A Study of the Characteristics of Glow-Discharge Voltage-Regulator Tubes

(Part 2)

By F. A. Benson*, M.Eng., Ph.D., A.M.I.E.E., M.I.R.E.

Vibration and Mounting

Current-voltage and striking characteristics have been obtained and measurements of initial drifts and life tests have been carried out with tubes mounted in a vertical position upside down and also with the axes of the tubes horizontal. All the results, including length of life, appear to be independent of the method of mounting.

Several tubes of each type have also been subjected to severe vibration tests. The tubes were mounted on a lever fixed at one end, the other end resting on a toothed wheel attached to a driving-motor shaft. They could, in this way be set in rapid vibration.

The tests indicate that vibration does not seriously affect stability. The changes in running voltages recorded were only of the order of 0·01 per cent. For best results, however, in applications where vibrations or sudden shocks are liable to occur, an anti-microphonic mounting should be used as specified by some manufacturers[16].

Photoelectric Effects

Baker[17] has observed certain photoelectric effects associated with several commercial neon glow lamps in America. He reports a case where moderate daylight reduced the striking voltage obtained for a tube kept in the dark by about 10 per cent.

It was, therefore, decided to examine all the glow-discharge tubes, at present under consideration, for such effects. The tubes were placed in the dark and then in moderate daylight. The striking voltages and running voltages were recorded for the two conditions.

No differences in the characteristics were observed with the tubes in the dark or in moderate daylight except for one tube of each of the types VR105 and VR150. In these two particular cases placing the tubes in the dark increased the striking voltages by about 12 per cent over those in normal daylight as already mentioned previously.

It appears, however, that, apart from these two types of tube, even where glow-discharge tubes are used under conditions where constancy of the striking voltage is important, it is unnecessary to keep the level of illumination within certain limits or to coat the envelopes with paint or other material to render them opaque. This also applies to the CV71 tubes for which an opaque coating is specified.

Operation with Reversed Polarity

For two reasons it was felt that a knowledge of the properties of tubes operating with the cathode potential positive with respect to the anode would be of interest. First, the author has experienced several cases where tubes have been accidentally used with reversed connexions. Secondly, glow-discharge tubes have been successfully applied to the stabilization of A.C. voltages in addition to D.C. ones. The striking and running voltage characteristics with reversed polarity have been determined for most tubes.

* *The University of Sheffield*

Striking Voltage

Table 5 shows the results obtained. It is difficult to draw any definite conclusions about striking voltage with reversed connexions. Even for tubes of the same type, in some cases the voltage is reduced, in others it is increased by reversing the polarity. For example, of the particular CV1070 tubes tested, the striking voltage was mainly lower with reversed connexions than when operating normally, only 3 out of 36 tubes striking at a higher voltage. The maximum decrease in striking voltage was 13V. For the 85A1 tubes, on the other hand, the majority struck at a higher value when reversed. The maximum increase was 28·5V, but a decrease of 7·5V was observed.

To explain the difference between the striking voltages in the two cases it is necessary to draw attention to the theory of striking for non-uniform fields.

TABLE 5—CHARACTERISTICS OF TUBES WITH REVERSED POLARITY

TUBE TYPE	STRIKING VOLTAGE VARIATIONS FROM TUBE TO TUBE (V)	RUNNING VOLTAGE FROM TUBE TO TUBE (V)	VARIATION FOR A SINGLE TUBE (MAX.) V.
CV1070 ..	103·5–119·5	85·0–112·0	16
85A1 ..	106·5–142	93·5–135·0	28
CV45 ..	‡	‡	‡
S130	‡	‡	‡
CV71 ..	130–160	132–187*	46*
KD60 ..	72–75.5	49–60.5	2.5
CV188 ..	100–115	78·0–95·5	14
G50/1G ..	58–75	48·0–51·5	2.5
G180/2M ..	172–197§	147–205§	58§
G120/1B ..	80–110	51·5–73	16
VR105 ..	122–132‖	103–157	54
VR150 ..	162–180‖	146–197†	27†
CV284 ..	80–117	64·5–86	16·5
NT2¶ ..	—	—	—

