On the Periodic Time of the Flashes of a Neon Lamp

By

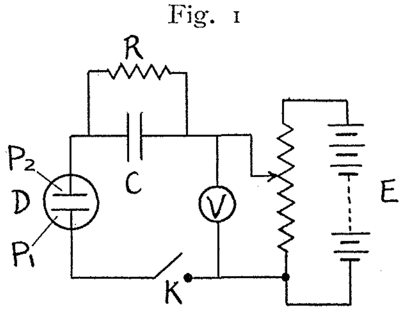
Tatsumi Terada

(Received July 30, 1934)

Abstract

Periodic flashes of a neon lamp are generated by an electric circuit in which a condenser, shunted by a high resistance across its terminals, is connected in series with the lamp and a battery. The discrepancy of the periodic time of the flashes, which appears between the observations and the calculations, is discussed in this paper. The flashing phenomenon is complicated by the requirement of a finite time for the discharge (lighting time), by the spark-lag and by some other factors, but the leakage of electricity through the gas in the lamp seems to be especially predominant as a cause of this complication. Lastly a new formula for the periodic time of the flashes is given.

Fig. 1



In Fig. 1, a condenser C shunted by a great resistance R is connected in series with a neon lamp D. If the circuit is closed by a key K and the applied voltage V is suitable, a "flash" first appears at the same time as the circuit is closed, and then periodic "flashing" is repeated. It was shown by the writer[1] that the periodic time T of the flashes was theoretically given by the formula

$$T=RC\log\frac{V-V_b}{V-V_c} \qquad \text{.........................(1)}$$

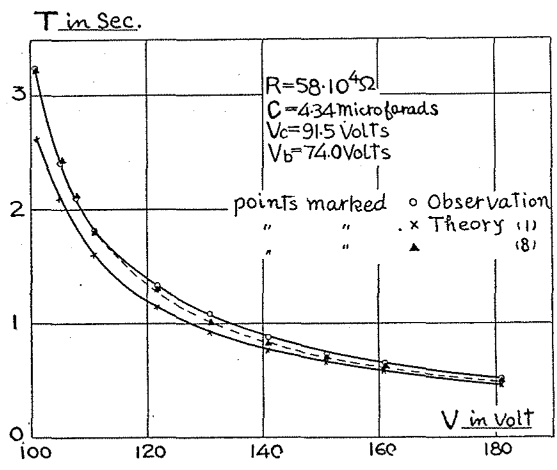
where V_c and V_b were the sparking and extinction potentials of the

1. The writer: These Memoirs, **17**, 85, (1934)

lamp and V an applied voltage. However, the periodic times observed under some experimental conditions—the resistance R and the capacity C were varied and the applied voltage was kept constant—were always greater than those calculated by the formula (1), and the greater the periodic time the greater the discrepancy (referring to Figs. 3 and 4 in the writer's previous paper). In the paper referred to above it was suggested by the writer that this discrepancy might be due to the electric leakage at the lamp and some other parts of the connections, to the time interval required by the discharge, and to the spark lag.

Recently the writer has made further investigations on this point with the apparatus shown in Fig. 1. Keeping the resistance R at 0.58 megohm and the capacity C at 4.34 microfarads, the writer observed the periodic time T with various applied voltages. The two curves plotted in full lines in Fig. 2 show the results observed (the points marked ○), and the times calculated by the formula (1) (the points marked ×), respectively. It is evident from the curves that the observed periods are always greater than those calculated as is observed in the former experiment.

Fig. 2



Next, to examine the effect of the spark lag on the periodic time of the flashes, the neon lamp was illuminated by the X-rays and the periodic times were observed under the experimental conditions of $R=0.58$ megohm and $C=4.34$ microfarads. The results obtained with various voltages are shown by the figures in Table I, where the last and the second columns show respectively the periodic times observed with and without the illumination of the X-rays.

It may be seen from this table that the periodic times did not differ much with the illumination of the X-rays. The observations also disclosed that the sparking and extinction potentials of the lamp

Table I

$V_c = 91.5$ volts

$V_b = 74$ volts

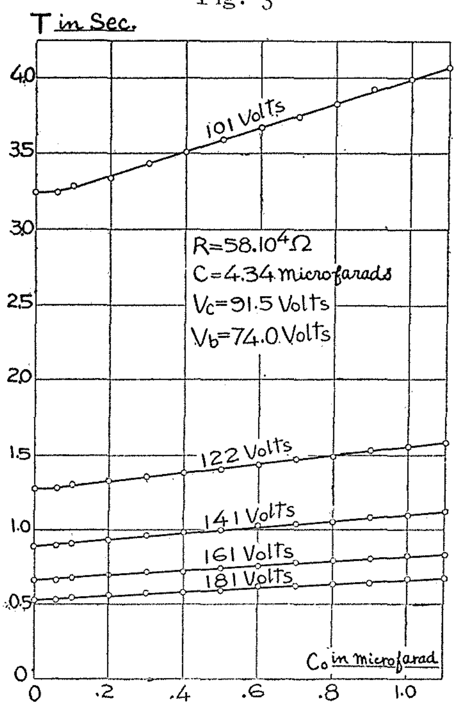
Volt	T in sec.	
	in the dark without the X-rays	with the X-rays
101	3.25	2.98
105	2.41	2.37
107	2.10	2.06
111	1.80	1.77
122	1.32	1.30
131	1.08	1.06
141	0.88	0.88
151	0.72	0.71
161	0.65	0.64
181	0.51	0.51

