THE RECTIFYING CHARACTERS OF ORDINARY ELECTRIC BULBS

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ABSTRACT

Rectified current derivable from an electric bulb when it is painted with Chinese ink has been observed. The rectifying characters of twenty three ordinary electric bulbs made by eleven different companies were studied. It was observed that the polarity of the rectified current derived from the surface of the bulb depends on the nature of the bulb and an explanation to account for the phenomenon has been attempted. Results showing the relation between the output and the input, the effect of the position of the paint on the bulb, the temperature, the composition of the paint and the nature of the bulb are given.

INTRODUCTION

The rectifying action of an electric bulb was first recognized by R. C. Burt[1] who obtained metallic sodium by electrolysis through the glass wall of an electric bulb. His method is to dip the bulb into sodium nitrate in molten state. A D. C. voltage applied to the hot nitrate liquid transfers sodium to the inside surface of the bulb by electrolysis through glass. This method has been used by physical chemists to determine the so-called transfer numbers. The manipulations, such as the heating and maintaining of a sufficiently high temperature of sodium nitrate in molten state, are apparently too inconvenient for any practical use.

The rectifying action to be considered in this paper occurred rather accidentally to Mr. Ch'en Shang-chin[2] in the summer of 1946. He

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1. R. C. Burt, *J. O. S. A.* **11** (1925), 87.

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painted half of the bulb on his writing desk with Chinese ink merely to protect his eyes from light irritation. On touching the paint part of the bulb with his hand he suffered unexpectedly a great shock. This amazing phenomenon attracted his attention to study the nature of the electricity. As a chemist, he found immediately that the electricity was D. C., for salt water could be electrolized by it.

If the Chinese ink painted on the electric bulb can produce the same effect as that observed by Burt, Ch'en's method has evidently two advantages over that of Burt: (1) the black Chinese ink is a good absorber of heat, so the bulb can be heated by the radiant energy from the incandescent filaments rendering no additional heating necessary; (2) since the whole set-up is very simple and economical the practicability of the rectifying action will be increased.

The rectifying action was systematically studied in this work. The result turns out to be more interesting than what has been first thought. The polarity of the outer electrode, i.e. the part painted by ink, is negative for some bulbs (hereafter called (−) bulbs), positive for other bulbs (hereafter called (+) bulbs). For certain bulbs the polarity changes back and forth from negative to positive (hereafter called (±) bulbs). For (−) bulbs metallic sodium is deposited on the inner surface of the bulb giving a silvery reflecting coating, while for (+) bulbs no such sodium deposition takes place, being a new phenomenon observed by the present authors.

EXPERIMENTS

The circuit used in the present experiment shown in Figure 1 is essentially the same as that of Burt[1]. L_1, used as a resistance in series with the bulb L_0 being studied, prevents too large a current passing through L_0 due to discharge between the filament leads when the sodium vapor pressure is increased, while, L_6 is a stabilizing resistance, preventing destructive discharge between the filament and the glass wall. Bulbs L_2, L_3, L_4, and L_5 are connected in series across the terminals of L_0 and L_1, so the potential between L_4 and L_5 is equal to that at the middle of the filament of Bulb L_0 and the overheating of one terminal of the filament is avoided.

In the present experiment 220 V bulbs are used. With an auto-transformer the main source is stepped up to 440 volts to enable the bulb

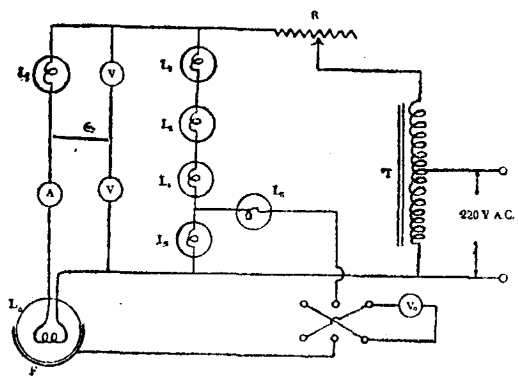


Figure 1. The Circuit

L_0 to be heated hot enough to mobilize the ions in the glass. Painted on the bulb is a layer of Chinese ink F surrounded by a sheet of tin foil which constitutes the outer terminal of the rectifier and works as the plate in a diode. The reversing switch is necessary when the polarity of F reverses.