KEY FOR TABLE 5

* *0.4 to 4mA only.*
† *5-15mA only.*
‡ *Only one tube of each type tested as at a current of about 70mA tubes arc over.*
§ *One anode used only.*
‖ *In normal daylight.*
¶ *Electrodes are the same shape. The characteristics for normal and reversed connexions are almost the same.*

Theory of Striking for Non-Uniform Fields

In the case of non-uniform fields Townsend's theory gives the following condition for striking[18]:

$$\int_0^d \alpha_n \left[e^{-\int_0^s (\alpha_n - \alpha_p) du} \right] ds = 1 \quad \ldots\ldots (5)$$

where the integration variables u and s, and distance between electrodes d are measured with the cathode as origin. α_n is often called the electron-ionization coefficient, and is the number of ions produced by collision by an electron per centimetre of path. If the polarity is reversed so that the anode is now the origin, the condition becomes:

$$\int_0^d \alpha_p \left[e^{-\int_0^s (\alpha_p - \alpha_n)du} \right] ds = 1 \quad \ldots\ldots (6)$$

where α_p is the positive-ion-ionization coefficient which is analogous to α_n.

Now α_n and α_p are not the same in general and so (5) and (6) are not satisfied at one value of applied voltage. Thus, the striking voltages for normal and reversed connexions are different.

Thomson's theory, based on the fact that positive ions liberate secondary electrons from the cathode leads to the same conclusions[18].

In this case:

$$\int_0^d \alpha_n \, ds = \frac{1 + \beta}{\beta} \quad \ldots\ldots\ldots\ldots\ldots (7)$$

or

$$e^{\alpha_n d} = \frac{1 + \beta}{\beta} = 1 + 1/\beta \quad \ldots\ldots\ldots (8)$$

where β is the number of secondary electrons liberated from the cathode per ion pair produced in the gas.

Now β is a function of the field strength at the cathode, hence value of α_n (and therefore of applied voltage) is different for normal and reversed connexions. It is to be expected that the field strength at the cathode will generally be greater when the cathode is the smaller electrode, i.e., with reversed connexions. Thus β will be the larger for this case and the applied voltage for striking smaller. That this is not always true may possibly be due to the fact that not nearly so much care is taken with the preparation of the anodes of the tubes as with the cathode surfaces.

Running Voltage

The results obtained are given in Table 5. It is seen that the regulation of all tubes is greatly increased by reversed polarity. The discharge becomes "abnormal" and the small "cathode" area becomes entirely covered by glow at quite a small current. The "abnormal" discharge gives the observed voltage rise with current over the working range.

Reversed-polarity running is generally accompanied by large random drifts, steps are still evident and hysteresis effects are very pronounced. In fact, if characteristics are taken several times, quite different values of running voltage are obtained at a given value of current, e.g. for the 85A1 type values of 8V are not uncommon.

Normal Operation after Running with Reversed Polarity

The striking voltages and running characteristics of the tubes were recorded with normal connexions after operation with reversed polarity to determine if the latter causes any permanent damage. Excluding the few tubes which arced (see Table 5), all others tested had the same striking voltage and running characteristics before and after operation with reversed connexions.

Effect of Reversed Polarity on Tube Life

Some tubes of Type CV1070 were run for a considerable time with reversed connexions. It was found that the running voltage increases very rapidly, in some cases more than 30 per cent during the first 200 hours of life.

Effects of Tube Age

Twelve tubes of the CV1070 type were tested on arrival from the manufacturer. Their age at that time was unknown. They were then stored and tested at intervals over a period of 3 000 hours. The striking voltages of the tubes were unchanged during this time. The running voltages were in all cases, however, increased, considerably during the first 1 000 hours and then remained nearly constant. The maximum increase in running voltage at a given value of current was 1·6V, the average value 1V and the minimum value 0·6V.

