.D. = 70 Volts.
Transformer P.D. = 70 Volts.

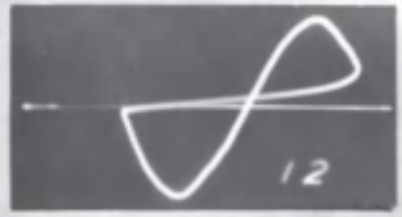
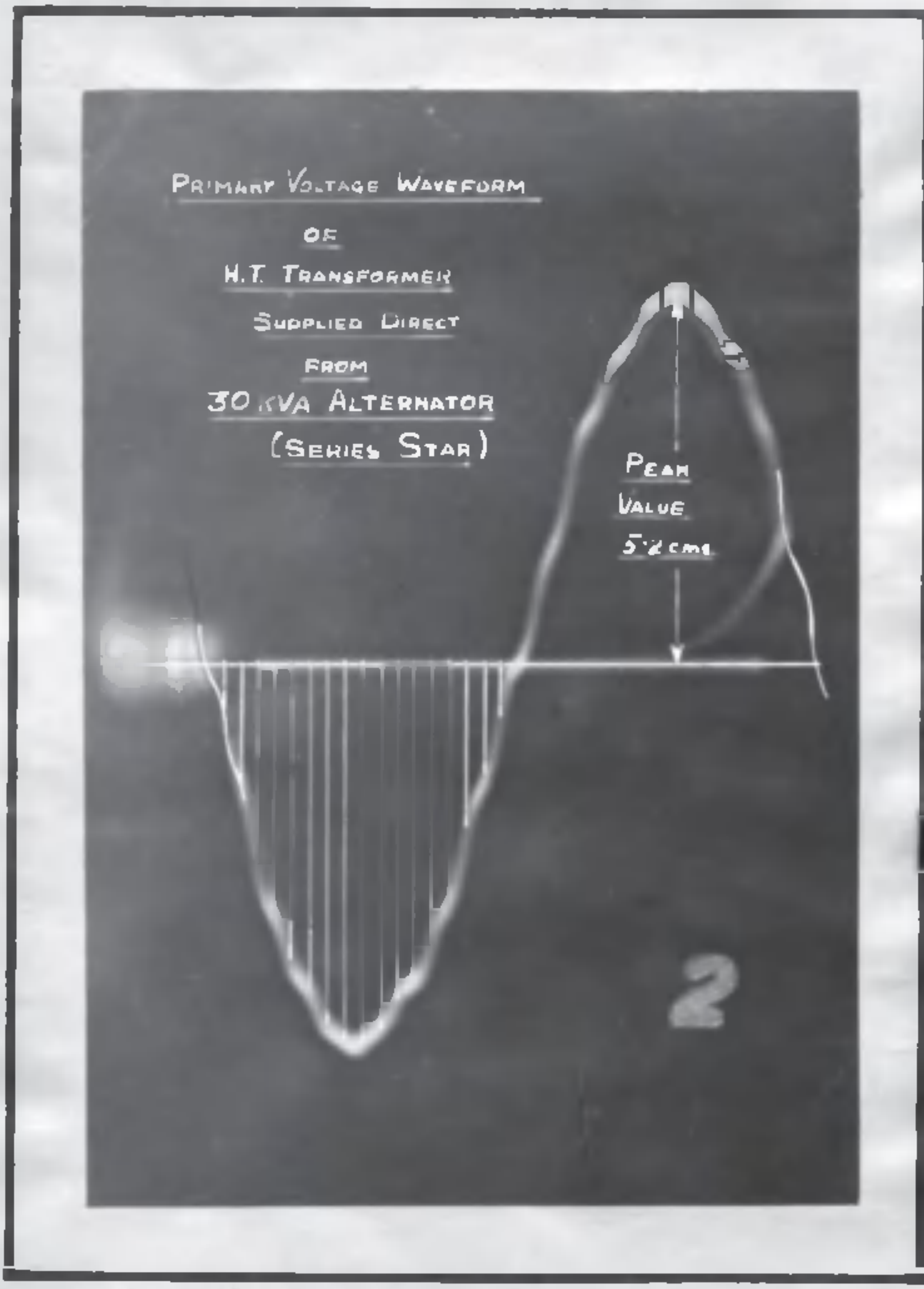
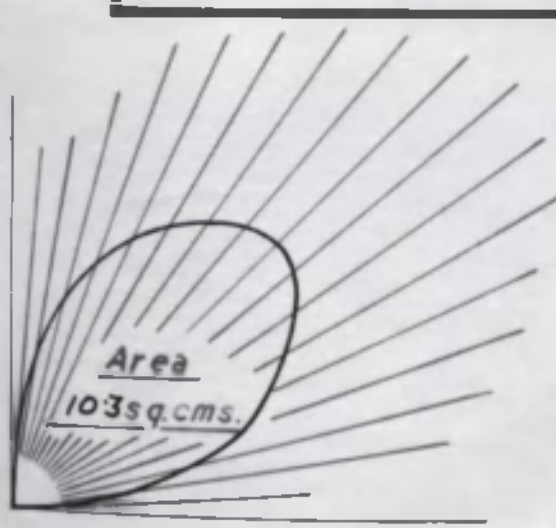


Fig. 42.



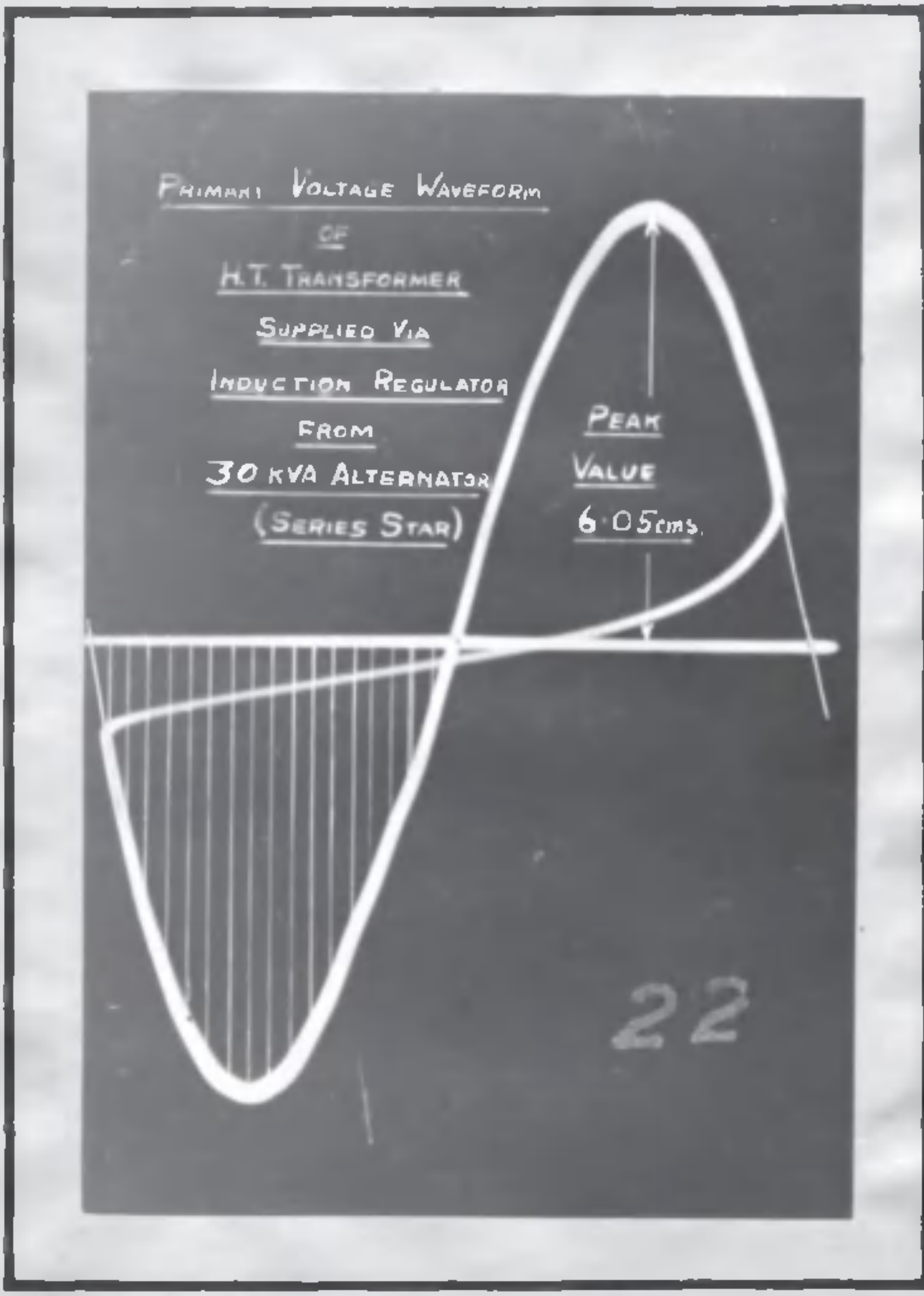


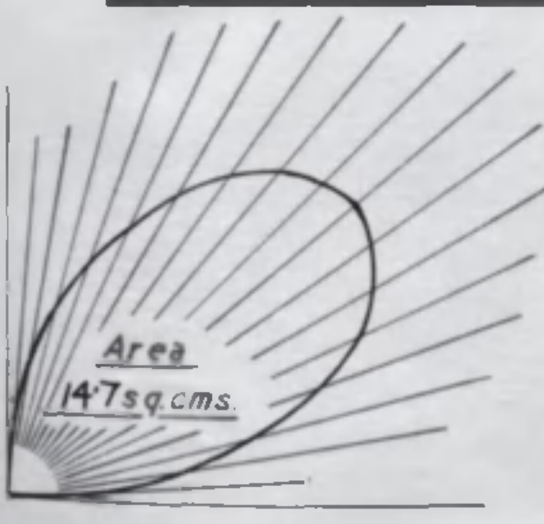
$$\text{R.M.S. Value} = \sqrt{\frac{4 \times 10{\cdot}3}{\pi}} = 3{\cdot}62$$

$$\text{Peak Factor} = \frac{5{\cdot}2}{3{\cdot}62} = 1{\cdot}43$$

$$\text{Conversion Factor} = \frac{1{\cdot}43}{1{\cdot}414} = \underline{1{\cdot}01}$$

Figure 43.



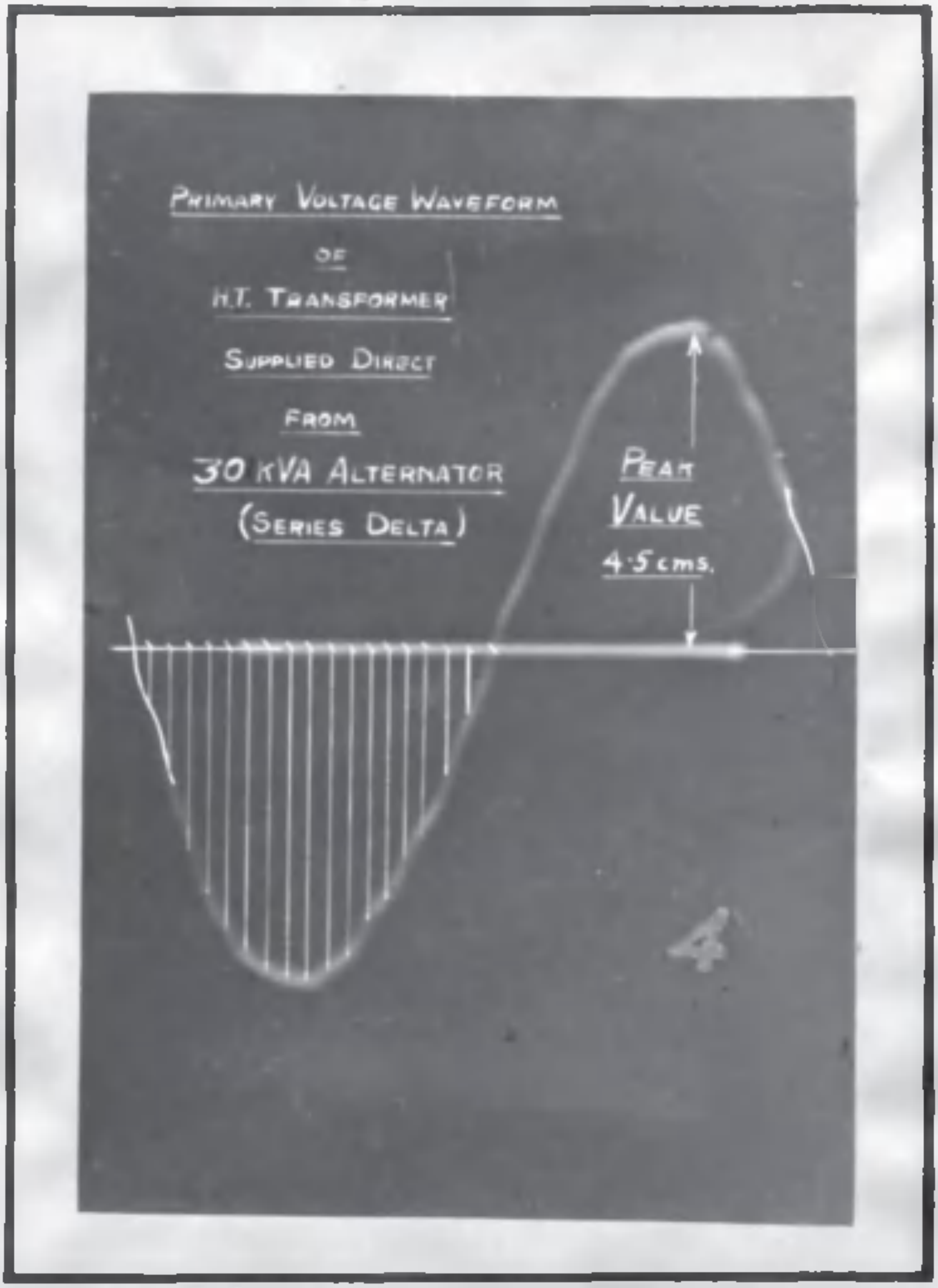


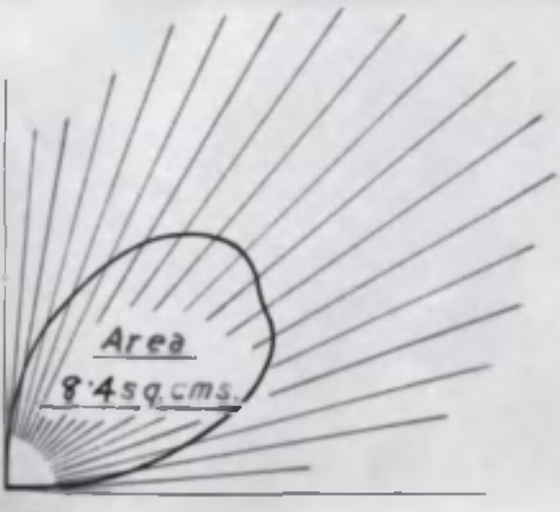
$$\text{R.M.S. Value} = \sqrt{\frac{4 \times 14{\cdot}7}{\pi}} = 4{\cdot}33$$

$$\text{Peak Factor} = \frac{6{\cdot}05}{4{\cdot}33} = 1{\cdot}39_5$$

$$\text{Conversion Factor} = \frac{1{\cdot}39_5}{1{\cdot}41_4} = \underline{\underline{0{\cdot}985}}$$

Figure 44.