As the internal resistance of the rectifier is high and a resistance of L_G is in series with the voltmeter, V_0, the voltmeter readings are by no means the potential, but the current with a series load of $(R_v + R_G)$ where R_v = resistance of the voltmeter and R_G the resistance of the bulb L_G for a current of a few milliamperes.

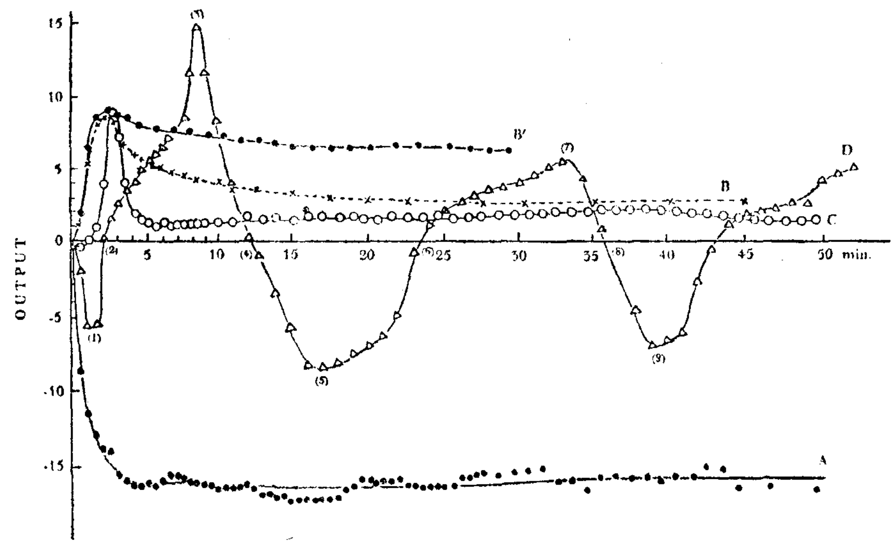
The resistance of the voltmeter has been found to be 48000 ohms, and the voltmeter readings can be converted into milliamperes by multiplying them with the factor .02. R_G is 100 ohms. The output current given in the present report are all expressed in terms of this sensitive voltmeter readings.

RESULTS

(a) The Polarity of the Rectified Current for Different Bulbs.

Bulbs obtainable in the market are of brands "VIC", "Edison", "東光"

"日 月", "準 光", "特 字", "シクニ", "マツダ" and several others of unknown brand. Chinese ink has been painted on each bulb in approximately equal area and density. Typical results are shown in Graph I.



Graph I. Typical Curves for Various Kinds of Bulbs

Curve A: for Bulb No. 5 (VIC 60 W) Input 160 V
B: for Bulb No. 19 (東光 40 W) Input 160 V
B′: ditto Input 220 V
(Output readings divided by 5)
C: for Bulb No. 3 (VIC 60 W) Input 160 V
D: for Bulb No. 23 (特字 60 W) Input 160 V

Curve A shows the case for a typical negative bulb whose output reaches a saturated value after about four minutes and tends to fade slowly when the bulb has been run continuously for over half an hour. This fatigue phenomenon is more pronounced for some bulbs like Bulb No. 6 (VIC 60w), No. 22 (準 光 60w) and No. 20 (東 光 40w). The zigzag shape of the curve indicates probably the effect of the fluctuation of input voltage and of the air current on the temperature of the bulb. Curves B and C show the case when positive bulbs are studied. The current first increases to a peak value, then goes down to a lower and a fairly constant value. Curve C represents the case when the output is initially negative and later changes to positive. Curve D is the case when the output changes repeatedly from negative to positive, the (±) bulb.