The increase of voltage observed is considered to be caused by contaminations of the cathode by gases from the glass walls which will take place to some extent whether current passes or not unless special precautions are taken as in the 85A1 tube. For these high-stability tubes, where any gases if produced are removed immediately by the molybdenum coating, the running voltage is almost constant with time during long resting periods. No results have been obtained for the other tube types, but it is reasonable to assume that they behave in a manner similar to the CV1070 samples.

Current Overloads

Peschel[19] has reported that accidental current overloads will frequently make glow-discharge voltage-regulator tubes entirely useless as regulators although they may appear to be functioning quite normally. His statements are misleading, however, as they give no details of the magnitudes or durations of the overloads in question.

The effects of overloads on the characteristics of tubes of the CV1070 and S130 types have been examined in some detail. Several CV1070 tubes were run with overloads ranging from 10 per cent to 700 per cent for periods between 15 seconds and 1 hour.

One important point arising from these tests is that, because of the large cathode area, the increase of voltage with current in all tubes is fairly small over a current range extending well beyond the maximum value.

It appears that overloads of 200 per cent can be applied for a period up to 1 hour without permanent damage to a CV1070 tube. The effect of larger overloads is to increase the running voltage for a given value of current, probably due to sputtering of the cathode by the discharge, but it is interesting to note that the regulation over the current range does not increase very greatly.

Changes in the characteristics of the S130 tubes become evident after overloads of 100 per cent applied for a few seconds only and the running characteristics move bodily by a few volts.

A slight overload (up to about 25 per cent) appears to do no damage to a tube of any type except that it reduces the useful life appreciably as discussed later.

Exposure to Magnetic and Electric Fields

All tubes are affected by exposure to stray magnetic and electric fields. In general, however, the effects of stray fields are not serious, but it is advisable not to place tubes near transformers or permanent magnets. Variations in running voltage of more than 20 per cent may be obtained by locating a tube close to a permanent magnet with a field strength of 1 500 oersteds. Fortunately tubes do not appear to be permanently affected by strong fields. Several tubes of the CV188 type operated in the gap of a 1500-oersted magnet for a short time gave their normal characteristics again when removed from the field.

Long-Term Tests

Variations in the characteristics of tubes of the CV1070, 85A1, S130 and KD60 types have been observed during the first several thousand hours of continuous operation. Each tube was run at an approximately-constant current and was exposed to small ambient-temperature changes. Mention has already been made of the observed increase in temperature coefficient of running voltage and the increase of initial drift with life. Attention has also been called to the effects of reversed polarity on life. It remains only to discuss the striking- and running-voltage variations with time and the effect of overloads on life.

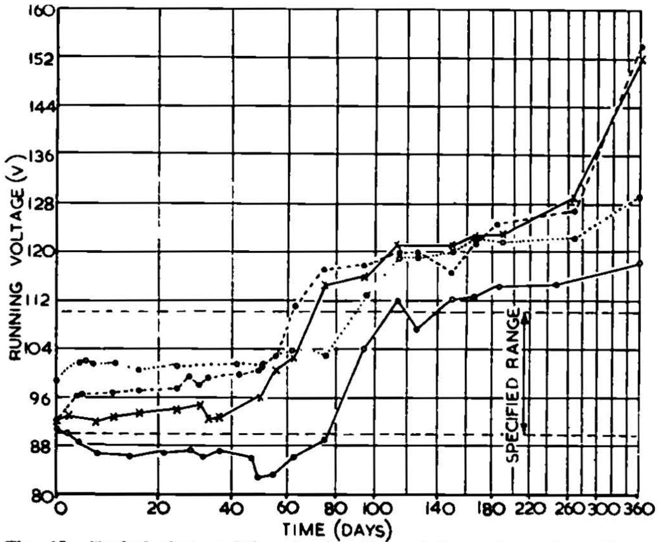


Fig. 15. Typical characteristics showing the variations of running voltage with time for tubes type S130 run continuously at approximately-constant tube currents of 5mA.