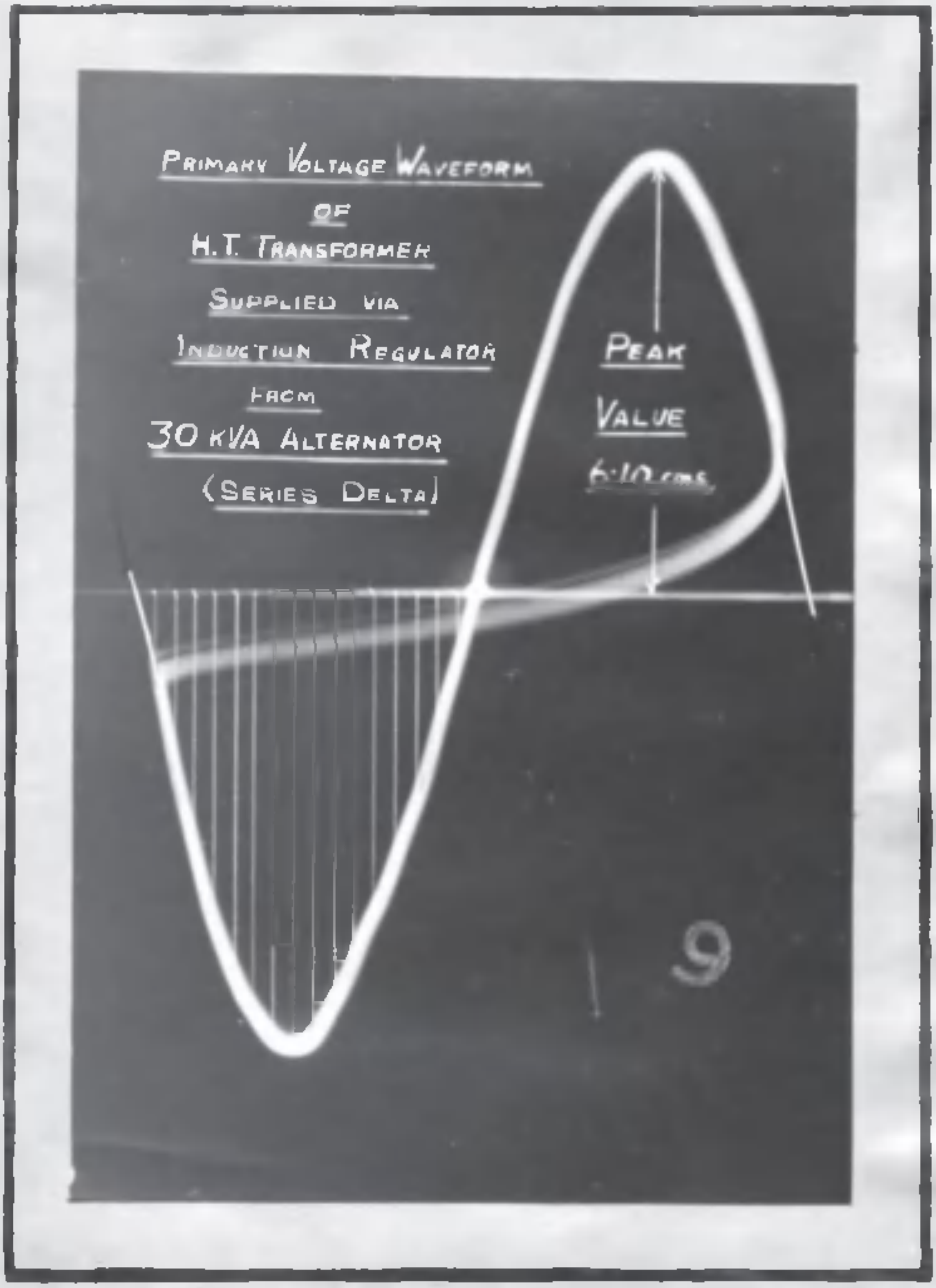


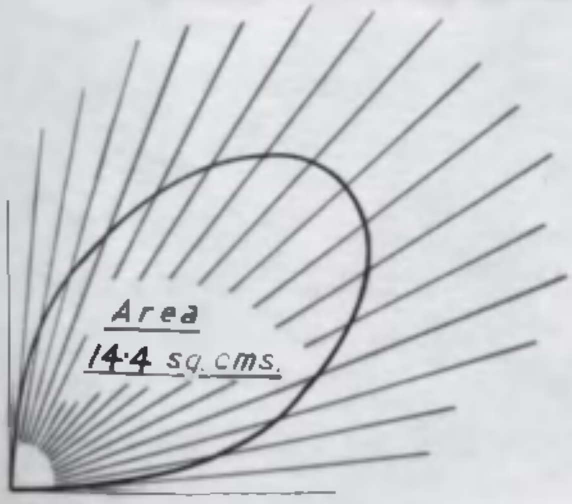
$$\text{R.M.S. Value} = \sqrt{\frac{4 \times 8 \cdot 4}{\pi}} = 3 \cdot 27$$

$$\text{Peak Factor} = \frac{4 \cdot 5}{3 \cdot 27} = 1 \cdot 38$$

$$\left.\begin{array}{l}\text{Conversion}\\ \text{Factor}\end{array}\right\} = \frac{1 \cdot 38}{1 \cdot 414} = \underline{\underline{0 \cdot 975}}$$

Figure 45.





$$\text{R.M.S. Value} = \sqrt{\frac{4 \times 14\cdot4}{\pi}} = 4\cdot28$$

$$\text{Peak Factor} = \frac{6\cdot10}{4\cdot28} = 1\cdot42$$

$$\left.\begin{matrix}\text{Conversion}\\ \text{Factor}\end{matrix}\right\} = \frac{1\cdot42}{1\cdot414} = \underline{\underline{1\cdot01}}$$

Figure 46.

Dispersion of Results.

In the foregoing results the dispersion of the observations from the mean value has in all cases been tabulated and the percentage dispersion calculated. The upper and lower limits are distinguished by positive and negative signs respectively. When the percentage dispersions of Tables 5, 6, 7, 9, 10, 12 and 13 are plotted, Fig. 47, to a common base of gap spacing no general law appears to be satisfied by these seven curves.

The average value of all the percentage dispersions is calculated at each gap setting, that is, the effects of the sphere mounting, the cleaning of the spheres prior to testing, the source of the voltage of supply, the wave form, etc., are completely ignored. On plotting these mean percentage dispersions to a base of gap setting, the black curve in Fig. 47 is obtained which is similar in form to that given by the measurements of M. Toepler* and observed by others.

M. Toepler drew attention to the fact that although the lower part of the calibration curve of a sphere gap is a straight line a critical point occurs at which the curve bends away from this straight line. This point of discontinuity, which varies with the diameter of the spheres, is difficult to locate. However, by plotting the dispersion of the observations Toepler claims that the marked increase of the dispersion

---

* Toepler, M., Zeits. f. techn. Physik. 13.8, p. 386, 1932.
Claussnitzer, J., E.T.Z., 38, p. 911-912, 1933.
Heuter, E., E.T.Z., 57, pp. 621-625, 1936.

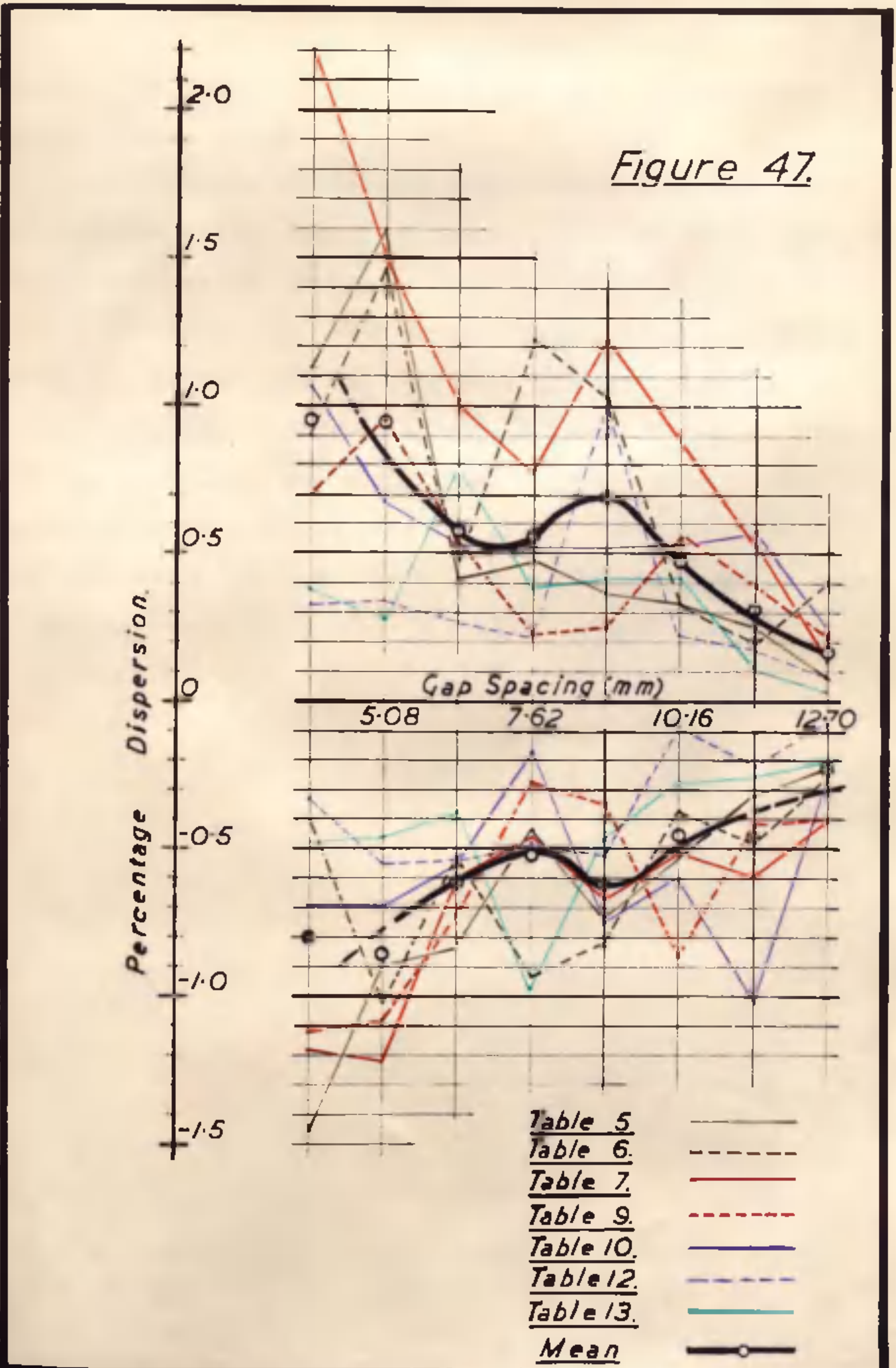


Figure 47.
2·0
1·5
1·0
0·5
0
-0·5
-1·0
-1·5
Percentage Dispersion.
Gap Spacing (mm)
5·08
7·62
10·16
12·70
Table 5
Table 6.
Table 7.
Table 9.
Table 10.
Table 12.
Table 13.
Mean

indicates the region of the discontinuity in the sparkover voltage/spacing curve.

No definite conclusions can be drawn from the result here obtained as the number of points on the curves is insufficient as well as the number of observations at each gap setting. (Toepler recommends at least twenty observations at each gap spacing before reliance can be placed on dispersion figures.) Nevertheless, the results do appear to indicate that at about 8.89 mm. (0.35 ins.) gap with 20 mm. diameter spheres the scattering of the observations increases. Presumably some change is taking place in the nature of the discharge at this gap spacing.

Conclusion.

In spite of its many limitations the sphere gap remains one of the standards of high-voltage measurement. This investigation therefore has been an attempt to reach a more thorough understanding of some of these limitations and in particular those directly applying to the installation described.

Sphere gap observations (up to gap lengths equal to the sphere radius) may be regarded as repeatable with sufficient accuracy if reasonable precautions are taken to ensure that conditions are unchanged - in particular:-

(i) After cleaning and removal of grease film from the surface, the spheres must not be touched.

(ii) At least 20 discharges should occur before observations are commenced.

(iii) At least 90 seconds should elapse between successive discharges.

(iv) All earthed bodies and h.v. connections should be kept as far as possible away from the gap, that is, there should be ample clear space around the gap.

It is further recommended that

(a) as the voltage measured by the sphere gap is the peak value, the standard calibration figures could with advantage be stated in these values instead of the doubtful term "r.m.s. sine wave" kilovolts,

(b) a blast of air of, say, 100 feet per minute across the gap improves its behaviour.

Appendix. I.

The Employment of Neon Lamps in Electrical Measurements.

INTRODUCTION.

On reviewing all the methods of calibrating the sphere gap one which appeared to offer possibilities with the apparatus available was that of a neon lamp in conjunction with a capacitive voltage divider. A comprehensive study was therefore made of the various papers which had been published dealing with the characteristics and uses of neon lamps in electrical measurements. The papers studied have been summarised under three headings:-

1. Theoretical consideration of the mechanism of the discharge.
2. General characteristics.
3. Uses of neon lamps.

Following this summary are particulars of numerous experiments carried out by the author with a view to determining the characteristics of a number of neon lamps and the various factors affecting their stability as standards in high-voltage measurements.

Theoretical Considerations.

Mechanism of the Discharge.

The exact mechanism of the complicated processes occurring within a discharge tube is still apparently a matter of conjecture, and, moreover is a subject for elucidation by the pure physicist. The treatment given, therefore, will employ the theories suggested, only in so far as they may be required to form a mental picture of the physical condition of the glow discharge in its various phases.

Recent experiments have shown that the atom consists of a number of electrons grouped around a heavy nucleus. The negative charges of the electrons being just equal to the positive charge of the nucleus, the atom is electrically neutral. However, the fact that a gas has a certain conductivity, though it is extremely low, is an indication that there are a few electrons that are not firmly bound in electrically neutral systems. The removal of an electron from an atom destroys the electrical balance within the atom, such that the remainder has a resultant positive charge, and is known as the positive ion, while the dissociated electron has a negative charge. The atom is said to be ionised.

When a difference of potential is applied to the electrodes of a tube, a field is set up, which at first is approximately uniform, with the result that the electrons are attracted to the anode and the ions to the cathode. As they move, the ions and the electrons encounter other atoms in their path. Since the electrons are much smaller and lighter than the ions they move at a higher velocity although under the influence of the same field as the ions. The electrons may, if the strength of the field is sufficient, be moving at such a velocity as to cause the atoms with which they collide, to become ionised by removing one or more electrons from them. This increase in the ionisation of the gas increases the conductivity of the tube.

The ions drift towards the cathode and accumulate near it. The excess of positive ions over electrons near the cathode establishes a positive charge in this neighbourhood. If the applied potential difference is sufficient this charge builds up until the difference of potential between it and the cathode, is large enough to impart to the positive ions a velocity of such a value that electrons will be liberated when the ions strike the cathode. Electrons thus liberated in the intense field now near the cathode, have a very high velocity and consequently a very great ionising power.

Accompanying this movement of charged particles, which accounts for the flow of electricity through the tube, there is the continual tendency of the free electrons within the gas to combine with positive ions. When this occurs light is produced, that is, we have a visible or luminous discharge. Light is also produced by an electron reverting to its normal position when, from any cause it had been disturbed, without actually being dissociated from the atom. Both of these effects are probably present when a glow discharge occurs.

The dark spaces appearing in the path of the discharge can be accounted for by the fact that the velocity of the electrons there is too high for recombination.

The drop in potential along the tube from anode to cathode will be far from uniform, but may be divided, roughly into three parts:- (i) the cathode drop - due to the accumulation of positive ions near the cathode most of the fall of potential in the tube occurs in the space between the cathode and the negative glow; (ii) the positive column drop - the drop in potential here is uniformly distributed throughout the length of the column and is usually relatively small; and (iii) the anode drop - the accumulation of negative charges at the anode produces an increase in the potential gradient near the anode.

Experiments to determine the potential distribution while discharge is taking place have for long been attempted. Obviously the method employed must not affect the discharge itself. Early attempts were made by inserting small probes into the discharge and measuring the difference of potential between them or between one of them and either electrode by means of an electrometer. This method has been modified and improved by Langmuir and Mott Smith in order to reduce the disturbing effects of the probes. Other methods employed consisted in shooting a beam of electrons through successive points in the discharge region and observing the deflections of the beam, while another method employed a spectrograph to study the energy radiated at various points of the discharge path.

The cathode drop is found to be constant for a given electrode material and a given gas pressure and so long as the negative glow does not completely cover the cathode. This value is known as the normal cathode drop. In the same way the current density is constant until the glow completely covers the cathode, or the area of the glow is proportional to the value of the current. This latter fact has been experimentally verified by H. A. Wilson*. If the current through the tube is increased beyond that required for the glow to cover the cathode completely, we have an abnormal cathode drop and an increase in the current density.

Associated with the fall of potential at the cathode is a phenomenon known as sputtering which is a form of vaporisation of the metal of the electrode. The bombardment of the cathode by positive ions causes local volatilisation of the electrode material with the result that atoms of the metal of the electrode are chipped off and are deposited on the glass wall adjacent to the electrode. A considerable amount of the neon gas in the tube is included with this deposit which in time renders the tube useless.

The factors governing the rate of sputtering are somewhat interdependent, such as, the material of the electrode which must have a high latent heat of vaporisation or the

---

* Wilson, H.A., Phil. Mag., 6.5.4. pp. 608-614, 1902.

electrode drop, which if it is large will result in the bombarding ions having a greater heating or vaporising power or the gas pressure, which may be sufficiently high to prevent the metal reaching the glass walls but would then cause the electrode drop to be excessive. The life of the tube is ended when the pressure of the gas within it has been so reduced by absorption that conduction through it can no longer take place under normal conditions.

No attempt is made in the foregoing theory of the mechanism to take into account the effect of mixtures of gases or of the presence of impurities or of occluded gases in the material of the electrodes. All of these considerably modify the functioning of the tubes. In this work we are concerned with the commercial type of neon discharge tube (or lamp) in which the actual gas content is not so important as the fact that the gas content remains constant. Overrunning of the lamps tends to ensure this constancy.

FURTHER REFERENCES.

Compton and Faulke. "The Origin of Ions in Unsustained Glow Discharge". Gen. Elec. Rev. 26, p. 755, 1923.

Guntherschulze, A. Mechanism of the Glow Discharge. Zeits. f. Phys. 303, pp. 175-186, 1924.

Holm, R. Theory of Glow Current. Phys. Zeits. pp. 497-535, Oct. 1924, pp. 412-420, June 1925.