It is to be noted that an input voltage of 160 V has been applied instead of 220 V so that the life of the bulb would not be considerably shortened by heavy current in the filament. If the input voltage is raised to 220 V the output current can be increased to 2-3 milliamperes for a load of 48000 ohms. In fact, the output current could amount to as much as 9 m. a. for a G. E. Electric bulb (220 V 60w) recently tested. The voltage of the rectified current is approximately equal to the input voltage. The output for Edison bulb No. 15, マツダ No. 17, and シクニ No. 14 are very small.

(b) Relation Between the Output and the Different Chemicals Painted on the Bulb.

Several different kinds of substances have been used as paint on the bulb :

1) Black smoke dust deposited directly on the bulb by burning benzene

2) Pure graphite powder in distilled water with a little gelatin

3) A mixture in equal amounts of graphite and sodium chloride in gelatin.

4) A mixture in equal amounts of graphite and sodium nitrate in gelatin.

The first two should contain no sodium while the last two contain a considerable amount of sodium compound. The effects of these four kinds of paint have been tested for the same two bulbs, one negative and the other positive. It is found that the density of the coating plays a much more important part on the change of the output than the effect of the presence of sodium compound in the paint.

The nature of the paints does not affect the polarity of the rectified current. Within a time of about 30 minutes all paints appear to produce approximately the same amount of effect. For paint 4) sodium nitrate tends to combust with carbon giving frequently zigzags in the readings. It has been found that any paint so long as it is conducting and is a good absorber of heat can produce the rectifying effect.

(c) The Output at Different Locations on the Bulb.

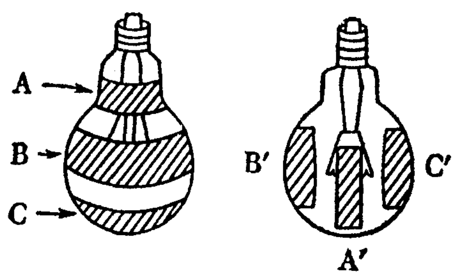
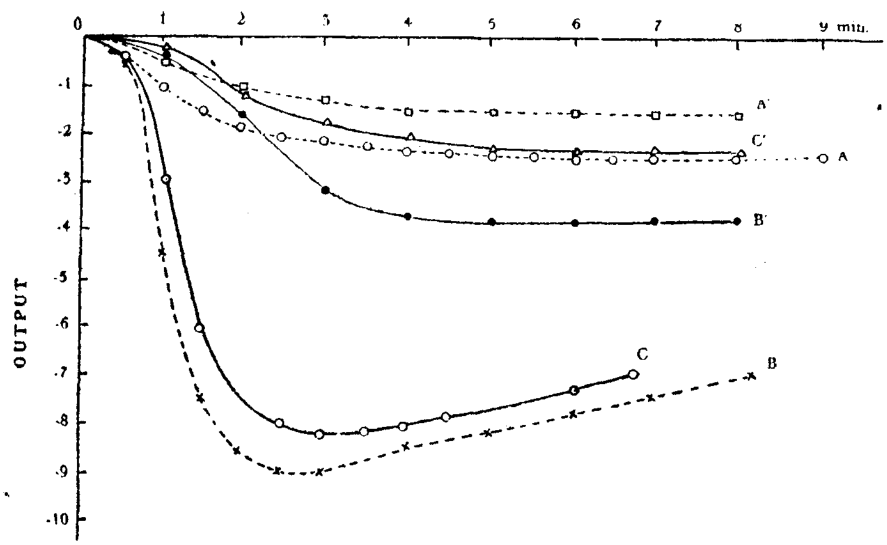


Figure 2.

An electric bulb is first painted in the shape of three horizontal rings as shown in Figure 2a and then repainted by three vertical strips as in Figure 2b. One of the vertical strips lies on the gap between the two filament leads while the other two are symmetrically located on both sides of A′. Separate tin foils are in contact with each strip. The results are shown in Graph II.