Running Voltage Variations

The CV1070 Tubes

Twenty-four tubes were run continuously at an approximately constant current of 5mA for about 10 000 hours. Some typical characteristics for the tubes are shown in Fig. 15. Other typical characteristics are given in Fig. 16 illustrating the voltage variations during the first 1 680 hours plotted to a larger scale than on Fig. 15.

It appears that for this type of tube the running-voltage/life characteristics can be divided into three parts:—

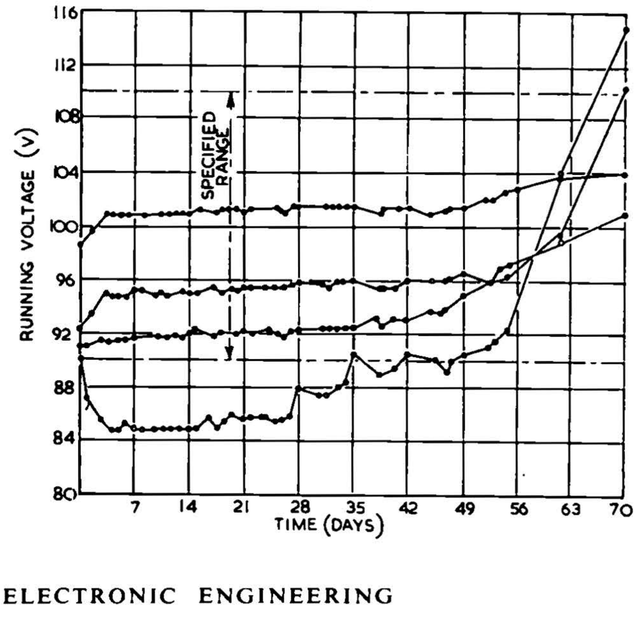
(1) An initial "ageing" period during which the voltage may change fairly rapidly. The duration of this period is, in general, about 100 hours, but may extend to 300 hours. Voltage variations of up to ± 10 per cent are observed. It seems worth while ageing tubes before putting them into service to take them out of this period.

(2) An intermediate period lasting up to about 1300 hours from the start during which only small voltage variations of a random nature are observed. The maximum variation during this period is less than ± 2 per cent, but the change is generally considerably less than this figure.

(3) A final period where again large variations occur and the voltage gradually increases even after it passes out of the specified range. It can be seen from Fig. 15 that after about 9 000 hours operation the running voltage may have increased by about 70 per cent. Apart from the fact that the glass envelopes darken with time the tubes appear to be running quite normally even after the voltage reaches its upper specified limit. Thus, it is advisable to replace tubes in any equipment before they have a chance of running into this final period of life.

All the tubes tested ended their useful life, i.e. reached period (3) at about 1300 hours within about 200 hours of each other. It does seem rather remarkable that tube life can be predicted fairly accurately for a given operating current.

Fig. 16. Typical characteristics showing the variations of running voltages with time for tubes type CV1070, run continuously at approximately-constant tube currents of .5mA.



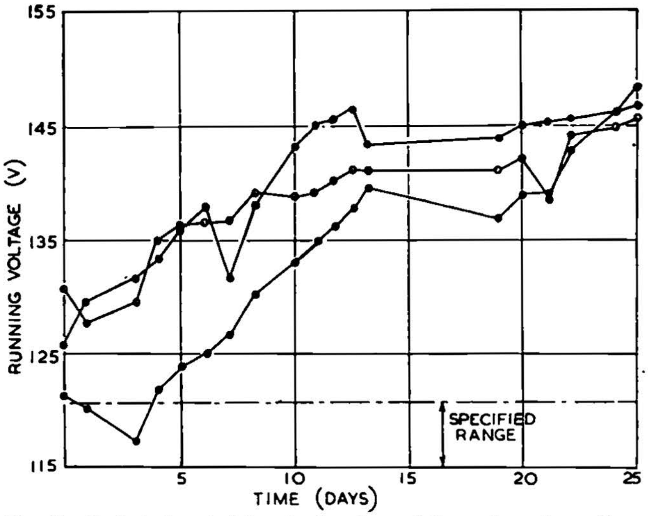
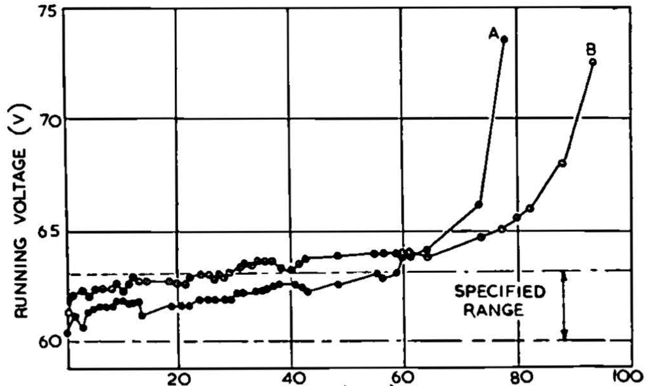


