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XXIX. *The Neon Tube as a Means of Producing Intermittent Currents.* By

S. O. Pearson, *B.Sc., and* H. St. G. Anson.

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ABSTRACT.

The Paper relates to an experiment in which a neon tube and a condenser in parallel are connected in series with a high resistance and source of current.

In these circumstances intermittent current is found to pass through the lamp, and the Paper discusses the conditions governing the frequency and duration of the resulting flashes.

In order to explain clearly the phenomenon to be described here it will be necessary first to consider briefly some of the chief characteristics of a neon tube. The tube consists essentially of a glass blub enclosing two metal electrodes and filled with neon gas at a low pressure. Experiments were carried out with a number of neon lamps as supplied by the General Electric Co. under the trade name of " Osglim."

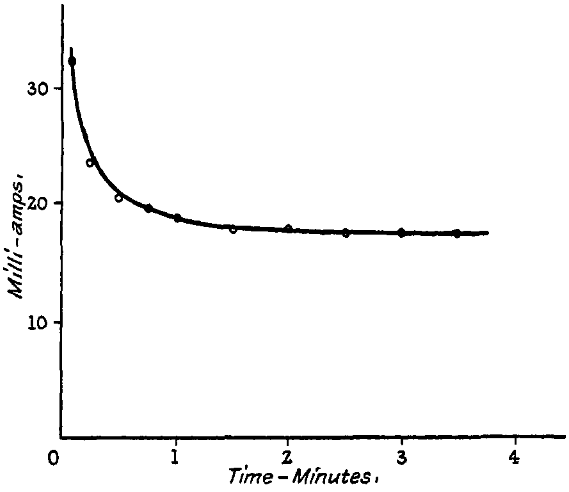

Fig. 1.—Variation of Current with Time.

In these lamps the electrodes have various shapes according to the purpose for which they are intended, *e.g.*, letters of the alphabet, &c.

When a suitable difference of potential is applied to the electrodes a discharge takes place through the gas and an orange-coloured glow is formed over the entire surface of the negative electrode or cathode. Under normal conditions the anode does not glow at all. It will be seen later that the effective resistance between the electrodes, when the lamp is glowing, decreases with increase of current; hence a steadying or ballasting resistance is connected in series and mounted inside the cap of the commercial type of lamp. In order to carry out the experiments described the resistances were removed from the caps and connected externally, thus enabling the actual difference of potential between the electrodes themselves to be measured.

When the lamp is first switched on the temperature of the gas in the bulb begins to rise, and hence its pressure increases. This may account for the fact that the current does not reach a steady value until several minutes have elapsed after first switching on. The initial value may be more than double the final steady value of the current for a given applied voltage. The curve of Fig. 1 shows how the current varied with time after first switching on with the lamp cold; the pressure across the electrodes was kept constant at 175 volts. The curve appears to be very similar in shape to an ordinary curve of cooling or " die-away " curve. It is evidently necessary to allow an interval of at least three or four minutes to elapse before measuring the current for any given voltage.

D.C. CHARACTERISTIC.

The steady current flowing through the lamp was measured for various values of the potential difference applied to the electrodes. It was found that as the voltage was gradually increased from zero, no current flowed and the lamp did not commence to glow until a value of 171 volts was reached. At this point the current suddenly increased from zero to 28·4 milliamps, and the glow was established. This critical voltage seems to be quite definite for a given temperature, but it was found that with the lamp hot after running for 15 minutes the critical voltage had risen to 179 volts. The initial value of the current at 171 volts was over 28 milliamps, but it reached a steady value of 14·7 ma. after about five minutes. The steady values of the current were obtained for increasing values of the voltage, and from the curve of Fig. 2 it will be observed that the current follows very approximately a straight line law. On reducing the voltage in stages it was found that the current did not cease to flow until the potential difference had fallen to

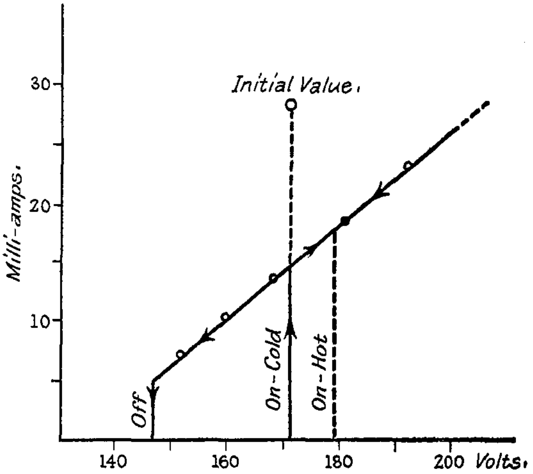

FIG. 2.—CHARACTERISTIC CURVE OF NEON TUBE.