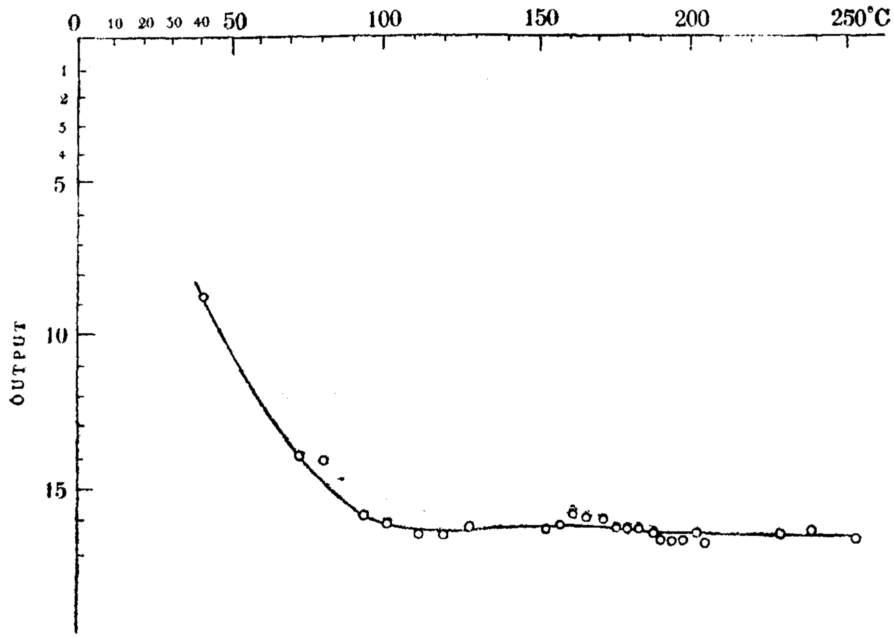


Graph II. Output at the Different Locations (Input 160 V for Bulb No. 9)

Horizontal Rings	Vertical Strips
A. On the neck	A′ near gap
B. At the middle	B′ Left of A′
C. At the bottom	C′ right of A′

(d) The Relation Between the Output and the Temperature of the Bulb.

The dependence of the output on the temperature of the bulb wall has been tested by putting the bulb into a metal can with asbestoes powder to fill the empty space so that the temperature of the bulb wall would not be influenced appreciably by the outside air currents etc.



Graph III. Output vs. Temperature For Bulb No. 5. Input 160 V

As shown in Figure 3 a thermometer placed in close contact with the bulb can be read from time to time. Results for Bulb No. 5 are shown in graph III. The output reaches a saturated value when the temperature is raised to a certain value, namely 110°C. Thus the output cannot be increased by merely increasing the temperature of the bulb.