Fig. 17. Typical characteristics showing the variations of running voltages with time for tubes type S130, run continuously at approximately-constant tube currents of 50mA.

Fig. 18. Typical characteristics showing the variations of running voltages with time for tubes type KD60, run continuously at approximately-constant tube currents of 1mA.



During the lives of the tubes the slopes of the current-voltage curves of Fig. 1 generally change considerably, the characteristics do not usually move parallel to themselves as might be anticipated.

The S130 Tubes

Twelve tubes were run continuously at an approximately constant current of 50mA. Some typical characteristics for the tubes are shown in Fig. 17. Large running-voltage variations are observed throughout the life of the tubes; there is no period corresponding to (2) as with the CV1070. Tubes which are within the specified range at the start soon pass out of it; voltage increases of up to 10 per cent during the first 150 hours seem usual and thereafter changes of 0·1V/hr are common. It will also be observed from Fig. 17 that large voltage drops occur quite frequently.

The KD60 Tubes

Two tubes only were available for life test so no generalizations can be made. However, the few results obtained are thought to be of some interest and are, therefore, included. The tubes were run at approximately-constant currents of 1mA. The characteristics obtained are shown in Fig. 18. An initial ageing period is evident during the first 50/100 hours. Thereafter the running voltage gradually rises until it passes out of the specified range. The time taken for this appears to vary considerably from tube to tube. After about 1500 hours operation the running voltage increases very rapidly with time.

At points A and B (Fig. 18) respectively the two tubes tested developed an oscillating glow. Records obtained by the manufacturer do show, however, that tubes of this type are capable of running satisfactorily for 5 000 to 8 000 hours depending on the current.

The 85A1 Tubes

Twenty-two tubes were run continuously at an approximately constant current of 5mA for about 10 000 hours. In contrast with the other types of tube these show little change of running voltage with time. There is an initial ageing period which lasts from about 50 to 200 hours. The maximum change of running voltage during this period was 0·5 per cent and the average change 0·3 per cent. After that, during the 10 000 hour tests the maximum change in running voltage was 0·6 per cent and the mean change 0·4 per cent. The variations are of a random nature. Even after 10 000 hours there is no evidence that the useful life of the tube is being approached.

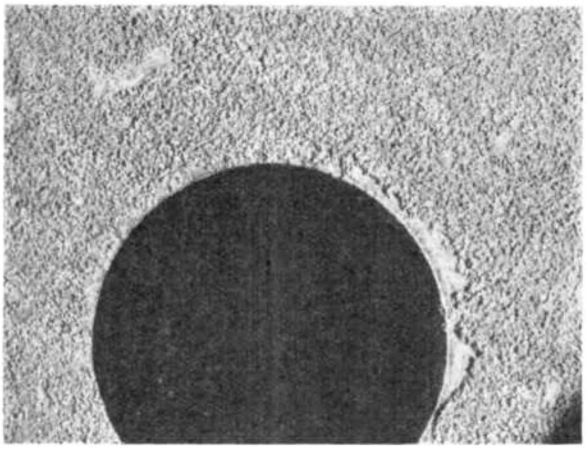


Fig. 19. Photo-micrograph of a portion of the cathode surface of a new CV1070 glow-discharge tube.