General Characteristics.

Striking Voltage.

If the potential difference between the electrodes is continuously increased the tube takes an extremely small current until the critical voltage, Vs, is reached, at which luminous discharge occurs. Since the gas column between the electrodes now becomes conducting, the current suddenly increases to a value depending only on the limiting conditions of the external circuit.

The striking potential, V_S, is dependent on many factors, among which may be mentioned, the material of the electrodes, the shape of the electrodes and the nature and pressure of the filling gas. With pure gas, V_S is higher than if even the smallest traces of impurities are present. As little as 0.0001% argon in a neon tube is shown by F. M. Penning* to alter its characteristics very considerably.

The ionisation of the gas in the tube by the applied voltage, takes an appreciable time, (though not more than a few seconds) so that the striking voltage V_S may be expected to be somewhat dependent on the length of the time of application of this voltage. Many investigators, with little agreement however, have attempted to account for this lag of the discharge after the voltage has attained the value V_S. For example the extensive researchs of J. Zeleny[x] and of J. W. Ryde[ø] lead them to attribute it to a special surface action due to an adhering

---

* F. M. Penning {Zeits. f. Phys. 46, pp. 335-348, 1928, Phil. Mag., 7, pp. 632-633, March, 1929.

x J. Zeleny, Phys. Rev. 16, pp. 102-125, Aug. 1920.

ø J. W. Ryde, Proc. Phys. Soc. 36, pp. 249-250, 1925.

layer of gas molecules on the electrodes, whereas, K. Zuber* states that the actual time lag appears to be due to chance! Zuber observes also that the mean time of lag is dependent on the outer radiation of the discharge tract.

L. F. Richardson[x] in a paper on "Mental Images and Sparks" remarks that, at the same applied voltage, the suspense or time of lag in striking varied between 6 and 69 seconds. In this uncertain behaviour he traces an analogy to the fickle behaviour of one's mind when called on to solve the same problem say once a year for many years in succession!

Assuming that a gas film exists, the positive ion bombardment during the early stages of the discharge may play an important part in the removal of these films, while any external ionising agent may conceivably hasten such removal.

That the lag was due solely to the fact that the gas in the tube was not pure has been pointed out conclusively by J. Taylor[ø] and others. L. E. Ryall[+] has recently stated that the lowest voltage which will cause a neon lamp to strike requires a time of application of about 10 seconds. If this time of application of the voltage before striking occurs is less than about 0.003 second he finds that V_s is independent

---

* K. Zuber, Ann. d. Phys. 76. pp. 231-260, 1925.

x L. F. Richardson, Psychological Review, 37. pp. 214-227. May, 1930.

ø (J. Taylor, Phil. Mag. 7.5.3. pp. 368-382 and pp. 753-770, 1927.
(N. L. Harris, Proc. Phys. Soc. 42, p. 169, Aprill, 1930.

+ L. E. Ryall, J. Sci. Insts. 7. pp. 178-186, June, 1930.

of this effect of initial ionisation, but, of course, is consistently higher than the "static" value.

The effect of external radiation has been found to reduce this lag. Some of the investigators claim that coating the bulb with radio-active substances such as radium bromide, uranium acetate, uranium oxide, etc. has a noticeable effect on the time of application necessary. The experiments of Oschwald and Farrant* are interesting in that they further claim that the striking voltage is reduced if the lamp is subjected to ionisation by an external agency. They described experiments with various light sources from which they deduced that the striking voltage was consistently reduced by about 9% irrespective of the light source if the intensity of illumination exceeded about 0.01 foot-candle. They observed the same reduction with uranium oxide applied to the lamp support while X-rays caused a reduction of about 20%. This effect has been attributed to the presence of impurities, particularly hydrogen. Other investigators[x] give conflicting opinions on the action of light on spark and glow discharges in pure gases as well as in mixtures of gases. Taylor and Stephenson[ø] mention the fact that light and other ionising agents, (e.g. radium bromide near the lamp) prevent excessive lag but have

---

* Oschwald and Farrant, Proc. Phys. Soc. 36, pp. 241. 1923-1924.

x (Pederson, P.O., Ann. d. Phys. 71, pp. 317-376. June 5, 1923.
(Penning, F.M., K. Akad. Amsterdam Proc. 32. pp. 341-343, 1929.

ø Taylor & Stephenson, J. Sci. Inst. 2. Nov. 1924, pp. 50-54 and pp. 154-158, 1925.

no effect on the striking voltage. Ryall* shows that with an illumination of 200 ft. candles V_s is unaltered!

The striking voltage may also be affected by the ionisation within the lamp itself due to a previous discharge. This can be demonstrated very simply by applying the striking voltage to the lamp and then very gradually reducing the applied potential difference. The luminous discharge is found to be maintained by a voltage very much less than the striking voltage. If the voltage is reduced just sufficient to extinguish the glow and then immediately increased the lamp will strike at a lower voltage than the normal striking voltage. The ionisation occurring when the lamp glows is thus persisting after extinction and it is found that the time taken for the lamp to return to its original condition is not constant but may vary from a few seconds to about a minute.

<u>The Extinction Voltage.</u>

This is the value to which the applied potential difference must be reduced in order just to extinguish the luminous discharge.

The extinction voltage is much more critical and consistent than the striking voltage, and is not subject to any appreciable time lag, due to the fact that the lamp is in its normal glowing condition just prior to extinction.

---

* Ryall, L.E., I.E.E.J. 69. pp. 891-897, July, 1931.

This, of course, applies to the conditions of gradual reduction of the applied voltage. A sudden reduction of the voltage may cause the lamp to be extinguished at a voltage higher than the normal value.

(The author recorded these observations on the extinction voltage in Nov. 1928. It was not until 1931 that reference to this was first published*.)

Volt-Ampere Characteristic.

Under normal circuit conditions, that is, relatively low values of external resistance, the volt-ampere characteristic is as shown in Fig. 48. As the applied potential difference is increased no current flows until the striking voltage, V_S, is attained, when the lamp strikes and the current jumps to the value I_S. If the applied potential difference is reduced the lamp will continue to glow till the current falls to I_E, corresponding to the extinction voltage V_E, when the lamp ceases to glow and the current falls to practically zero.

The phenomena preliminary to glow discharge are of considerable importance but are not observed with ease, since they are of a transitory nature due to the fact that the external circuit is usually able to supply an adequate amount of energy to cause the tube to glow as soon as the cumulative

* L. E. Ryall, I.E.E.J. 69, pp. 891-897, July, 1931.

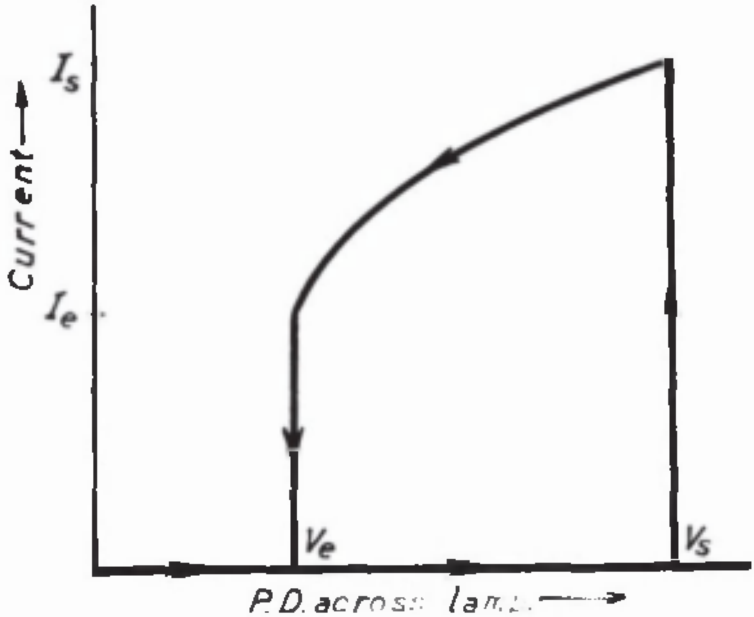


Figure 48.

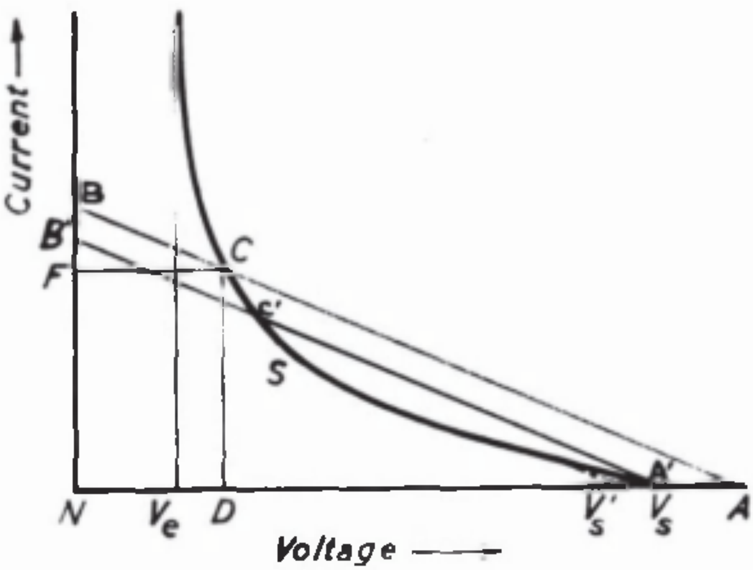


Figure 49.

ionising action in the tube sets in. Stroboscopic studies of this part of the discharge have been carried out by Penning* and by Clarkson*. A close approximation to the conditions is obtainable if a sufficiently high resistance is put in series to control the energy supplied.ϕ The large series resistance is kept fixed and the supply voltage gradually increased. No current flows until the voltage, V_s, is reached. A slight diffuse glow appears and a small current flows. If now the current through the tube is increased (say by increasing the voltage across the circuit and keeping the resistance fixed) the voltage across the tube is found to decrease as shown (Fig. 49). After point S is reached the glow appears almost normal and the potential difference across the tube rapidly falls to V_E, the normal extinction voltage, corresponding to the current I_E at extinction.

Let the external resistance be R ohms, and let the applied voltage, E, be represented by NA. If C is any point (V,i) on the characteristic then DA is the drop across the external resistance. Joining AC and projecting to B we have,

$$DA = NA - ND = E - V = Ri = R \times NF.$$

$$\therefore \; R = \frac{DA}{NF} = \text{gradient of line AB to the current axis.}$$

i.e., AB is a resistance line with respect to the current axis.

---

* Penning, F.M., Phys. Zeits., 27, pp. 187-196, Jan. 27, 1926.

* Clarkson, W., Phil. Mag. 1927, pp. 849, 1002, 1341.

ϕ Taylor, Jas., Phil. Mag., pp. 368-382, Feb., 1927.

With this resistance R and an applied voltage V_s. the lamp will strike and current flow if the parallel to AB (i.e. A'B') cuts the curve as at C'. There is thus a critical resistance which may be put in series with a neon tube, the value of which is given by the slope of the tangent to the corona characteristic. If the external resistance exceeds this value the tube will not glow.

The actual shape of the volt-ampere characteristic for the corona region, (i.e. with an applied voltage equal to V_s, the striking voltage) varies considerably for different types of tube, as it is influenced by such factors as shape and distance apart of the electrodes, gas pressure, etc. All discharge tubes however have this 'falling' or 'negative' characteristic, namely, the larger the current flowing the less the potential difference required to maintain it.

With a voltage, V_s' (Fig. 49) just slightly less than the striking voltage V_s, applied to the tube for some time, intermittent slight flashing is observed. This irregular behaviour, indicating that the ionisation within the tube is insufficient to maintain a continuous glow discharge, might be accounted for by impurities present in the gas or in the electrodes.

The stability of such neon tubes at or near the striking voltage may thus be expected to be easily affected by any external conditions which might assist ionisation. Experimental observations taken by the author and recorded later in this report bear out this expectation.

The complete volt-ampere characteristic, Fig. 50, may be given as the combination of Fig. 48 and Fig. 49. The current taken by a neon tube for any voltage V across it, after the striking voltage V_s has been applied to it, may have either the value PR or PQ depending on whether or not the external circuit can supply an adequate amount of energy to completely ionise the gas.

A. C. Characteristics of Neon Lamp.

When a sinusoidal alternating potential is applied to the electrodes of a neon lamp through a stabilising resistance the discharge will pass and reverse each half cycle, if the peak value is sufficient to cause the lamp to glow, i.e., if the peak value is equal to or greater than V_s. As shown in Fig. 51 when the voltage reaches V_s the current suddenly rises to I_s. Assuming the negative resistance characteristic of the tube swamped by the stabilising resistance the current varies with the voltage till the voltage falls to V_E when the current suddenly drops to zero. The lamp remains extinguished till the voltage reaches V_s in the next half cycle, after which the current goes through similar variations as before but in the reverse direction.

The current wave form assumed above (parts of sine curves) would apply approximately to a tube in which the electrodes are exactly similar and the cathode drop never exceeds the *normal* value, i.e. the glow never completely covers the cathode. If the electrodes are dissimilar the voltage

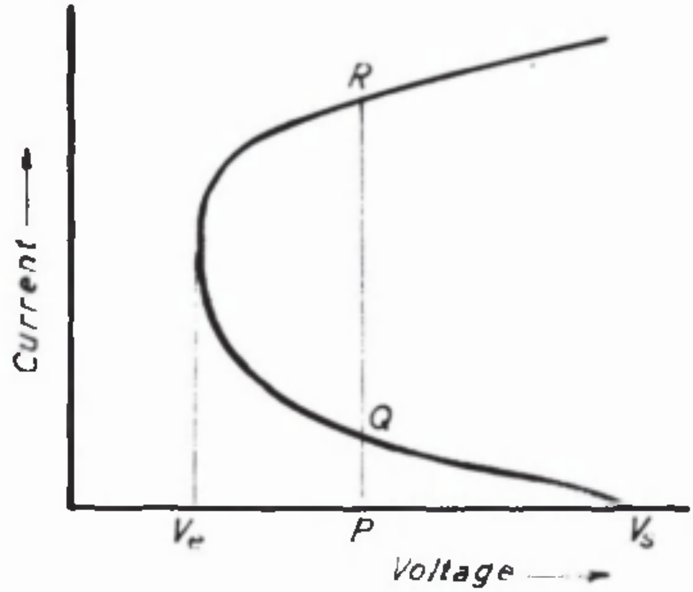


Figure 50.

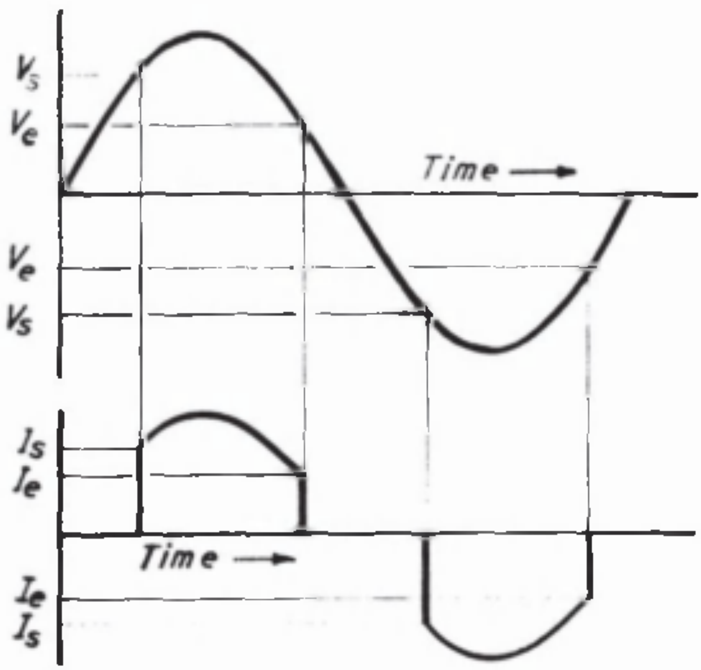


Figure 51.

across the tube may not be the same during the two half cycles. This will occur if the cathode fall is abnormal as when the smaller electrode is the cathode. The current will consequently have different values during each half cycle.

The wave forms obtained in practice with long lengths of neon tubes supplied from a high reactance transformer differ considerably from those indicated above.

If, as is reasonable with a transformer having a reactance of about 90%, the wave form of the current is assumed to be nearly sinusoidal over a large part of the cycle and zero over the remainder an approximation to the voltage required across the tube has been determined* from the fact that this voltage has to satisfy two conditions at any instant, (a) that imposed by the negative resistance characteristic of the tube, (Fig. 52) $V_t = f(i)$, V_t being the voltage across the tube, and (b) that imposed by the regulation of the transformer, $V_t = V - L\frac{di}{dt}$, where V is the open circuit voltage and L is the equivalent reactance of the transformer of which the resistance is neglected.

Assuming a sine wave of current through the tube the variation of potential difference across the tube can be derived from the volt-amp. characteristic (Fig. 52) and will be of the form shown in Fig. 53.