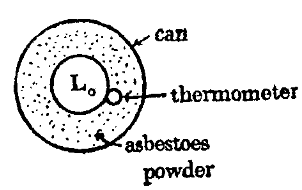
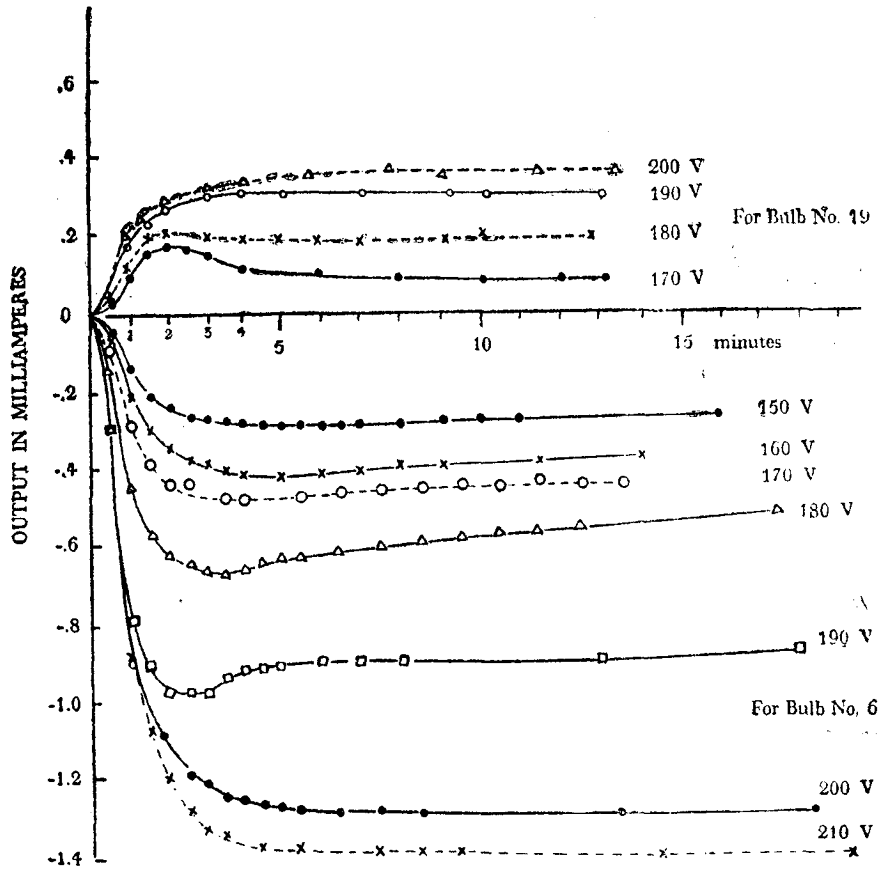
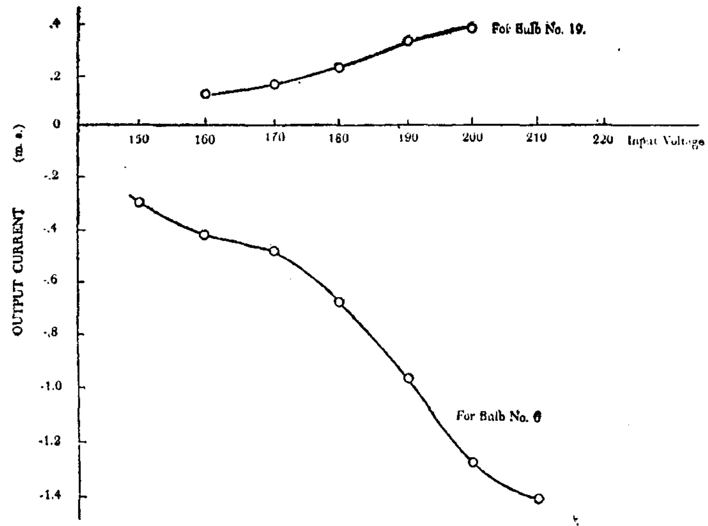


Figure 3.

(e) The Relation Between the Output and the Input.



Graph IV. Output current for Different Input Voltages



Graph V. Output Current vs. Input Voltage

Two bulbs, one (−) and one (+), have been employed to find out the relation between the D. C. derivable from the glass bulb, i.e. the output current, and the A. C. voltage used to light the bulb, i.e. the input voltage. Several different input voltages are tested. The voltage of the rectified current is about 10-20 volts lower than that of the impressed A. C. Graph IV, plotted with output vs. time gives the results. It appears that the curves for low impressed voltages usually has a weak maximum at the second or third minute and then change to a steady value. For voltages higher than 200 V the weak maximum nearly disappears. In graph V curves drawn with output current vs. input voltage, the values of the output current are their maximum values taken from Graph IV.

(*f*) *The Relatian Between the Output and the Pressure Inside the Bulb.*

The gas pressure inside the bulb is considered as the chief factor which changes the polarity of the output. It has been estimated by means of a high frequency tester. Positive bulbs appear to give always a glow discharge, but the (−) bulbs do not. A detailed study of this problem is still in progress.