STRIKING-VOLTAGE VARIATIONS

The striking voltages of the tubes were recorded at various stages throughout the long-term tests. The striking voltage increases with life, very considerably in many cases.

For the CV1070 tubes the striking voltage increases by from 8 to 90 per cent in the first 7 500 hours. At this stage the majority of the striking voltages were well outside the upper specified limit.

For the S130 tubes increases in striking voltage from 5-16 per cent are observed during the first 1000 hours of operation.

For the two KD60 tubes tested the striking voltage increase amounted to about 5 per cent in the first 1500 hours. There seems to be some evidence that the magnitude of the change of striking voltage with time for this type of tube is a function of the tube current, the lower the current the smaller the variation.

In the case of the 85A1 tubes the maximum increase in striking voltage is less than 5 per cent during the first 10 000 hours operation and after this time all the voltages are still well inside the specified limits. Many tubes of this type showed no change of striking voltage with time.

CURRENT OVERLOADS

A few CV1070 tubes were run continuously at an approximately constant current of 10mA (i.e. at 25 per cent overload). There is an initial ageing period in the running-voltage/life characteristics as before lasting from about 50 to 100 hours, during which the voltages change quite rapidly. These changes may be either increases or decreases. In contrast with the life characteristics obtained for currents of 5mA, however, there is no period where the voltage remains nearly constant. Instead the running voltage increases gradually, after the ageing period, in a random manner at a rate of about 5mV/hr for approximately 1000 hours and, thereafter, at a much faster rate.

No results have been obtained for other types of tube.

DISCUSSION OF RESULTS

During the life of a tube of the CV1070 or S130 type a visible deposit forms on the glass envelope. This is caused by sputtering of the cathode by the glow-discharge and is greatly accelerated by current overloads. Figs. 19 and 20 show photo-micrographs of portions of the cathode surfaces of a new CV1070 tube, and a tube of the same design after 2 000 hours continuous operation at a current of 5mA, respectively. The new tube shows a uniform cathode surface suggesting an oxide coating on a metal base. This coating has been completely removed in 2 000 hours by sputtering and explains the cause of the observed running-voltage variations for tubes of this type.

Fig. 20. Photo-micrograph of a portion of the cathode surface of a CV1070 glow-discharge tube after 2,000 hr. continuous operation at a current of 5mA.

The deposit, during its formation on the glass envelope, will trap some of the gas in the tube and, therefore, will alter its pressure. However, the cathode drop in a discharge tube is substantially independent of the gas pressure. Liberation of gases from the glass walls by the glow-discharge may also be responsible for some variation of running voltage. These gases may contaminate the cathode or the original gas filling and increase the working voltage. It has been shown by Langmuir[20], and others[8,9], for example, that a discharge in neon liberates gases, in particular oxygen, from the glass walls. In the 85A1 tubes, which when run continuously for as long as 10 000 hours show quite small variations of running voltage, the molybdenum layer on the tube walls shields the glass from the discharge and prevents liberation of gases. It also acts as a getter. It is not sufficient, however, to introduce the molybdenum anywhere in the tube, it must be on the glass walls. Further, sputtering of the molybdenum cathode in an 85A1 tube does not appear to be troublesome.

Conclusions

It has been demonstrated that glow-discharge tube characteristics show considerable variations, not only from tube to tube of the same design, but also with the passage of time and with changes in ambient temperature. Many of these variations appear to have been largely unrecognized in the past. Tubes of the high-stability types show substantial improvements over the earlier designs. However, for use in high-stability power-supply or other precision circuits, it appears that glow-discharge tubes are not suitable unless they are specially chosen, and used under carefully-controlled conditions. A careful revision of tube specifications is necessary, particularly since in many cases they are somewhat misleading.