Introducing the fact that the load is intermittent the actual voltage across the tube will follow the open circuit

---

* C. M. Summers, Elect. Eng. 51, pp. 772-775, Nov. 1932.

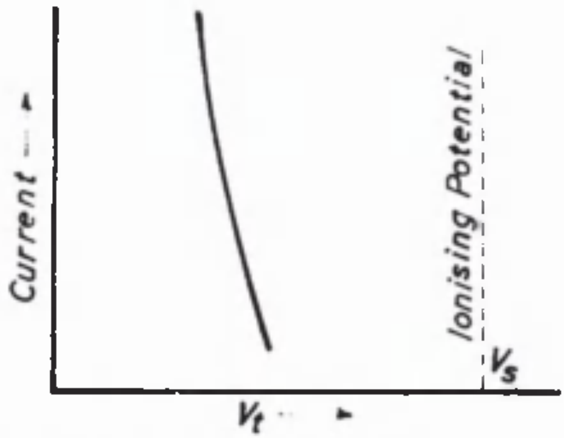


Fig. 52.

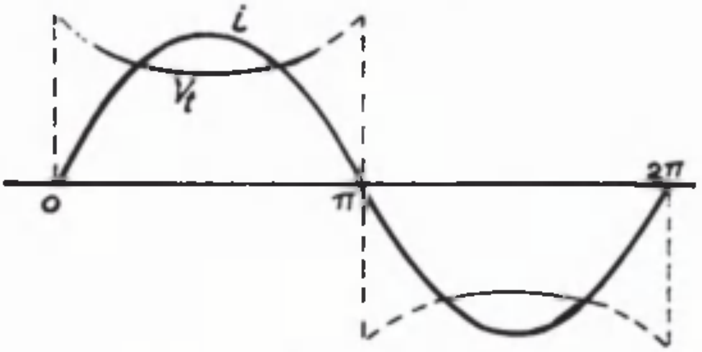


Fig. 53.

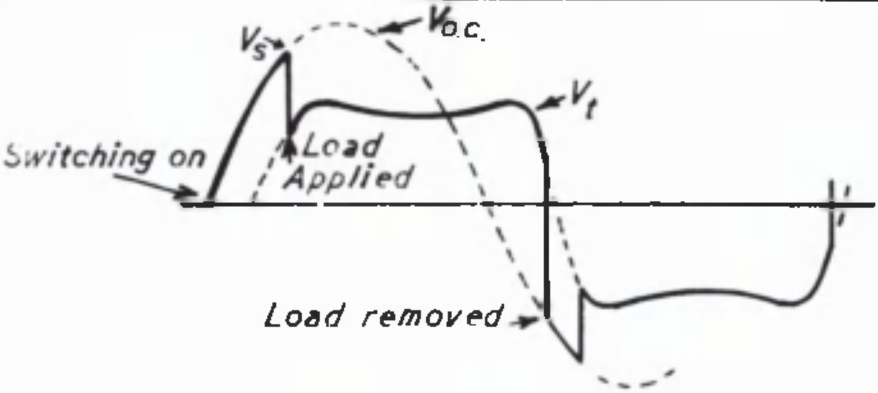


Fig. 54.

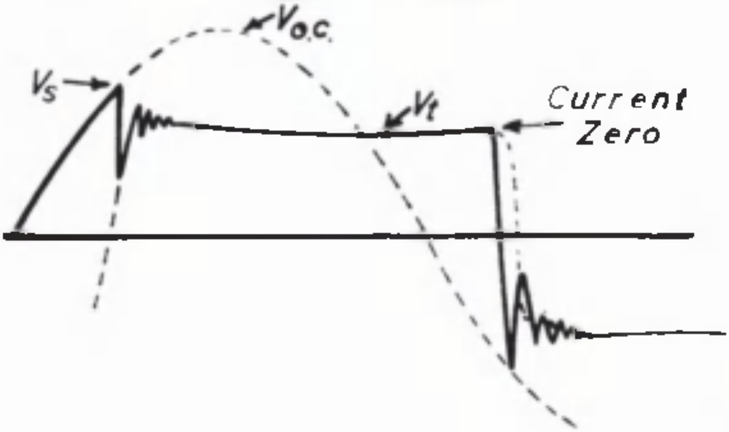


Fig. 55.

characteristic of the transformer when the lamp current is zero and the tube characteristic when ionisation takes place. The result would be as indicated in Fig. 54 except that the negative characteristic of the lamp introduces a certain instability since any change of the voltage across the lamp after striking has occurred is accompanied by a corresponding negative change in the current. The instability thus introduced may be damped out before the end of the half cycle if the reactance of the transformer is sufficiently high. This results in a wave form somewhat as shown in Fig. 55 and is in close agreement with oscillographic records obtained by C. M. Summers for such arrangements of transformers and neon tubes.

Flashing.

The employment of a discharge tube as an oscillation generator has received marked attention for some time. The first recorded use of a neon lamp for this purpose is the patent by Hart* in 1922 although the phenomenon appears to have been independently discovered by Anson* about the same time.

The circuit employed for flashing conditions is as shown (Fig. 56, p. 95). A neon lamp shunted by a condenser is connected in series with a high resistance across a direct-current supply.

On switching-on, since the lamp resistance is practically infinite we have a condenser and resistance in series, and therefore the voltage across the lamp at any instant is given by

$$v = V\left(1 - \varepsilon^{-\frac{t}{CR}}\right) \;.....\; \text{Eqn. (1)}$$

where V is the assumed constant supply voltage.

When the voltage across the tube rises to the striking value, V_s, the gas in the tube becomes conducting, so that the tube is a low impedance across the condenser which commences to discharge. The energy stored in the condenser thus becomes available to give a visible glow in the lamp. The high series resistance prevents the supply maintaining the glow and therefore the glow will persist only until the potential difference

* Hart, Patent No. 201272, 1922.

* Pearson & Anson, Proc. Phys. Soc. 34, pp. 175-176 and pp. 204-212, 1921-1922.

across the condenser falls to the extinction voltage, V_E, of the lamp. At this value, the glow is extinguished and the condenser starts charging again and the cycle is repeated. The lamp thus flashes at a frequency determined by the values of R, C, V_s, V_E and the supply voltage. The frequency can be determined approximately as follows:-

Let t_E and t_s be the time required for the voltage across the condenser to reach V_E and V_s respectively, after the switch is closed, then, substituting in Eqn. (1), the duration of the dark period is given by

$$t_s - t_E = -CR\log_\varepsilon\left(1 - \frac{V_s}{V}\right) + CR\log_\varepsilon\left(1 - \frac{V_E}{V}\right)$$
$$= CR\log_\varepsilon\left\{\frac{V - V_E}{V - V_s}\right\}$$

The calculation of the light period or discharging period would require a knowledge of how the resistance of the glowing lamp varies with the voltage across its terminals. However, it may be shown that the light period is short compared with the dark period, (usually less than 1%) so approximately the duration of the dark period may be taken as the periodic time of the flashes or

$$\tau = CR\log_\varepsilon\left\{\frac{V - V_E}{V - V_s}\right\} = k\,CR \text{ where } k = \log_\varepsilon\left\{\frac{V - V_E}{V - V_s}\right\}$$

$$\therefore k = \text{constant if } V_E \text{ and } V_s \text{ are constant.}$$

or Frequency of flashing $= \frac{1}{\tau} = \frac{k'}{C\,R}$ where $k' = \frac{1}{k}$

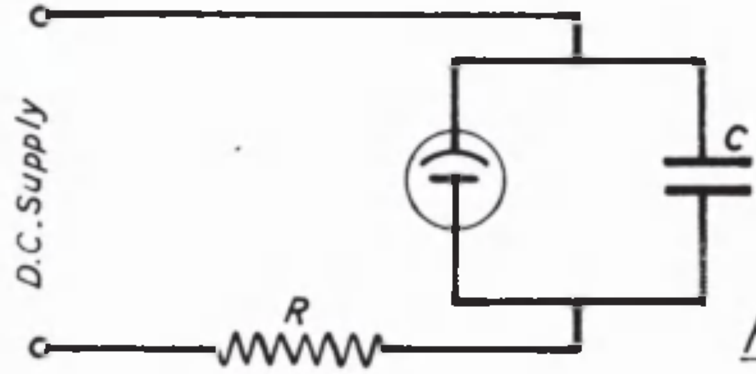


Fig. 56.

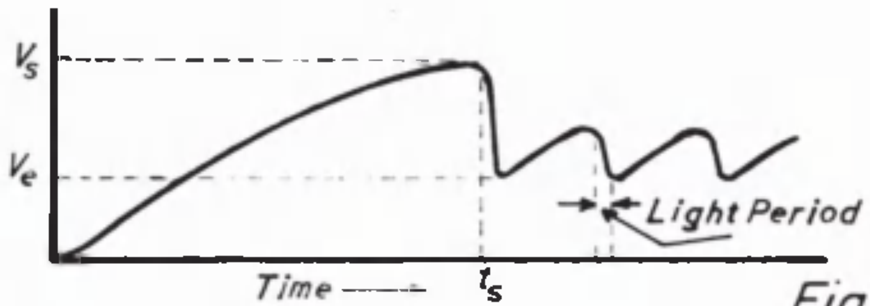


Fig. 57.

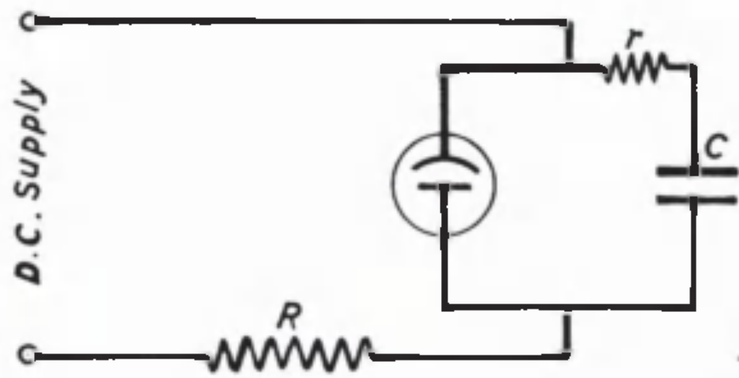


Fig. 58.

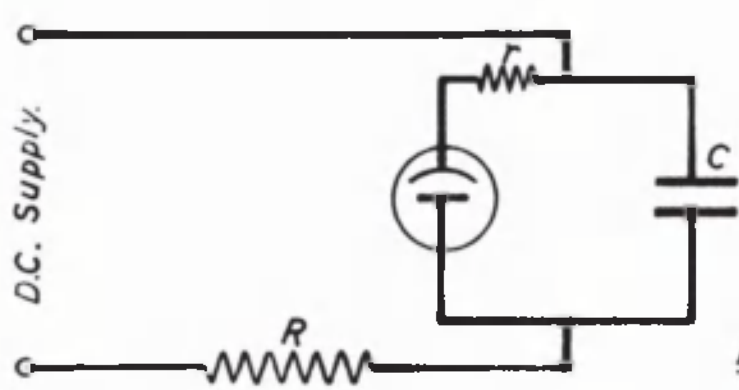


Fig. 59.

The accompanying oscillograph (Fig. 57)* clearly illustrates the relative proportions of the dark and light periods.

The initial striking voltage is in excess of succeeding values. In other words the mean voltage of the sustained oscillation is considerably lower than the striking voltage.

V_E and V_S are liable to show progressive change and erratic fluctuation and there may be variation of the time of lag, in consequence of which this type of oscillator proves, in practice, to be unreliable. Conditions can be rendered more consistent by increasing the resistance of the discharge path* during the luminous period in either of the two ways shown in Figs. 58 and 59. Exposing the lamp to certain ionising agencies may improve conditions.

---

* A. B. Wood, Proc. Phys. Soc. 42, pp. 157-169, April 1930.

* Taylor & Clarkson, Proc. Phys. Soc., 36, pp. 269-278, 1923.

Uses of Neon Lamps.

Comparison of High Resistances - Substitution Method.

With the circuit indicated,* Fig. 60, telephones can be employed for the observation of the time of flashing.

With the unknown resistance X in circuit a value of capacitance in parallel with the lamp is chosen so that the time Tx for 100 flashes can be conveniently counted. The time between flashes should not be greater than about 2 seconds. With this value of capacitance a standard resistance, R, can now be substituted to give the time, T_s, of 100 flashes slightly greater than that with X in circuit.

The unknown resistance is then approximately given by

$$X \doteqdot \frac{Tx}{Ts} R$$

The approximation arises from the fact that the time-resistance graphs for this circuit, although they are straight lines, do not pass through the origin, probably owing to the resistance of the battery and remainder of the circuit.

If, however, a second observation is taken with a value of R chosen to give, with the same supply voltage, the time of 100 flashes slightly less than that with X in circuit, the value of X may be found by interpolation.

---

* Taylor & Clarkson, J. Sci. Insts. 1. pp. 173-182, 1923-1924.

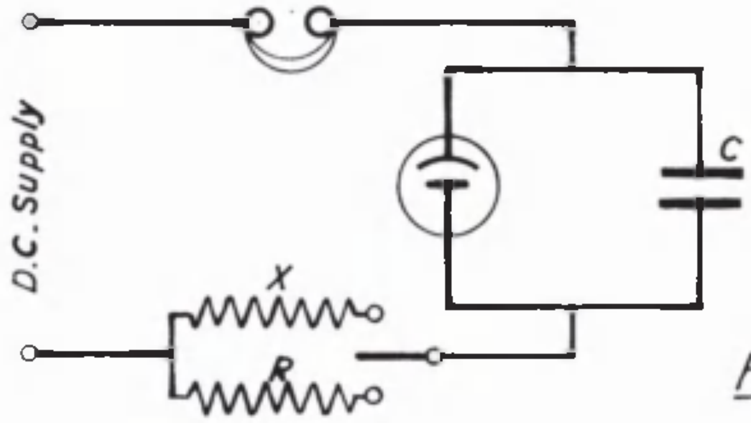


Fig. 60.

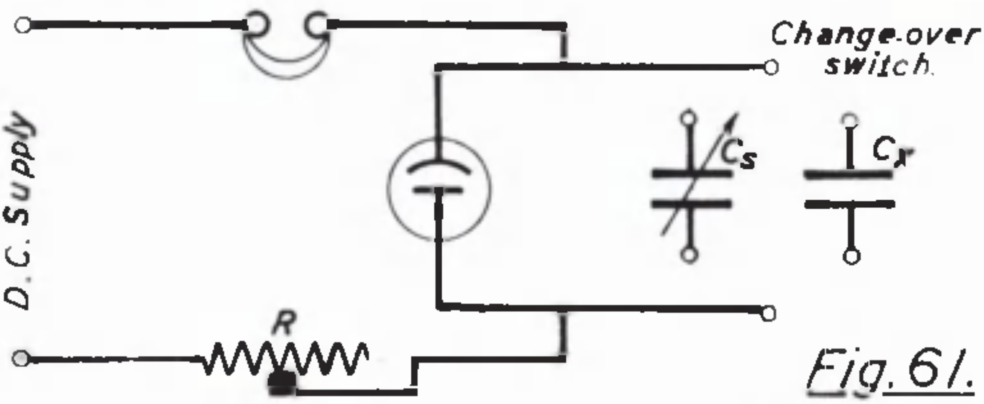


Fig. 61.

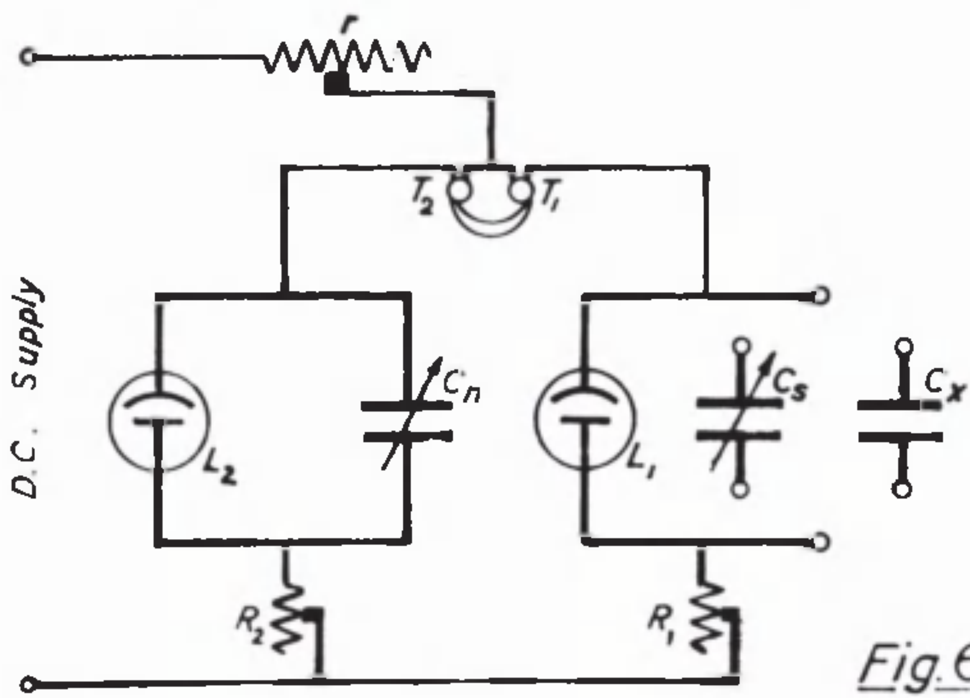


Fig. 62.