147 volts—a figure well below the critical starting voltage. Mr. J. H. Ryde has shown that the steady current taken by the lamp is given by :—

$$I=(V-e)/\{(MA)^{-1}+R\}$$

where

V=voltage across lamp and series resistance,
e=constant (viz., the extrapolated intercept on the V-axis of the straight part of the V, I curve),
M=a constant of the order of 10^{-4}, dependent on the area and material of the electrodes and the pressure and purity of the gas,
A=area of cathode,
R=resistance fitted in series with lamp.

In order to determine the effects of temperature on the steady values of the current and on the critical values of the voltage, a lamp was immersed in water and tests made with the water at various temperatures between zero and 100°C. The curves of Fig. 3 show how the steady values of the current are dependent on the temperature—the higher the temperature the lower the current for any given voltage. Three curves are given, namely, at 200, 180 and 170 volts respectively. This seems to show that the change of current with time after first switching on is, to some considerable degree, accounted for by the rising temperature. It has been stated by some observers that this change in current with time is due to occluded impurities which are admitted in order to reduce the critical voltages and to prevent spluttering and consequent blackening of the glass ; and that if the gas be pure there is no change of current with time. This implies that temperature plays no part—a conclusion which does not seem to tally with the experimental results given.

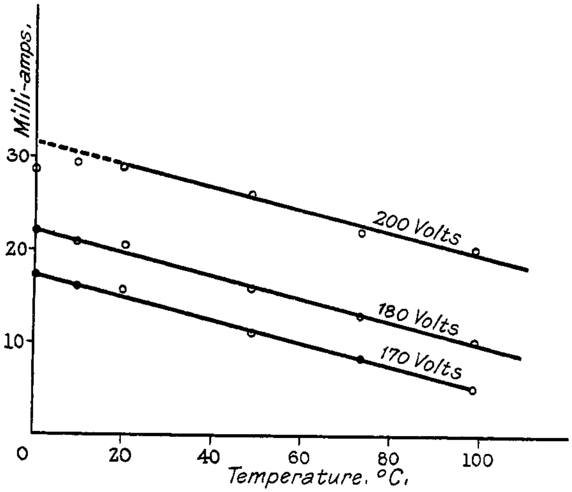

FIG. 3.—EFFECT OF TEMPERATURE ON CURRENT.

Fig. 4 shows the effect of the temperature of the surrounding medium on the upper and lower critical voltages.

FLASHING OF THE LAMP.

We have seen that no current flows until the voltage across the electrodes reaches a certain definite value ; that is, the resistance is to all intents and purposes infinitely great for all values of voltage up to the value at which the discharge through the gas commences. When a condenser of capacity K farads is connected in series with a high resistance R and a constant voltage V is suddenly applied to the ends of the circuit, the condenser will begin to acquire a charge and the voltage v across its terminals will rise according to the law $v=V\left(1-\epsilon^{-\frac{t}{KR}}\right)$, where t is time in seconds after switching on. If the lamp is connected in parallel with the condenser as in Fig. 5, it will obviously flash on as soon as the voltage across the condenser reaches the critical value at which the discharge through the gas commences. When this occurs the condenser becomes shunted by a fairly low resistance—that of the lamp—and begins to lose its charge in consequence. The lamp will continue to glow until the pressure across it and the condenser falls to the lower critical voltage at which the current through the lamp ceases. If a and b represent the upper and lower critical values respectively of the voltage, the glow

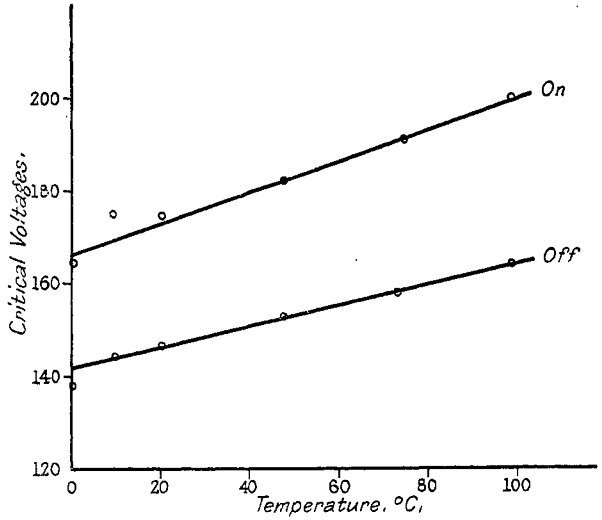

FIG. 4.—EFFECT OF TEMPERATURE ON CRITICAL VOLTAGES.

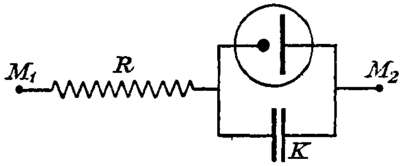

Diagram of Connections.

FIG. 5.

will last while the voltage falls from a to b. As soon as the glow ceases, the condenser charges up again from b to a, and so the process is repeated indefinitely.