did not suffer any appreciable effect by the illumination of the X-rays. If we consider that the chief effect of the X-rays was to diminish the spark lag and that the effect of the rays on the sparking and extinction potentials was comparatively small, it follows immediately from the experimental results mentioned above that there is not any notable effect of the spark lag on the periodic time of the flashes, at least under the present experimental conditions.

Next, the writer measured the lighting time of the lamp with a rotating camera. As the light emitted from the lamp was converged by a lens, being focussed on the camera, a dark line whose length corresponded to the time of lighting would be impressed on the film. By this method, it was found that lighting time was 0.048 sec. in the average though the values varied from 0.042 to 0.056 sec. under the same experimental conditions, and consequently that the time was so small that it was negligible for the consideration of the periodic time of a few seconds or more.

In the deduction of the formula (1), the capacity between the electrodes of the neon lamp was neglected. In order to investigate the effect of this capacity on the periodic time of the flashes, a precision mica condenser C_0 was connected in parallel with the electrodes P_1 and P_2 of the lamp (Fig. 1) and the periodic times corresponding to various values of C_0 were observed. In Fig. 3, the curves were plotted by

Fig. 3



taking the periodic time T as ordinates and the capacity C_0 as abscissae. The periodic time increases generally with the capacity C_0 for all the applied voltages, the rate of the increase of time for the smaller voltages being greater than that for the greater voltages. However, the effect of the capacity was so small that it could not be observed when the variation of C_0 was smaller than about 0.07 microfarad. From this, it seems to the writer that the effect of the leakage of electricity thro' the gas in the lamp or along the glass wall of the lamp is much more probable as the cause of the discrepancy between the calculated and the observed periods of the flashes of the lamp.

Next, to test the effect of the leakage of electricity in our circuit on the periodic time of the flashes, the whole apparatus with the exception of the battery was enclosed in a metal box arranged for adjustment of humidity. The experiment was carried out with a neon lamp of $V_c=91.5$ volts, $V_b=74$ volts and under the experimental conditions $R=0.58$ megohm and $C=4.34$ microfarads. The periodic time of the flashes was observed in an atmosphere of varying degrees of humidity (temperature fluctuated only between 19.5°C and 21.5°C).

Table II

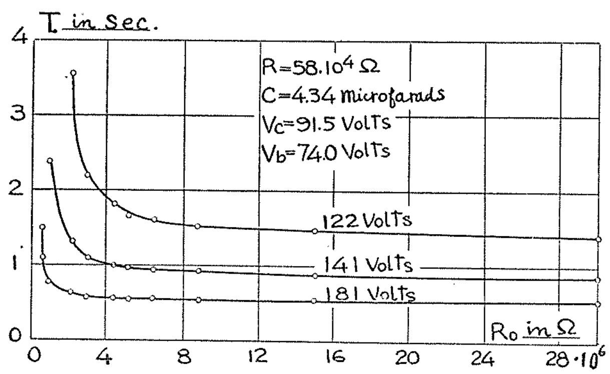
T in sec.

Relative humidity / Volt	45%	55%	65%	75%	96%
100	2.59	2.86	2.95	2.97	3.14
110	1.71	1.82	1.91	1.93	1.98
120	1.30	1.35	1.44	1.45	1.50
130	1.04	1.07	1.16	1.17	1.20
140	0.90	0.91	0.99	1.00	1.03

Some of the results observed are given in Table II. Even if the leakage of electricity through the condenser increases with humidity, this effect rather acts to shorten the time contrary to the actual observation. Therefore, the observed increase of the periodic time T with humidity seems to be due to the increase of the leak of electricity along the glass wall of the neon lamp. In fact, the insulation resistance along the glass wall of the lamp was reduced with the increase of humidity—about 100 megohms for 55% and 40 megohms or less for 96% of relative humidity.