<u>Example</u>. X ≑ 1.3 megohms.

<u>Resistance</u>.	<u>Time of 100 flashes</u>.
1.8 megohm	69.6 secs.
X	57.1 "
0.8 megohm	40.2 "

$$\therefore X = 1.8 - \frac{69.6 - 57.1}{69.6 - 40.2}(1.8 - 0.8)$$

$$= 1.8 - 0.425$$

$$= 1.375 \text{ megohm.}$$

<u>Comparison of Capacitances</u>.

(a) <u>Substitution Method</u>.

The procedure employed is similar to that for the comparison of high resistances. With the unknown capacitance in circuit, Fig. 61, R is adjusted to give a convenient rate of flashing. R is kept fixed at this value and the rate of flashing is recorded for C_X and two values of C_s greater and less than C_X. The unknown capacitance is determined by interpolation; as here again the time-capacitance graphs, although straight lines do not pass through the origin.

This method is suitable for values of standard condenser between 0.1 μF and several microfarads.

Example. $C_x = 5 \mu F$.

Resistance R constant at 0.5 megohm.

$C \mu F$.	No. of flashes.	Time (secs.)	Time for 100 flashes.	
6	25	57.6	230.4	ts'
X	30	58.2	194.0	tx
4	40	63.0	157.5	ts"

$$C_x = C_s - \frac{ts' - tx}{ts' - ts''}(C_s' - C_s'')$$

$$= 6 - \frac{(230.4 - 194.0)}{(230.4 - 157.5)}(6 - 4)$$

$$= 4.9998 \mu F.$$

(b) Beat Method.

For the comparison of capacitances less than $0.1 \mu F$ a note or beat method is preferable (Fig. 62).

C_x = unkown capacitance

C_s = standard variable capacitance

C_N = variable capacitance.

Procedure.

(i) With C_x across L_1, R_1 is adjusted to give a high pitch note (about 5000 cycles per sec.) in phone T_1.

(ii) R_2 and C_N are adjusted to give a note in T_2 of nearly the same frequency and intensity. Fine adjustment of C_N must finally be made so that the beats heard in the phones are conveniently counted.

(iii) C_s is then substituted for C_x and adjusted critically till the same beat is obtained then $C_x = C_s$.

The function of r is to vary the coupling between the two circuits, since the beat note is produced more by inter-circuit coupling than in the head. r must not be too high or high pitched notes are difficult to obtain. The sensitivity of this method is sufficient to indicate a difference of 2 cm. (2.5 $\mu\mu$F).

Measurement of Voltage.

(a) Using Vs as a standard.

For the measurement of voltage the lamp may be connected as shown (Fig. 63) through a variable potential divider. The voltage across the lamp is gradually raised from zero until the lamp strikes. The magnitude of the supply voltage can then be calculated from

$V = V_S . \frac{R}{r}$ where V_s is the striking voltage of the lamp which is connected across the part, r, of the total resistance R.

This method of measurement can be applied to either steady unidirectional or alternating voltages. In the latter case the peak value is, of course, obtained.

For the measurement of peak values of transients* (such as in starting or switching on or off in direct current circuits) the modification in procedure amounts to the pre-setting of the potential divider so that when the peak value occurs, the lamp just strikes.

The accuracy of the method obviously depends on the constancy of V_s under all conditions of wave form, frequency, temperature, etc.

(b) Using V_E as a standard.

As has already been remarked the extinction voltage is more consistent than the striking voltage, since it is not

* Korblein, A., E.T.Z. 51, pp. 1486-1489, Oct., 1930.

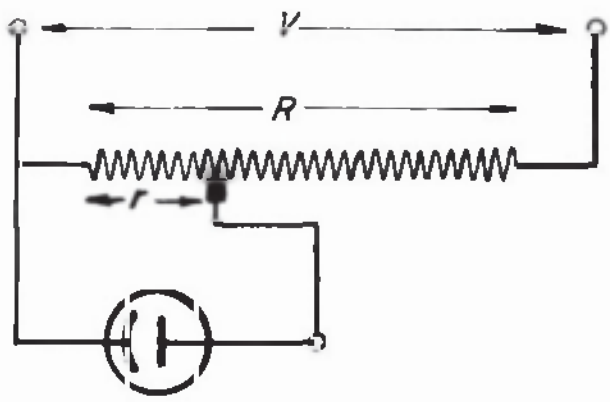


Fig. 63.

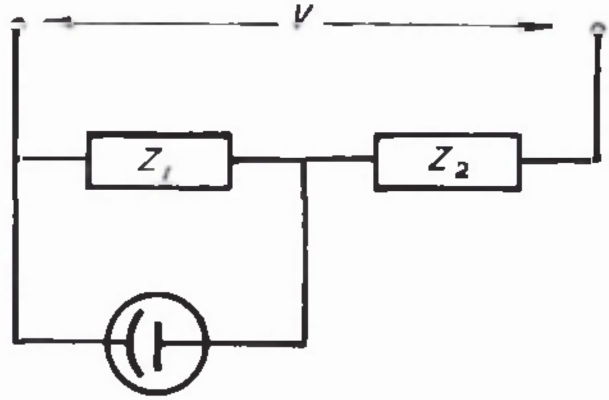


Fig. 64.

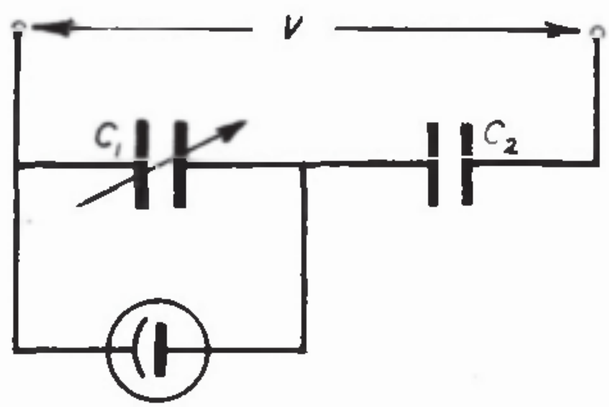


Fig. 65.

subject to time-lag effects due to the lamp being always in the same ionised state prior to extinction.

The circuit arrangements are as in Fig. 63. The part r, of the total resistance, R, is adjusted so that the lamp is glowing for a short time and then it is gradually reduced until the lamp is just extinguished.

Then as previously $V = V_E . \frac{R}{r}$ where r is now the value at extinction.

As the lamp is passing current just before extinction it may have an appreciably low resistance, say r_n, which is in parallel with r. The modification required to be made in the above expression to take account of this is as follows:-

$V = V_E + V'$ where V' is the drop over R-r

and $$\frac{V'}{V_E} = \frac{R - r}{r r_n / (r + r_n)} = \frac{(R - r)(r + r_n)}{r r_n}$$

$$\therefore \quad V = V_E + V_E\left(\frac{r R - r^2 - r r_n + R r_n}{r r_n}\right)$$

$$= V_E \frac{R(r + r_n) - r^2}{r r_n}$$

$$= V_E \left\{\frac{R}{r} + \frac{R}{r_n} - \frac{r}{r_n}\right\}$$

If r_n is assumed infinitely great we have

$$V = V_E . \frac{R}{r}$$ as before.

For the measurement of voltage on alternating current circuits the potential divider may consist of any two similar and variable impedances in series, e.g. two condensers, two inductances or two resistances.* The lamp is connected across one of the impedances, Z_1 in Fig. 64, and the value of Z_1 or Z_2 or both varied until the critical voltage occurs across the lamp, then

$$V_{max} = V_s\left(\frac{Z_1 + Z_2}{Z_1}\right) = V_s\left(1 + \frac{Z_2}{Z_1}\right).$$

The most convenient type of potential divider for the measurement of very high voltages consists of two condensers in series, as shown in Fig. 65. The greater part of the voltage is dropped across the fixed condenser, C_2, of small capacitance. The variable capacitance, C_1, is reduced until the lamp glows then, if C_s is the value of C_1 on striking

$$V_{max} = V_s\left(\frac{C_s + C_2}{C_2}\right) = V_s\left(1 + \frac{C_s}{C_2}\right).$$

When using the extinction voltage as standard, the capacitance C_1 is reduced so that the lamp glows and then C_1 is increased until the lamp is just extinguished, then

$V_{max} = V_E\left(1 + \frac{C_E}{C_2}\right)$ where C_E is the value of C_1 at extinction.

---

* A. Palm. Zeits. f. tech. Phys. pp. 223-245 & 258-270, 1923.

As before this expression requires to be modified in order to allow for the current taken by the lamp prior to extinction. To make this correction a knowledge of the impedance of the lamp is essential. The simplest equivalent impedance of the lamp under these circumstances would be that of a condenser of capacitance, say C_n.

$$\text{Then } V = V_E + V'$$
$$= V_E + V_E \left(\frac{C_E + C_n}{C_2}\right) = V_E \left(1 + \frac{C_E}{C_2} + \frac{C_n}{C_2}\right)$$

where C_n is the equivalent capacitance of the neon lamp and varies with the frequency.*

At 33 cycles per second $C_n = 51\mu\mu F$
" 50 " " " $C_n = 34\mu\mu F$
" 83 " " " C_n $22\mu\mu F$

The equivalent lamp capacitance will thus vary with different supply wave forms and thereby may introduce serious errors.

The striking voltage should be used at all times when the wave form is expected to be irregular and of course is the only critical voltage which may be used for the measurement of transient voltages.

---

* L. E. Ryall. I.E.E.J., 69, pp. 891-897, 1931.

Measurement of Current Peaks.

The use of a neon lamp, for the measurement of current peaks, as in starting and switching, is employed* as shown (Fig. 66) by connecting a known resistance, R_s, in series with the main circuit and measuring the drop across this as for voltage peaks. Then

$$I_{max} = \frac{V_{max}}{R_s} = \frac{V_s \frac{R}{r}}{R_s}$$

$$= \frac{V_s}{R_s} \cdot \frac{R}{r}$$

If the voltage drop across R_s is too low to strike the lamp a direct current biassing voltage can be put in series with the lamp, so that the additional voltage required to strike the lamp is quite small, and is equal to the volt drop in R_s due to the peak current (Fig. 67).

Then, if E is the value of the biassing voltage

$$I_{max} = \frac{V_m}{R_s}$$

$$= \frac{(V_s - E)}{R_s} \cdot \frac{R}{r}.$$

In alternating current circuits the volt drop across R_s can be transformed to a suitable value by means of a transformer of known ratio in either of the two ways indicated in Figs. 68 and 69.

---

* A. Korblein, E.T.Z. 51, pp. 1486-1489, Oct. 1930.

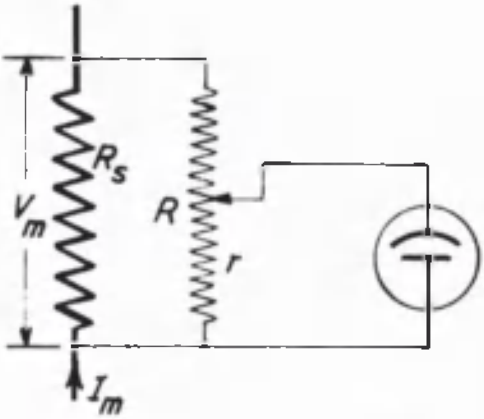


Fig. 66.

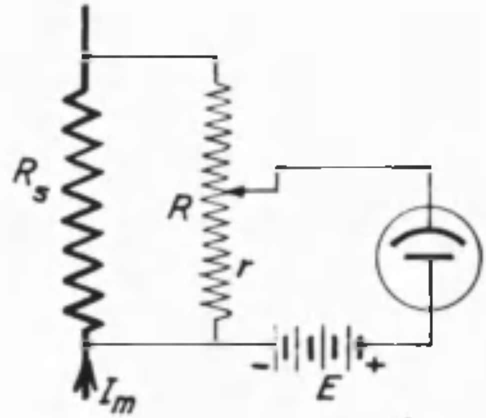


Fig. 67.

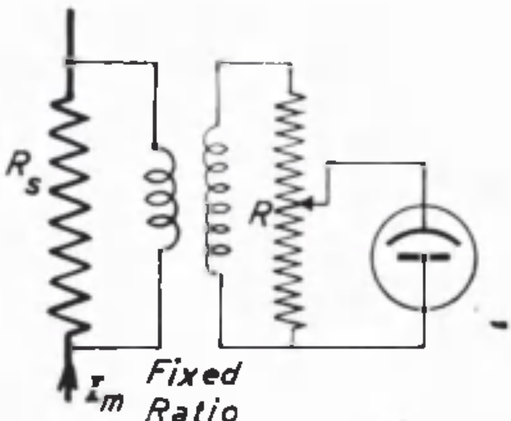


Fig. 68.

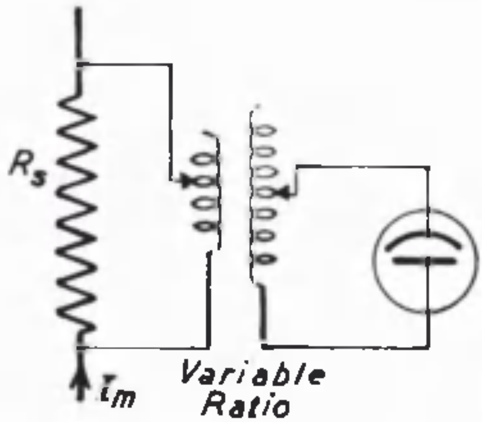


Fig. 69.

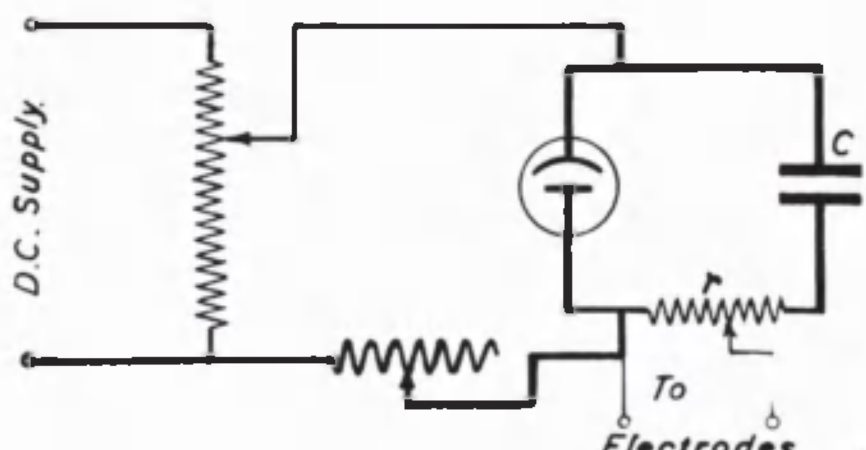


Fig. 70.

Physiological Applications.

The flashing neon lamp circuit has been extensively used* for physiological purposes, e.g. as a source of supply to provide a stimulus to muscular specimens. The stimulus may be obtained (Fig. 70) by inserting a non-inductive potential divider in the discharge circuit of the condenser.

The advantages of this method over an induction coil are that (a) it is silent, (b) no mechanical contacts are required, (c) the amplitude and frequency of the strength of the stimulus can be varied easily within suitable limits and (d) comparisons of the strengths of stimuli are easily made since the strength of the stimulus is approximately proportional to the distance travelled along r and to the capacitance C of the condenser.

---

* Daly, I. de Burgh, Proc. Physiol. Soc. 59, pp. 28-29, July 5, 1924.

Leyshon, W.A., J. Sci. Insts. 8. pp. 202-204, June, 1931.

Experimental Results.

1. Preliminary Stabilization and Testing of Stability.

2. Effect of an external electric field on the critical voltages of a neon lamp.

3. Shielding of neon lamps.

Preliminary Stabilization.

The fact that the striking voltage of a neon lamp is found to be raised if the lamp has been allowed to stand idle for some time is taken* as an indication that an adsorbed film of gaseous impurities has formed on the electrodes. The passage of the discharge to a certain extent cleans the surface with a consequent reduction of the striking voltage.

The striking voltage being thus dependent on the condition of the electrodes, a preliminary stabilization of the lamps has been recommended by L. E. Ryall[x] whereby impurities are driven from the electrodes by overruning the lamp for some time.

Following this recommendation closely, six lamps were prepared for testing. At the same time an investigation of the effect on the striking voltage of overrunning the lamps was carried out.

Measurements were recorded of the striking voltage of the lamp in the condition in which it was delivered. The lamp was then connected to the 250 volt supply and allowed to glow for about 4 hours, - the current during this time being the normal value of about 22 milliamperes.

The striking voltage was immediately measured and found to be about 10 volts higher than previously. On being

---

* N. L. Harris, Proc. Phys. Soc. 42, p. 169, April 15, 1930.

x L. E. Ryall, J. Sci. Insts. 7, pp. 177-186, June, 1930.

allowed to rest for 4 days the striking voltage was found to have returned to its normal value.