Acknowledgments

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Appendix

TABLE A.—VARIATIONS IN STRIKING VOLTAGES OF TYPE CV1070 TUBES

(*NOTE.—The tubes were not all obtained at the same time but in batches over a period of two years.*)

SAMPLE	VOLTAGE	SAMPLE	VOLTAGE	SAMPLE	VOLTAGE
1	131·5	13	117·0	25	117·0
2	119·0	14	122·0	26	114·5
3	118·5	15	122·5	27	117·5
4	111·0	16	126·0	28	114·0
5	134·0	17	125·0	29	118·0
6	119·5	18	113·0	30	119·0
7	125·0	19	116·0	31	114·0
8	116·0	20	127·0	32	120·0
9	130·0	21	120·0	33	119·0
10	122·0	22	124·0	34	122·0
11	128·5	23	115·5	35	117·0
12	129·0	24	116·5	36	115·5

TABLE B.—VARIATIONS IN STRIKING VOLTAGES OF TYPE 85A1 TUBES

(*NOTE.—The tubes were not all obtained at the same time but in batches over a period of two years.*)

SAMPLE	VOLTAGE	SAMPLE	VOLTAGE	SAMPLE	VOLTAGE
1	112·5	13	113·5	25	113·5
2	115·5	14	113·0	26	114·0
3	113·5	15	112·5	27	113·5
4	112·5	16	113·5	28	114·0
5	112·5	17	116·0	29	116·5
6	111·5	18	115·0	30	111·0
7	112·5	19	113·5	31	110·5
8	114·0	20	114·5	32	111·5
9	114·5	21	112·5	33	112·5
10	112·5	22	115·5	34	113·0
11	113·5	23	112·0	—	—
12	112·0	24	111·5	—	—

TABLE C.—VARIATIONS IN STRIKING VOLTAGES OF TYPE S130. TUBES

SAMPLE	VOLTAGE	SAMPLE	VOLTAGE	SAMPLE	VOLTAGE
1	143·0	8	141·5	15	150·5
2	166·0	9	161·0	16	160·0
3	167·0	10	167·5	17	169·0
4	157·0	11	155·0	18	153·0
5	157·0	12	167·5	19	150·0
6	149·5	13	175·0	—	—
7	172·0	14	144·5	—	—

TABLE D.—VARIATIONS IN STRIKING VOLTAGES OF TYPE CV71 TUBES

(*NOTE.—Independent of whether glass bulb is rendered opaque as required by specification, or not.*)

SAMPLE	VOLTAGE
1	141–151
2	145–170
3	140–160
4	145–162
5	140–155
6	149–157

TABLE E.—VARIATIONS IN STRIKING VOLTAGES OF TYPE KD60 TUBES

SAMPLE	VOLTAGE
1	74·0
2	77·0
3	75·5
4	75·0
5	78·5
6	80·0

TABLE F.—VARIATIONS IN STRIKING VOLTAGES OF TYPE CV188. TUBES

SAMPLE	VOLTAGE
1	106·5
2	118·0
3	117·0
4	109·5
5	112·5
6	110·5

TABLE G.—VARIATIONS IN STRIKING VOLTAGES OF TYPE CV45 TUBES

SAMPLE	VOLTAGE	
	a	b
1	125·0	145
2	115·0	154
3	120·0	158
4	121·0	153
5	118·0	153
6	124·5	156

(*a*) *Ignition electrode connected to 220V D.C. positive through a 54k*Ω *resistor*
(*b*) *Ignition electrode not connected.*

TABLE H.—VARIATIONS IN STRIKING VOLTAGES OF TYPE VR150 TUBES

SAMPLE	VOLTAGE
1	160
2	154
3	157
4	131–147*
5	172
6	150

* 131 *volts in ordinary daylight.* 147 *volts in the dark.*

TABLE I.—VARIATIONS IN STRIKING VOLTAGE OF TYPE NT2 TUBES

SAMPLE	VOLTAGE
1	72·0
2	62·0
3	61·0
4	65·5
5	67·0
6	62·0

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