DISCUSSION

The bulb acts like a diode rectifier except that the plate is replaced by the hot glass wall of the bulb, and instead of applying a voltage on the glass wall, a D. C. voltage can be derived from it. The action of the ($-$) bulb first known to Burt[1] may be represented by the equation :

Na_2SiO_3 (In hot glass)	$\rightleftarrows$	$2\ Na^+$	+	$SiO_3^{=}$		$SiO_3^{=}$
		+		+		$\downarrow$
		2 (e)		$2\ Na^+$	+ 2 Cl^-	SiO_2
		$\downarrow$		$\downarrow$	$\downarrow$	+
						0
		2 Na (Deposited)		Na_2SiO_3	Cl_2	+
					+	2 (e)
					2 (e)	

The metallic sodium deposit inside the bulb comes from the neutralization by thermal electrons of the sodium ions presented in the hot glass. The $SiO_3^{=}$ ion gives away its negative electrons probably by combining with other sodium halides or by decomposing into SiO_2 and oxygen as shown in the diagram. It is the field of the thermal electrons that causes the negative charges in the bulb to leave the bulb.

It is obvious that the current obtainable from the rectification depends greatly on the mobility of the ions in the glass. Pyrex glass bulb gives nearly imperceptible effect unless the bulb has a very high temperature.

As shown in Fig. 4, let L be the bulb, F the layer of ink painted on it, and the dotted line the electrical connections. If the bulb is run by A. C., and at the instants when A is positive and B negative, the middle part C has a potential lower than that at A but higher than that at B. The part CA has a higher positive potential than that at F, so no electrons can be ejected by that part. The potential along wire BC is lower than that at F or CA, so the thermal electrons emitted by the part BC

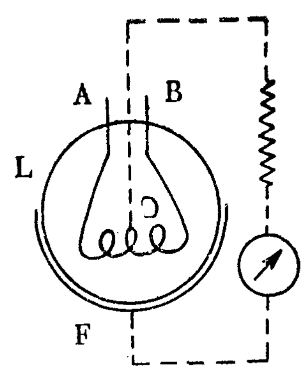


Figure 4.

will be attracted to F or to CA. The part returning to CA will cause an additional current load in the filament. The part captured by the inner surface of the bulb will render metallic sodium to be formed according to the above equation.

When B becomes positive and A negative the action is just reversed. Thus the two parts of the filament operates alternately as a full wave rectifier to produce D. C. with small ripples.

The phenomenon of the (+) bulb may be explained by the secondary emission hypothesis. When the pressure inside the bulb is very low, the thermal electrons emitted from the filament BC may acquire sufficient kinetic energy to knock off new electrons on bombarding the glass wall, and at the same time are not caught by the sodium ion of the glass. Accordingly these secondary electrons are attracted to part CA, resulting in a positive potential at F.

Gas-filled bulbs should always behave as (−) bulbs because the pressure in the bulb is high and thus the mean free path of the electrons are considerably shortened; so electrons will release part of their energies by colliding with the gas molecules in the bulb enabling no secondary electrons be knocked off.

It will be a very interesting part of this work if the typical curves for the variety of bulbs given in Graph I could be satisfactorily accounted for. In view of all the foregoing considerations it is easy to conceive that the shape of the curves is chiefly controlled by three important factors:

1) The gas pressure inside the bulb
2) The potential difference between the filament and the bulb wall
3) The temperature and the coating of the inner surface of the bulb.

An increase in gas pressure inside the bulb will decrease the speed of collisions between the thermal electrons and the bulb. Thus the polarity of the rectified current will depend greatly on this factor. On the other hand increase in potential difference between the filament and the bulb-wall will increase the speed of collisions between the thermal electrons and the bulb, and thus increases the density of the rectified current. The geometrical configuration of both the bulb and the filament, ,aud the input voltage are all factors to change the potential difference.