The resistance, about 5,000 ohms., was now removed from the cap, and a current of 40 milliamperes maintained through the lamp for about 4 hours. The voltage required for this had to be increased from 140 volts at the start to 170 volts at the finish of this overrunning period.

The striking voltage immediately after overrunning was found to be about 20 volts higher than the original value. However, after resting for 4 days the lamp recovered and the striking voltage was again about equal to its original value.

From the above it would appear that overrunning the lamp has no effect on the striking voltage so long as the lamp is given sufficient time to recover. After the lamp had been overrun, however, there appeared to be greater consistency between successive readings, showing in a general way that the lamp was in a more stable condition.

Testing of Stability.

The neon oscillator circuit with detector as shown, Fig. 71, was employed to test the stability of the neon lamps.*

Unless the lamp is in a stable condition the oscillations are found to cease when the capacitance is reduced below 0.001 microfarad. The frequency of the oscillations can be increased above the audio frequency range (20 kilocycles) if

* L. E. Ryall, J. Sci. Insts. 7, pp. 177-186, June, 1930.

the lamp is stable. The capacitance can be reduced to less than 50 micro-micro-farads before the oscillations cease with a consequent sudden change in the appearance of the glow. With some lamps although the condenser capacitance can be reduced to zero, the oscillations continue due to the capacitance of the neon lamp and the lamp holder. The slightest instability of the lamp decreases this ultra-audio frequency to one within the range of the condenser.

The procedure, then, is to observe the condenser reading corresponding to the maximum frequency obtainable. If this frequency is below about 20 kilocycles per sec. the lamp should be rejected. After the lamp has been rested for some days the experiment is repeated, and if the condenser reading for maximum frequency is unaltered the lamp is assumed to be stable.

All the lamps except one passed this test satisfactorily and were used in the subsequent experiments.

In the case of the lamp which failed, although it oscillated above audio frequency, an intermittent violent flash occurred. On examining this lamp it was found that, at one of the leading-in wires a leak had developed. This, causing the vacuum to be imperfect, would account for the irregular behaviour of the lamp in the oscillatory circuit.

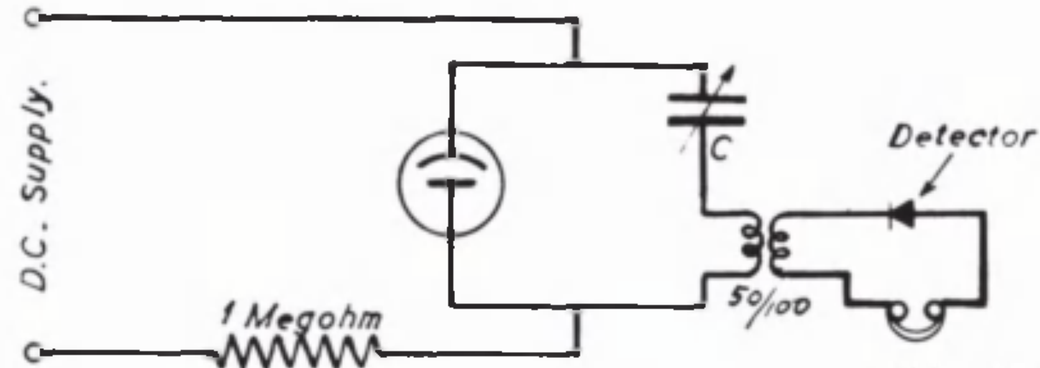


Fig. 71.

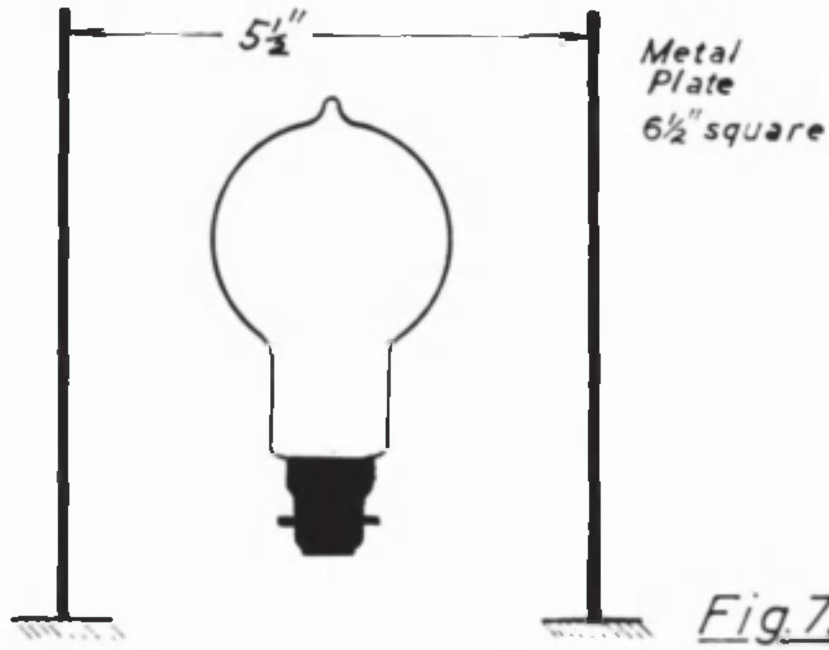


Fig. 72.

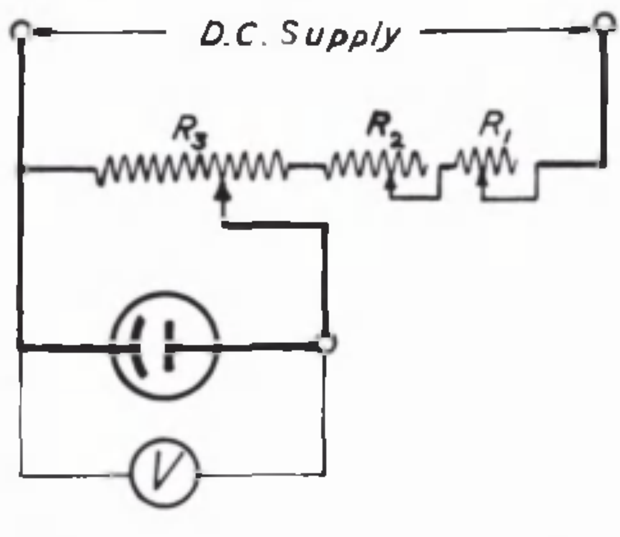


Fig. 73.

The Effect of an External Electric Field on the Critical D. C. Voltages of a Neon Lamp.

Although unable to observe any alteration in the striking voltage of a neon lamp by subjecting it to the radiation from such ionising agents as

(i) light from a 60 watt gas filled lamp,

(ii) barium oxide pasted over the bulb of the neon lamp,

(iii) uranium oxide used as in (ii),

(iv) partially exhausted radium needles powdered and used as in (ii)

and (v) light from a similar neon lamp, experiments were carried out to find the effect of placing the lamp in (a) an alternating electric field and (b) a steady electric field.

This investigation was prompted by the fact that the striking voltage had been observed to be reduced when the lamp was in the neighbourhood of a high voltage lead. As the results observed were somewhat similar to the photo-electric effects described by Oschwald and Farrant*, the precaution was taken of performing the experiments in a dark room with only the scale of the voltmeter illuminated.

The arrangement of the apparatus was as shown (Fig. 72), the neon tube being supported between two metal plates carried on wooden blocks. Only the bee-hive type of neon tube was used in these experiments.

---

* Oschwald & Farrant, Proc. Phys. Soc. 36, p. 241, 1923-1924.

The potential difference between the plates was varied by adjustment of the excitation of the alternator connected directly to the plates. For voltages above 600 volts between the plates, suitable h.v. transformers were employed.

For the d.c. voltage between the plates a number of secondary cells was employed.

The measurement of the voltage between the plates was carried out by means of an electrostatic voltmeter or from the ratio of transformation of the transformer and the observed voltage on the L.T. winding. The fact that either of these methods could be employed was verified by carrying out a test below 600 volts with the supply taken from the transformers and the induction regulator. The results were found to agree with those obtained when the supply was taken direct from the alternator.

The D.C. supply to the neon tube was obtained as shown in Fig. 73. The routine adopted throughout was as follows:- the tapping on R3 was kept fixed in such a position that with R1 and R2 all-in, the voltage across the tube was considerably below that at which the tube could glow.

R1 and R2 were then very gradually cut out until the tube was just caused to glow. By adopting this procedure the resistance in parallel with the lamp remained unaltered. The voltage recorded was the value attained just before the glow was observed. When this striking voltage had been recorded R1 and R2 were immediately increased gradually until the glow was just extinguished. This extinction voltage was also recorded. R1 and R2 were then increased to their maximum values. This was repeated several times for each value of the field and an average taken of both the striking and extinction voltages.

The values obtained for the striking voltage of a given lamp on different occasions varied by one or two volts, but for any one set of readings they were quite consistent.

The striking voltage was observed to be much higher if the lamp had been standing idle for some time. To eliminate the effect of this uncertain initial condition the lamp was caused to glow six times before any observations were recorded.

The rate at which the voltage applied to the lamp was increased or decreased was found to have an important bearing on the critical voltages. As these voltages were recorded by a Kelvin Multicellular voltmeter the rate of application was governed by the necessity of giving the voltmeter time to indicate any changes made in the circuit.

A typical set of observations is recorded in Table 15. For a given set of conditions the striking voltage is observed to be very consistent. The divergence from the mean value is generally much less than one per cent, except near the critical value of the electric field between the plates when the lamp is obviously in an unstable condition. This condition is apparent with 380 volts between the plates with the conditions considered.

Table 15.

Typical set of observations of striking voltage.

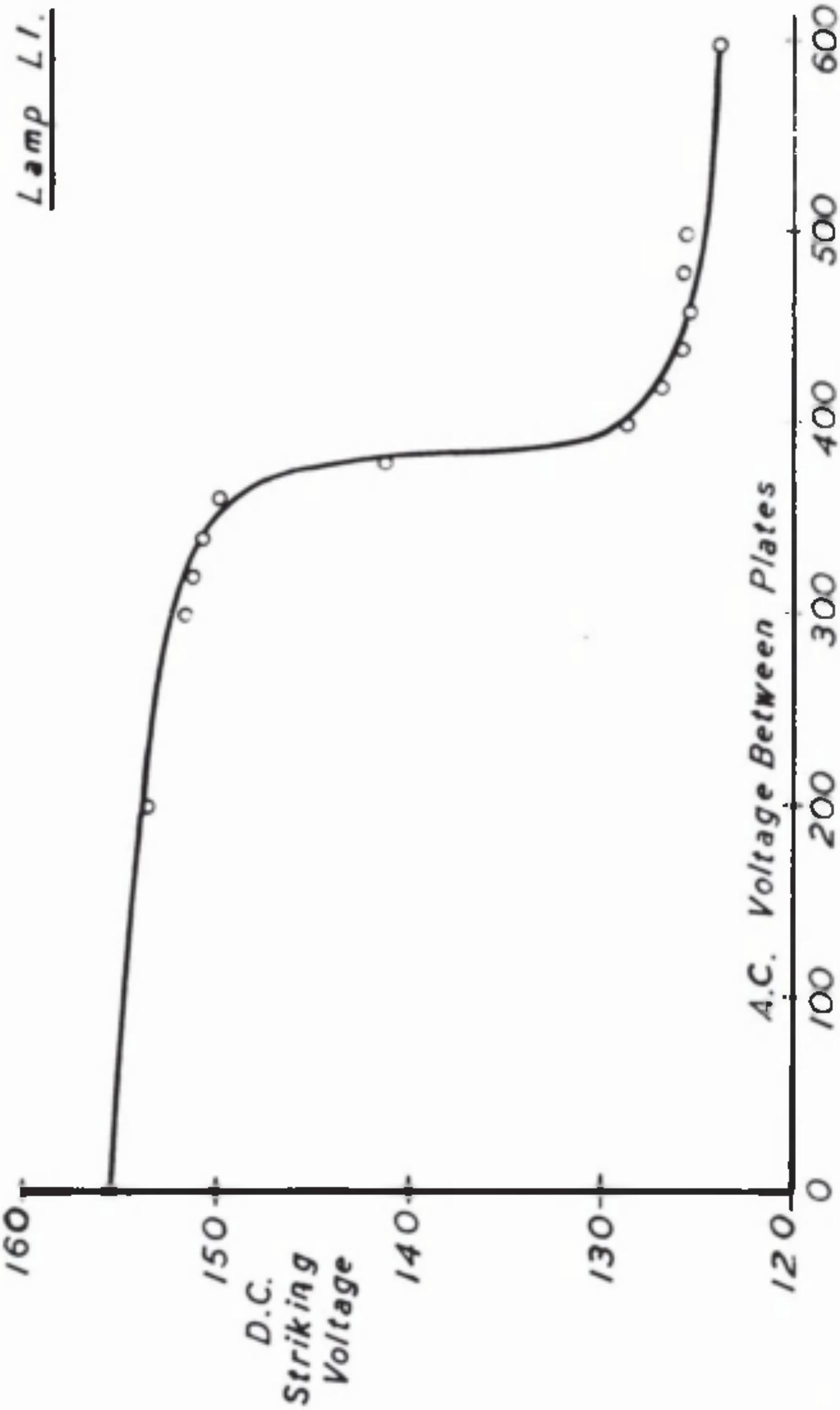
Supply to Plates = 50 cycles/sec.

One Plate Earthed.

Hive Glowing

LAMP L 1.

Voltage Between Plates	D.C. Striking Voltage		Extinction Voltage.
	Observed Values	Mean.	
0	154·7, 154·9, 155·3, 154·9, 154·7, 154·3	155·3	119·9
200	153·3, 154·3, 153·7, 153·9, 154·1, 153·3	153·7	119·9
300	151·7, 151·3, 152·1, 151·3, 151·9, 151·7	151·7	119·9
320	151·1, 151·1, 151·5, 150·9, 151·3, 151·5	151·3	119·9
340	150·9, 151·1, 150·7, 150·9, 150·7, 150·9	150·9	119·9
360	150·7, 149·1, 150·3, 149·7, 150·3, 149·7	149·9	119·9
380	145·0, 137·0, 138·6, 137·0, 141·4, 140·4 142·6, 139·6, 146·0, 143·2, 140·0, 141·3	141·4	119·9
400	128·7, 127·7, 129·1, 128·5, 128·3, 129·1	128·6	119·9
420	127·3, 127·5, 126·9, 126·7, 126·9, 126·7	127·0	119·9
440	125·4, 125·8, 125·2, 125·8, 126·2, 126·2	125·8	119·9
460	125·8, 126·0, 125·2, 125·4, 125·2, 125·6	125·6	119·9
480	125·8, 125·8, 126·0, 126·2, 126·0, 126·2	126·0	119·9
500	126·2, 125·8, 126·0, 125·6, 125·2, 125·4	125·8	119·9
600	123·4, 123·8, 123·8, 123·2, 123·4, 123·6	123·6	119·9



Lamp L1.
160
150
140
130
120
D.C. Striking Voltage
0
100
200
300
400
500
600
A.C. Voltage Between Plates

Fig. 74.

From Table 15 and the graph (Fig. 74) of the striking voltage plotted to a base of the field strength (or, simply, the voltage between the plates) it is seen that the striking voltage decreases gradually at first as the field strength increases. When a certain value of field intensity is attained, however, the striking voltage suddenly decreases to a value only a few volts greater than the extinction voltage.

It is the purpose of the following experiments to investigate this phenomenon and to determine the conditions upon which it depends.

In all the tables of results following this, only the mean true voltages are recorded.

Resistance in series with lamp.

The effect of resistance in series with the lamp was investigated by (a) taking a set of readings with the protective ballast resistance in the lamp holder and (b) taking a second set with this resistance removed. The magnitude of the ballast resistance in this type of lamp is about 5000 ohms.

The removal of this resistance had a negligible effect on the characteristic being investigated. Due to the absence of this resistance the current taken by the lamp after the striking voltage was attained, was very much greater. This sudden increase in current caused a sudden drop in the lamp terminal voltage. With the arrangements employed the drop was of the order of 10 volts, so that the voltmeter could be used as an indicator of the occurrence of striking without actually having the lamp visible. This was a particularly convenient method when screens were employed over the lamp bulb. All the lamps tested therefore had the ballast resistance removed from the lamp cap.

Variation of Frequency of Alternating Field.

The frequency of the voltage between the plates was varied over the range from 25 to 60 cycles per second and observations taken of the d.c. striking voltage of the lamp. As seen from Table 16 and Fig. 75 the effect is apparently independent of frequency. Consequently a d.c. supply to the plates should produce exactly similar results.

Table 16.