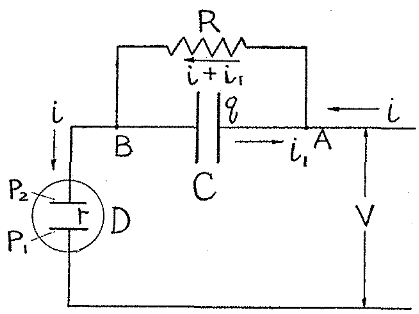
To show this fact more clearly, a high resistance R_0 was connected in parallel with the electrodes P_1 and P_2 in Fig. 1 and the periodic time of the flashes was observed. The curves in Fig. 4 represent the results obtained with various voltages and constant humidity of 65%, and show that the increase of the periodic time T was, in each case,

Fig. 4



very rapid when the shunt resistance R_0 became smaller than a certain value peculiar to the applied voltage, though the increase was very slow with greater resistance R_0. When R_0 was reduced below 2 megohms for 122 volts, 0.9 megohm for 141 volts and 0.5 megohm for 181 volts, the flashes did not appear at all. As, however, the insulation resistance along the wall of the lamp is, in general, much greater as mentioned above, it would appear that the leakage along the wall of the lamp does not play an important rôle in our problem. If this is so, the leakage of electricity through the gas in the lamp seems to be an important cause for the present problem. There is a great number of ions in the gas just after the extinction of the lamp, and the electric field between the electrodes of the lamp is compara-

Fig. 5



tively strong even in this stage, for the potential difference between the electrodes is greater than the extinction potential. Therefore, it is expected that ionization takes place in the gas up to a certain point and that the leakage of electricity through the gas is comparatively marked even after the extinction of the lamp. Thus, the resistance to leakage is never infinite, but finite though it will vary with the potential difference between the electrodes and the structural conditions of the lamp.

Now, let us assume approximately that the resistance to leakage, represented by r, is constant during the extinction of the lamp. Further suppose that the currents in the branches of the circuit, at any moment after a flash of the lamp, are i, i_1 and $i+i_1$ respectively as shown in Fig. 5 and that q is the charge of the condenser C at the time t. Then, we have

$$(i+i_1)R=q/C \qquad \text{.................................(2)}$$

and

$$\left.\begin{aligned} i_1&=-dq/dt \\ ir&=V-q/C \end{aligned}\right\} \qquad \text{.................................(3)}$$

where V is the applied voltage. By eliminating i and i_1 in the equation (2), we have a differential equation

$$V=q/C+(dq/dt+q/CR)r. \qquad \text{..................(4)}$$

The solution of the equation (4) is given by

$$\frac{CRr}{R+r}\log\left[\frac{R+r}{CRr}q-\frac{V}{r}\right]=-t+\text{const.} \qquad \text{......(5)}$$

By substituting the boundary conditions

$$q=(V-V_b)C \quad \text{for} \quad t=0 \qquad \text{.....................(6)}$$

and

$$q=(V-V_e)C \quad \text{for} \quad t=T \quad \text{(periodic time of "flashes")}$$
$$\text{.............................(7)}$$

in the equation (5), it is found that

$$T=\frac{CRr}{R+r}\log\frac{\frac{r}{R+r}V-V_b}{\frac{r}{R+r}V-V_c} \qquad \text{..............(8)}$$

If r is very great in comparison with R, the equation (8) becomes

$$T=CR\log\frac{V-V_b}{V-V_c}. \qquad \text{.........................(9)}$$

The formula (9) is the same as that obtained in the previous paper or the equation (1) in this paper.

The points marked ▲ in Fig. 2 were obtained with the formula (8) by taking r as 18.7 megohms. And it seems to the writer that this

Fig. 6

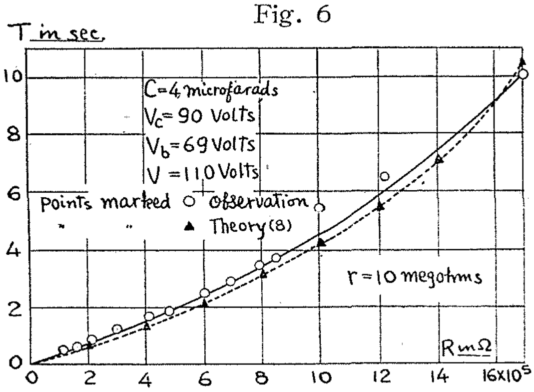
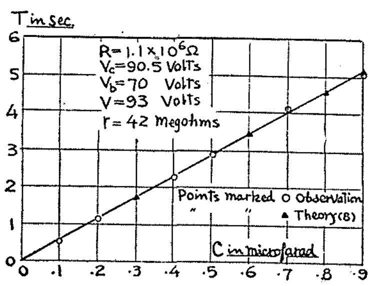


Fig. 7



theoretical curve drawn in broken line was generally in agreement with the observed one. Next, assuming that the resistance to leakage were 10 megohms and 42 megohms respectively for Figs. 3 and 4 in the previous paper, the writer plotted again the theoretical curves by means of the formula (8). From Fig. 6 and Fig. 7 obtained respectively in thus manner, it was also found that these theoretical curves were nearly in accordance with the observed ones.

In conclusion the writer wishes to express his sincere thanks to Professor U. Yoshida for the interest he has taken in this research.