The degree of ionic activity in the glass, and the amount of work required to knock electrons off from the glass of the bulb, i.e. the work function, depend greatly on the temperature of the bulb.

The gas pressure in bulbs like those which give curve A should not be too low to produce secondary electrons. So they act as (−) bulbs. The rectified current increases with the temperature of the bulb until it is heated to a stationary value. The fatigue phenomenon might be due to the gradual decrease of the Na^+ ion concentration in the glass.

Curves B and C are typical curves for (+) bulbs in which the pressure is considered as low enough to have secondary electrons. The pressure in bulb No. 19 should be still lower than that in Bulb 5. The fact that the current increases first to a maximum and then changes to a lower but constant value is caused by the production of these secondary electrons which increase very rapidly the density of space charges, resulting in a decrease of the speed of collisions of the electrons with the bulb. As a consequence the current decreases to a constant value until an equilibrium condition is reached. For curve C the output starts as negative when the glass is not hot enough to produce secondary electrons. The current in this case comes mainly from polarization. As the glass becomes hot its electrons are easily knocked off.

Curve D represents typically the rectifying behavior of these bulbs whose gas pressure and other conditions are on the boundary between that for (−) and (+) bulbs. Here it may be interesting to point out that secondary electrons may appear to come out more easily if metallic sodium is present on the surface of the glass. Thus in this case the bulb will behave negative if no sodium is on the inner surface of the bulb but will be positive if the surface is coated with a trace of metallic sodium. As shown in curve D the bulb is negative at the first instant. Later as the sodium metal is deposited by electrolysis on the inner surface, production of secondary electrons begins and the curve turns up to positive. The sodium coating slowly evaporated. By the instant for the first maximum, marked 3, the trace of sodium should be so small that the glass surface will be gradually exposed. The production of secondary electrons becomes practically zero at the instant marked by 4. The bulb behaves negative until the instant marked by 5 is reached. From 5 on, the sodium deposited on the surface within the interval from 4 to 5 starts to produce gradually secondary electrons until instant 6 at which no appreciable electrolysis takes place. The process then repeats itself accordingly.

From Results (b) the chemical composition of the paint appears to influence very little the rectifying process, so long as the paint is conducting and is a good absorber of heat. According to the theoretical considerations just detailed the sodium salt in the paint should exhibit no effect on the output of the (+) bulb, for no sodium in the glass wall is electrolized. But for (−) bulbs, sodium ions in the glass do change into metallic sodium. If the material painted on the bulb contains no sodium, the supply of sodium ions should be insufficient. Consequently, the output should show distinctly a fatigue phenomenon. The fact that this is not shown in the result might be due to the abundance of sodium compound in the glass. The effect is very small if the tests do not continue for a time longer than half an hour.

The results shown in Graph II can be easily accounted for as due to the asymmetry of the construction of the filament and the non-equidistant separations between different parts of the filament and the glass wall. This would produce different potential gradients and different internal resistances at various points in the bulb. So the density of the output resulted would vary with locations, and would be different with different bulbs.

The middle ring B which is closest to the filament, has the largest output, the vertical strip A′ located at the gap of the filament leads the smallest. The output for strips B′ and C′ situated at symmetrical positions are quite different, because the potential between L_4 and L_5 is not exactly at the middle part of the filament.

As shown in Graph V the output is not quite a linear function of the input, especially for (−) bulbs. Between input voltages 170-195 V the output increases more rapidly with the input. According to this graph if the bulbs are operated by 220 V instead of 160 V the maximum readings in outputs for Graphs I, II, and III should be increased five times as much. (Cf. Curves B and B′ of Graph I.)

Electrical leakage usually encountered in water baths of chemical laboratories using electric lamps as heaters cannot be entirely avoided. In the light of the present experience it should not be due to insufficiency in insulation but to the effect here studied.

This same effect happens in damp places such as underground air-raid shelters. A layer of white coating on the inside wall of many old bulbs in those shelters is chiefly metallic sodium.