Voltage Between Plates	D.C. Striking Voltage.				
	f=60	50 A	50 B	40	25
0	153·7	155·3	154·3	154·3	155·5
200	153·5	153·7	153·5	153·3	153·5
300	152·1	151·7	151·7	151·5	152·3
320	151·5	151·3	151·3	151·5	150·3
340	151·5	160·9	151·1	150·7	149·5
360	147·7	149·9	147·5	144·7	140·8
380	133·1	141·4	137·0	127·6	128·4
400	127·8	128·6	128·1	127·4	126·0
420	126·0	127·0	127·5	127·4	125·6
440	126·4	125·8	127·7	126·2	125·6
460	125·8	125·6	127·6	126·0	125·4
480	125·4	126·0	127·4	125·5	125·4
500	125·4	125·8	127·1	126·0	125·2
600	124·8	123·6	125·2	125·2	124·8

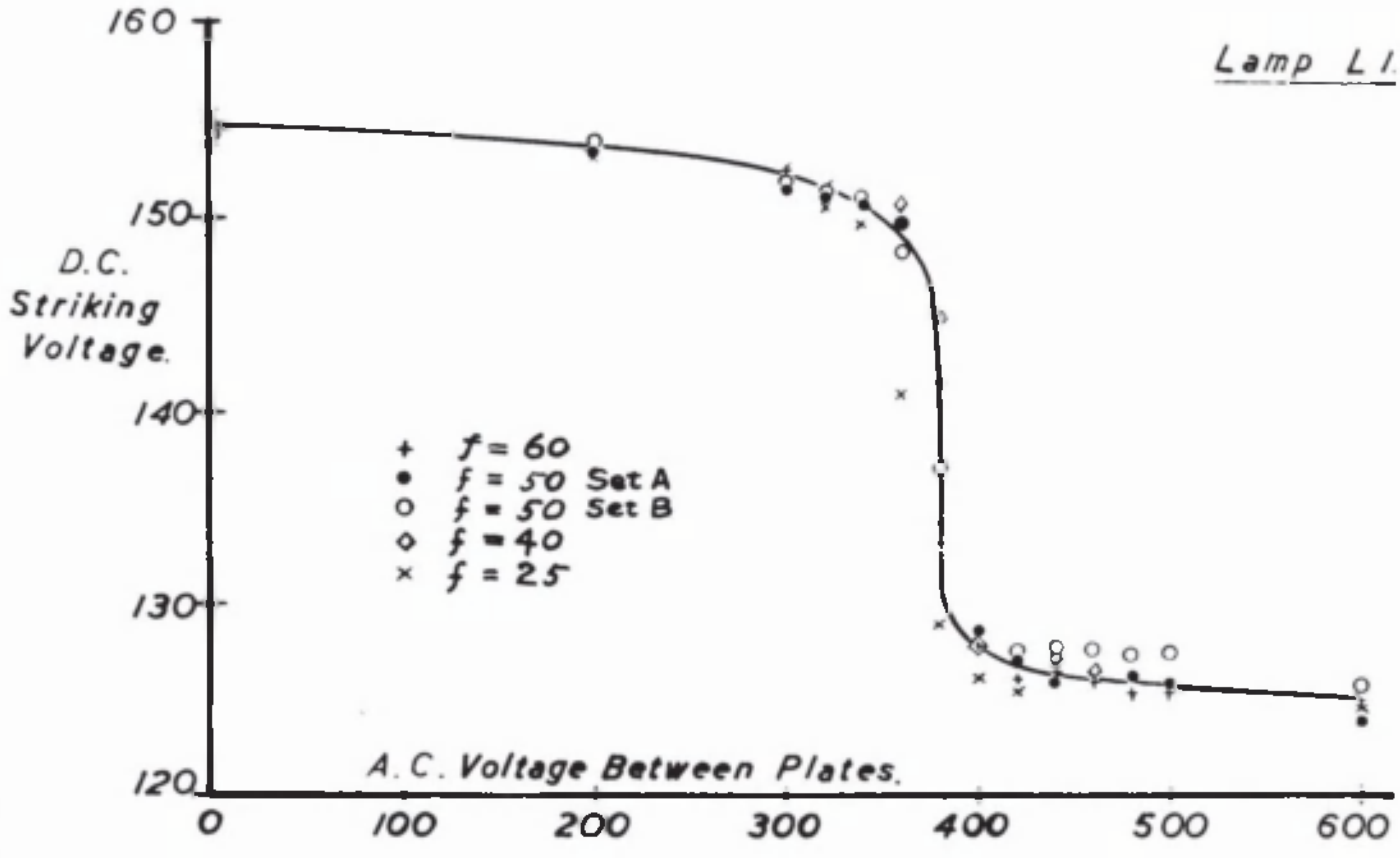

Lamp L1.
160
150
140
130
120
D.C.
Striking
Voltage.
+ f = 60
• f = 50 Set A
○ f = 50 Set B
◇ f = 40
× f = 25
A.C. Voltage Between Plates.
0
100
200
300
400
500
600

Fig. 75.

Steady Field - D.C. between plates.

On first attempting this experiment it was found impossible to produce any diminution of the striking voltage with the 1200 volts d.c. obtainable (by connecting all available cells in series). However, by earthing one or other of the plates the phenomenon observed with a.c. was repeated.

The battery supply to the neon lamp being included in the D.C. supply to the plates would make the distribution of the field between the plates totally different from that with A.C. Hence unless one of the plates was earthed it would be impossible to have the lamp in a field sufficiently intense to affect the striking voltage.

Nevertheless the results of this experiment (Table 17) serve to show that the effect of a d.c. field on the striking voltage of a neon lamp is similar to that of an a.c. field.

Alternating Field - effect of earthing one plate.

Following the observations with a steady field the effect of earthing the plates in turn was investigated (Tables 18 and 19).

From Table 18 it is seen that, only when one plate is earthed, the critical field strength is produced with about 440 volts between the plates. Whereas when neither plate is earthed the striking voltage is not affected until about 1200 volts is applied to the plates (Table 19). Here again the altered distribution of the field with one plate earthed may account for this change in the voltage applied to the plates.

Table 17.

Steady Field — D.C. between plates.

Voltage Between Plates	D.C. Striking Voltage			Extinction Voltage.
	Positive Plate Earthed	Negative Plate Earthed	Neither Plate Earthed	
0	155·5	155·5	154·3	122·5
200	156·5	155·5	154·3	122·5
400	153·9	155·1	154·3	122·5
500	154·1	154·7	154·3	122·5
600	152·9	154·3	154·3	122·5
700	153·3	153·1	154·3	122·5
800	152·3	145·3	154·3	122·5
850	150·1	135·3	154·2	122·5
900	129·3	125·0	154·0	122·5
1000	129·3	125·4	153·3	122·5

Table 18.

Voltage Between Plates	D.C. Striking Voltage			Extinction Voltage
	One Plate Earthed	Other Plate Earthed	Neither Plate Earthed	
0	154·3	153·5	156·6	122·3
340	151·9	151·7	156·0	122·3
360	151·3	151·5	155·8	122·3
380	150·5	151·1	155·7	122·3
400	149·3	149·3	155·6	122·3
440	145·5	146·0	154·1	122·3
460	133·3	137·7	154·1	122·3
480	133·2	137·9	154·1	122·3
500	133·3	137·5	153·3	122·3

Table 19.

Neither Plate Earthed.

Voltage Between Plates.	D.C. Striking Voltage	Extinction Voltage
0	153·7	122·7
400	153·5	122·7
600	153·7	122·7
900	153·7	122·7
1000	153·5	122·7
1100	152·5	122·7
1200	140·2	122·7
※ 1300	139·6	?
※ 1600	137·2	?

※ Flashing occurs at 137 volts and extinction voltage is indeterminate.

With neither plate earthed the conditions within the lamp were much less stable when the voltage between the plates exceeded 1200 volts. This condition was manifest by intermittent flashing occurring at a voltage somewhat lower than that required to maintain a steady discharge. The extinction voltage was quite indeterminate under these conditions.

Results on Other Lamps.

That the preceding results are not characteristic of one particular lamp was verified by repeating the experiments on five lamps purchased on different occasions. The observations are recorded in Table 20 and curves therefrom are drawn, Fig. 76.

From these figures and curves it is seen that similar effects are observed with all the lamps. The drop in the value of the striking voltage after the critical field strength is reached is remarkably consistent, being about 30 volts for each lamp. The fact that the critical field strength is not exactly alike for all of the lamps can be accounted for by the differences in gas content, gas pressure and constructional details of the various lamps.

Continuously applied voltage less than Vs.

To determine the effect of sustained weak ionisation within the lamp, the voltage applied to the lamp was maintained at 156 volts (i.e., about 4 volts below the striking voltage) and readings of the striking voltage recorded from time to time.

Table 20.

Voltage Between Plates	D.C. Striking Voltage				
	L 1.	L 2.	L 4.	L 5.	L 6. (Lamp Number)
0	154·3	158·6	151·7	165·9	160·6
200	153·5	157·0	150·5	164·1	160·2
250	153·5	156·5	149·1	163·0	159·8
280	152·7	155·5	141·2	162·7	169·0
300	151·7	154·3	131·7	161·9	158·8
320	151·3	152·0	128·2	160·0	158·0
340	151·1	147·0	126·5	158·5	167·5
360	147·5	137·0	125·5	165·0	156·8
380	137·0	132·5	125·0	145·0	156·3
400	128·1	132·1	124·8	139·8	148·7
420	127·5	131·5	124·5	137·0	140·4
450	127·7	130·8	124·3	135·5	131·7
500	127·1	130·5	124·0	135·3	130·0
600	125·2	130·5	124·0	135·0	129·5
Extinction Voltage	119·9	131·1	120·0	133·5	129·3

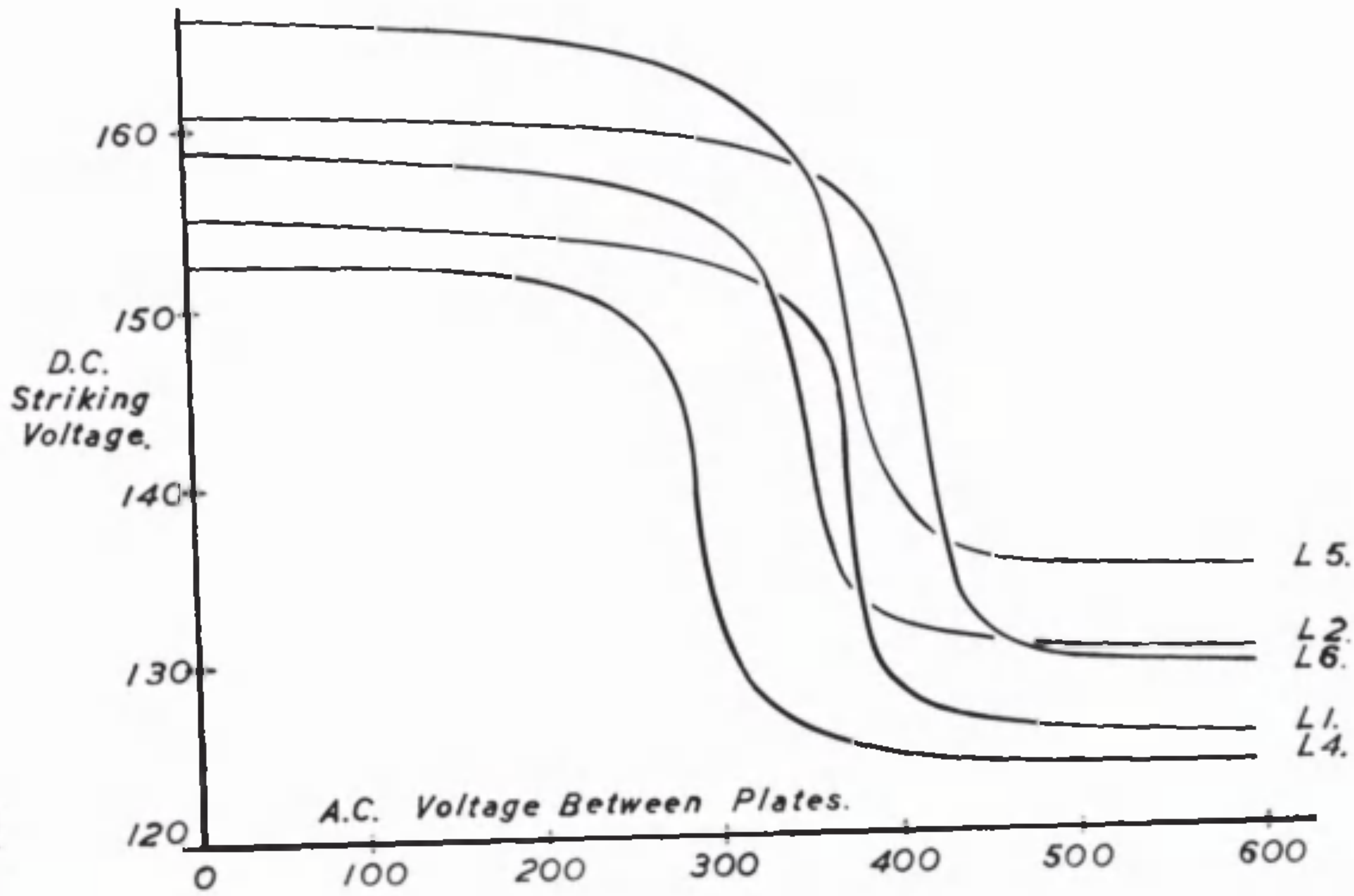

160
150
140
130
120
D.C.
Striking
Voltage.
0
100
200
300
400
500
600
A.C. Voltage Between Plates.
L 5.
L 2.
L 6.
L 1.
L 4.

Fig. 76.

Immediately after striking, the voltage was reduced till the lamp was extinguished and then the voltage was raised again to 156 volts. The results showed that a voltage slightly less than the striking voltage although applied for some considerable time is incapable of producing sufficient ionisation to alter the striking voltage of the lamp in any way.

<u>Alternating Supply to lamp</u> in a.c. field.

With an alternating voltage supplied to the lamp in an alternating field the striking voltage remains unaltered although the voltage between the plates was increased to 30,000 volts (corresponding to a field strength of about 300 volts per cm. with neither plate earthed) Table 21.

From zero to 1,000 volts between the plates intermittent flashing of the hive and disc occurred when a voltage of 103 volts was applied to the lamp. At 105 volts the disc glowed steadily and the flashing at the hive ceased. This value of 105 volts was recorded as the striking voltage for the disc.

Above 10,000 volts between the plates the intermittent flashing was very considerably reduced, due probably to the fact that the space between the electrodes was now completely ionised. A faint glow was observed to spread over the lamp bulb at this value of field strength.

At 30,000 volts between the plates and the disc striking voltage applied to the lamp a faint glow appeared to

Table 21.

Lamp L5.

Voltage Between Plates	A.C. Striking Voltage	
	Hive	Disc
0	104·8	114·0
300	105·2	112·2
400	105·2	111·6
500	105·2	111·2
600	105·2	111·2
1500	105·2	113·6
3,000	105·6	113·4
4,500	106·0	113·0
6,000	106·2	111·4
7,500	106·2	111·6
12,000	105·4	110·8
30000	105·4	109·8

attach itself to the hive. This glow merely increased in brightness when the voltage was raised to the hive striking voltage.

Shielding of Neon Lamp.

A fine mesh brass gauze shield in the form of a cylinder with one end closed was fitted over the lamp and all the preceding tests repeated. In no case was it found possible to produce any marked change in the value of the striking voltage. The shield in all tests was carefully earthed.

The values shown in Table 22 give the striking voltages of the lamp when supplied with alternating and direct current supplies. With a.c. supply to the lamp intermittent flashes in the lamp often preceded the steady glow. The voltage recorded in the table corresponds to the steady glowing conditions.

Table 22.

LAMP L5 Osglim Beehive fitted with earthed, finemesh brass shield.

Striking Voltage			
D. C.		50 Cycles A.C.	
HIVE	DISC	HIVE	DISC
159·6	140·8	114·0	103·6
158·2	140·6	113·8	103·4
159·2	140·4	113·2	103·4
160·0	140·2	113·4	103·8
160·2	140·4	113·6	103·6
159·4	140·6	113·6	103·6
159·0	140·6	114·0	103·4
161·0	140·4	113·6	103·6
159·4	140·4	113·4	103·6
160·0	140·8	113·8	103·8
159·6	140·4	113·6 rms 160·5 max.	103·6 rms 146·5 max.

MEAN VALUES

Conclusions.

The various observations recorded herein would appear to indicate that the striking voltage of a neon lamp was consistent to within 1 per cent, if the lamp was carefully protected by an earthed shield. However, during the experiments unexpected values of striking voltage were obtained which might be as much as 3 or 4 per cent sometimes above and sometimes below what appeared to be the mean value. Such readings were not recorded but served to indicate that some instability existed in the lamp. The procedure developed into getting an impression of the mean value from the first few readings of the striking voltage and then, if discharge did not immediately occur about this value, the voltage was allowed to remain unchanged for some time and usually the lamp flashed either after a few seconds or a few minutes. Coating the lamp bulb with various radio-active materials failed to reduce this phenomenon appreciably.

This time lag in the striking of neon lamps has been observed by many experimenters.* Residual ionisation of the gas is the usually accepted explanation of the variation of

---

* P. O. Pedersen, Ann. d. Phys. 75, pp. 827-847, Dec. 1924.
A. Palm, Zeit. f. Hoch. Freq. 23, pp. 12-18, Jan. 1926.
F. M. Penning, Phys. Zeits. 27, pp. 187-196, 1926.
loc cit., p. 81.

the sparking potential in such gas discharges.

The somewhat negative conclusion is therefore arrived at that neon lamps are not sufficiently reliable to permit of their being used as a standard of comparison in high-voltage measurements.

Consequently, the author considered that further pursuance of this research would not be profitable.

Appendix II.

Voltage Measurement by Electrostatic Voltmeter and Resistance Potential Divider.

Voltage Measurement by Electrostatic Voltmeter and Resistance Potential Divider.

As a check on the sparkover voltage which would be independent of the transformer ratio an attempt was made to measure the voltage on the h.v. side by means of an electrostatic voltmeter and a potential divider.

The resistance potential divider was constructed in the form shown in Fig. 77. The units of the divider are made up of mica cards or plates wound with double silk covered nickel-chrome wire (36 S.W.G.) in slots in the mica. The direction of winding the coils is reversed in adjacent slots by doubling round the mica tooth before commencing the next coil.

Particulars of each unit are as follows:-

Mica cards 6" x 3"	Coils per card 26.
Slots 1/10" wide x 1/10" deep.	Turns per coil 36.
No. of cards 9.	Resistance 43,680 ohms.

The inductance of these units obviously will be extremely small due to the reversal of the winding and the small area enclosed by each turn. The subdivision of the winding on each card into 26 sections keeps down the self capacitance to a low value. The overall time constant is consequently extremely small.

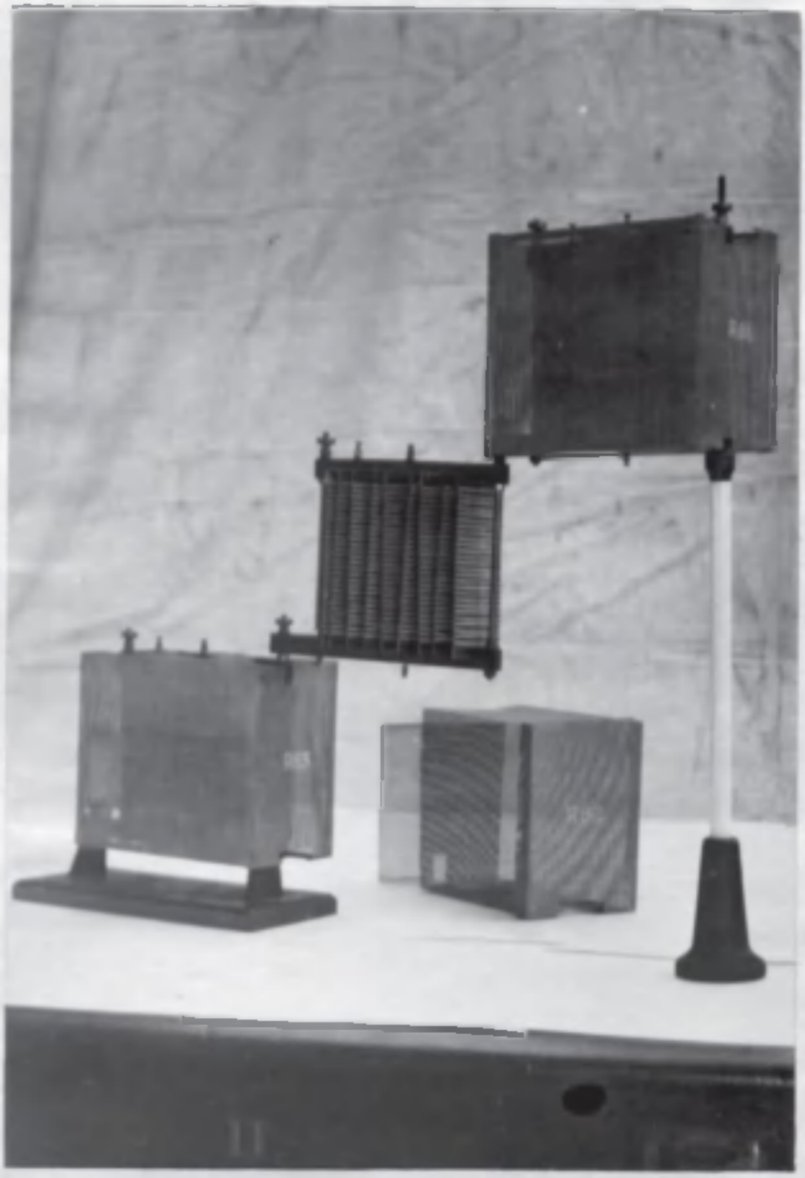


Figure 77.

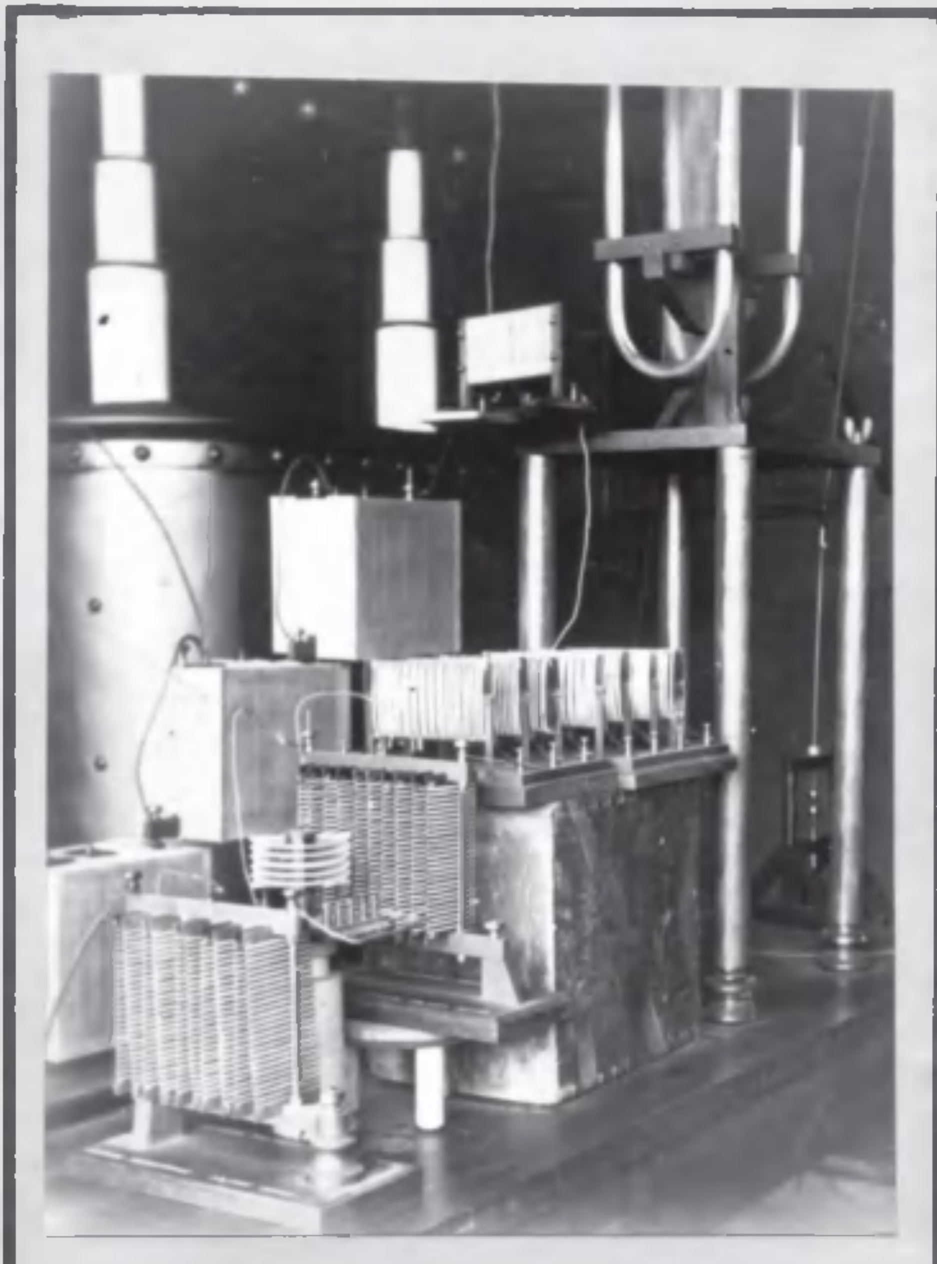


Figure 78.

Three such units were made up, each enclosed in a perforated zinc shield. These three units formed the main potential divider.

To eliminate or compensate for electrostatic effects, viz. distributed capacitance to earth, self capacitance and capacitance to extraneous bodies, the screens shielding the units were maintained at a potential corresponding approximately to the mean potential of the unit enclosed. This was done by having a subsidiary potential divider which could be tapped at suitable points to give the desired screen potentials. As will be seen in the foreground of Fig. 78 the sections of this subsidiary potential divider are similar to those of the main potential divider but are not screened.

It can be shown* that the phase angle at the earthed end of a number of shielded resistances joined in series will be zero if the shields of the two end units are maintained at 5/12 of the pd. across these units while the remaining shields are at mid potential.

In the potential divider constructed of three sections the tapping points on the subsidiary potential divider have been arranged as shown in Fig. 79b. The theoretical values indicated in Fig. 79a have been approached with sufficient practical accuracy to ensure the ideal of zero phase angle being approximately obtained.

* "Instrument Transformers," B. Hague, p. 363, 1936.
Orlich and Schultze. Arch. f. Elektrot., 1, pp. 1-15, 88-94, 232, 1913.

H.V. POTENTIAL DIVIDER.

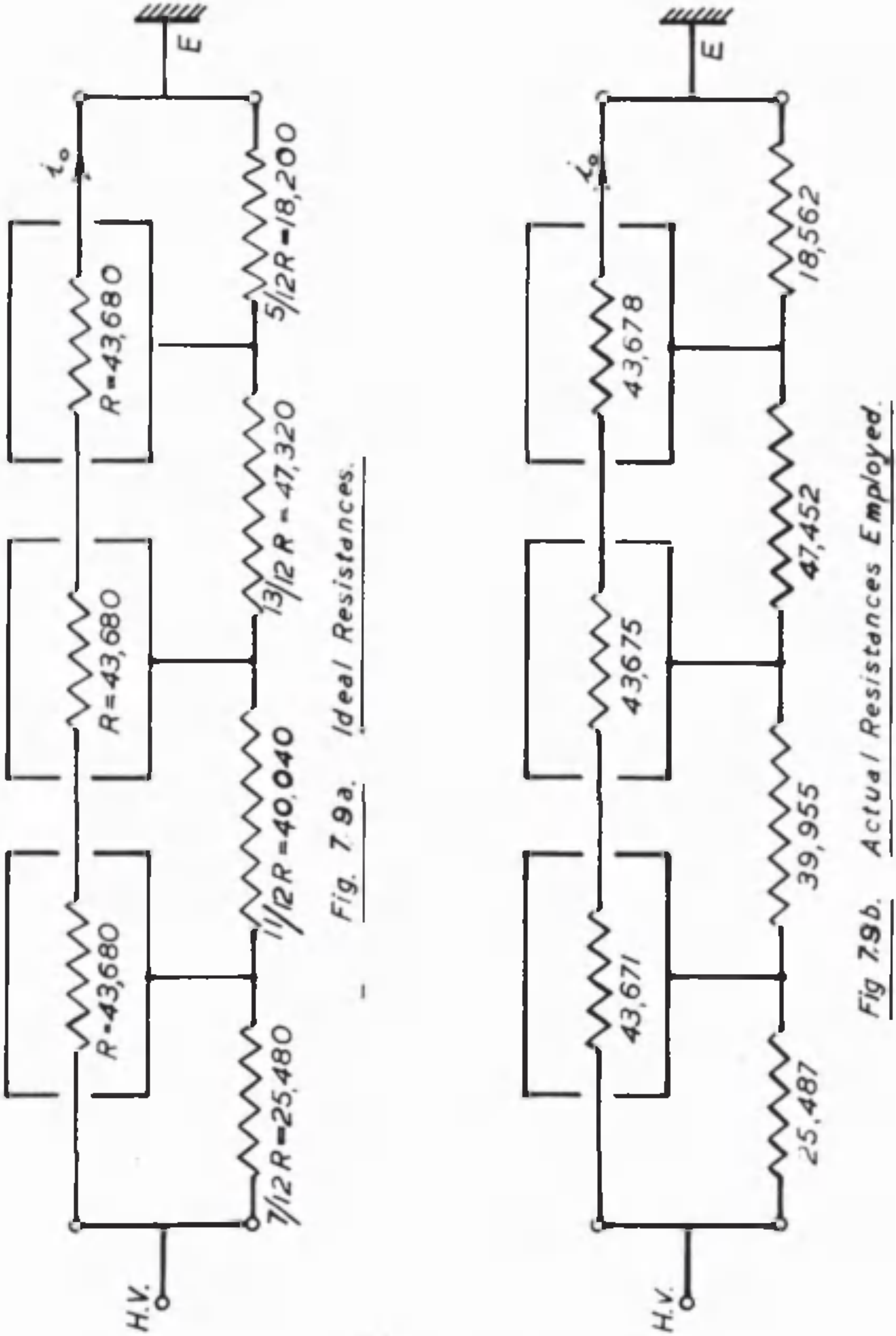


Fig. 7.9a. Ideal Resistances.

Fig 7.9b. Actual Resistances Employed.

Figure 7.9.

As the resistance units are capable of carrying a current of 0.1 ampere for a reasonable length of time the arrangement can be used for the measurement of voltages up to 12.5 k V. and is thus suitable for checking the three lowest points of the previous calibrations.

The connection of the voltage divider with its screening resistance in parallel with the sphere gap was a relatively large load on the transformer. Oscillograms were taken of the wave form of the secondary p.d. of the transformer when supplying this load. This was done by inserting similar slide wire resistances (about 1600 ohms each) into the circuits of the main and the subsidiary dividers at the earthed end. The volt drop over part of the resistance inserted in the main divider circuit was applied to the voltage circuit of the oscillograph.

The difference between this secondary voltage wave form and that of the primary when the voltage divider was disconnected (Fig. 43, p. 64) was considered insufficient to justify any modification being made in the value of the conversion factor.

Electrostatic Voltmeter.

A Kelvin type electrostatic voltmeter, measuring from 500 to 2,000 volts and, with additional weights, from 1000 to 4000 and from 2000 to 8000 volts, was carefully calibrated on direct current up to 5000 volts. This instrument, after calibration in situ, was connected across one third of the main potential divider at the earthed end. It thus measured the r.m.s. value of one third of the total secondary voltage required to produce sparkover of the sphere gap which was connected with its protective high resistance, in parallel with the voltage divider across the transformer.

The illuminated scale of the electrostatic voltmeter was conveniently observed through a telescope beside the voltage control resistances outside of the protective earthed wire guard.

Results.

The spark-over voltage was first obtained using the voltage divider and the electrostatic voltmeter. Without alteration of the gap the voltage divider was disconnected and the spark-over voltage determined from the reading of the primary voltage and the transformation ratio. This procedure was repeated at the other gap settings and the results tabulated, (Table 23).

The agreement between the two sets of observations is seen to be quite satisfactory and within the limits of accuracy of sphere gap measurements.

Table 23.

Breakdown Kilovolts

2·54	3·81	5·08	2·54	3·81	5·08	Gap (mm.) Length
6·90	9·75	12·23	7·10	10·19	12·61	
6·82	9·62	12·30	7·08	10·18	12·51	
6·85	9·70	12·30	7·12	10·08	12·62	
6·98	9·67	12·23	7·07	10·08	12·57	
6·85	9·70	12·40	7·12	10·17	12·58	
6·93	9·70	12·30	7·08	10·15	12·55	
6·77	9·82	12·35	7·10	10·17	12·59	
6·85	9·84	12·40	7·07	10·12	12·57	
7·02	9·88	12·23	7·10	10·18	12·59	
6·98	9·78	12·18	7·12	10·15	12·55	
6·90	9·82	12·30	7·13	10·11	12·55	
6·90	9·75	12·30	7·10	10·16	12·57	Mean
	9·95	12·42		9·95	12·42	E.R.A. Value

Voltage Divider (first three columns) — Transformer Ratio (last three columns)

Conversely it can be concluded from these results with the voltage divider that for all practical purposes the nominal ratio of transformation of the h.v. transformer, 660/101,700 can be taken as correct when the secondary load consists only of a sphere gap and its protective resistance.

ACKNOWLEDGMENTS.

The author desires to express his indebtedness to Professor G. W. O. Howe for his ever willing advice and guidance in the carrying out of this research and in the discussion of the results.

To Dr B. Hague thanks are also due for his assistance on many occasions but in particular with the calibration of the electrostatic voltmeter and the setting up of the h.v. potential divider.

Acknowledgment is also made of the loan of a 3,000 volt dry battery from Professor Taylor Jones of the Natural Philosophy Department.