By adjusting the values of R and K the frequency of flashing can be varied over a very wide range. The authors have obtained frequencies as low as one flash in several minutes and so high as to be above the range of audibility. The audible frequencies of flashing are best detected by means of a telephone connected in the condenser branch circuit.

CALCULATION OF PERIODIC TIME.

The dark period lasts whilst the condenser is charging up from the voltage b to the voltage a. This is quite easily calculated if we know definitely the values of a and b. There is no difficulty in measuring a experimentally, since the gas is quite cool when the glow commences; but in the case of the lower critical voltage b, a difficulty arises—the duration of the light period is a very small fraction of a second; in fact, in some cases it may only last for one-millionth of a second. We shall see later that the light period is very short compared to the dark period and hence there is very little heating effect on the gas when the lamp is flashing, which means that the gas is still cool when the light period comes to an end. To measure the lower critical voltage experimentally it is necessary to reduce the applied voltage gradually with the lamp glowing, which allows the gas to heat up; and so the true value with the gas cool cannot be obtained.

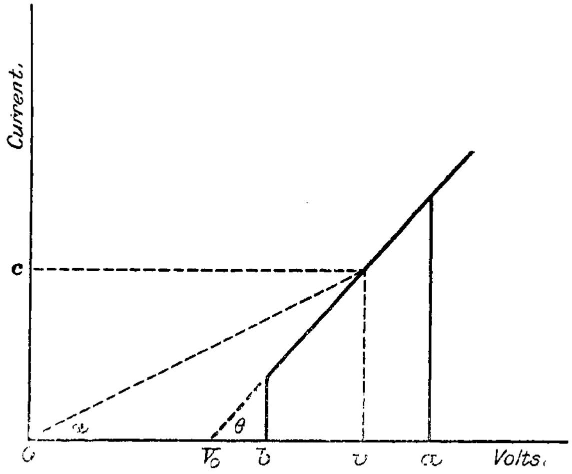

FIG. 6.—TYPICAL CHARACTERISTIC CURVE.

The time of one dark period differs from the time of one complete cycle by much less than 1 per cent. Hence, if the time of one complete cycle is measured it is possible to calculate the lower critical voltage very approximately.

Let T_1=duration of one dark period

=time for condenser to charge from b to a,

then

$$T_1 = KR \log (V-b)/(V-a) \quad \ldots\ldots \quad (1)$$

In a particular case the values were as follows :—

$$\begin{aligned} T_1 &= 0{\cdot}83 \text{ sec.} \\ K &= 1{\cdot}0 \text{ microfarad} \\ R &= 10^6 \text{ ohms} \\ V &= 200 \text{ volts} \\ a &= 171 \text{ volts} \end{aligned}$$

from which we get :—

Lower critical voltage, $b=139{\cdot}6$ volts.

In order to calculate the duration of one light period it is necessary to know how the resistance of the glowing lamp varies with the voltage across the electrodes. Fig. 6 shows a typical characteristic curve, and from it we can deduce an expression for the resistance in terms of voltage across the electrodes. Put

$$\begin{aligned} \cot \theta &= r' \\ &= (v-v_0)/c \end{aligned}$$

Now $c=v/r$, where $r=$ effective resistance of lamp.

Therefore $$r' = r(v-v_0)/v$$

and $$r = v \,.\, r'/(v-v_0) \text{ ohms.}$$

We are now in a position to find the duration of one light period.

Let v=voltage across the condenser at any time t seconds after commencement of flash. When $t=o,\ v=a.$

Charging current from supply and flowing through R

$i_1=(V-v)/R$, where $V=$ constant applied voltage.

Current flowing through lamp

$$\begin{aligned} i_2 &= v/r \\ &= (v-v_0)/r' \end{aligned}$$

Resultant current flowing from condenser, or rate of discharge

$$\begin{aligned} i &= i_2 - i_1 \\ &= (v-v_0)/r' - (V-v)/R \\ &= v(1/R+1/r') - (V/R+v_0/r') \end{aligned}$$

Also rate of discharge

$$i = -\frac{dq}{dt} = -K\frac{dv}{dt}$$

Hence $$\frac{dv}{dt} + \frac{1}{K}\,(1/R+1/r')v - \frac{1}{K}\,(V/R+v_0/r') = 0,$$

the solution of which is

$$v = \frac{Vr' + v_0 R}{R+r} + A e^{-\frac{R+r'}{KRr'}t},$$

where A is a constant which can be determined from the initial conditions, viz., when $t=0$, $v=a$.

Hence
$$A=-\frac{Vr'+v_0R}{R+r'}$$

Therefore voltage across lamp at any time t after commencement of flash is
$$v=\frac{Vr'+v_0R}{R+r'}\left(1-\varepsilon^{-\frac{R+r'}{KRr'}t}\right)+a\varepsilon^{-\frac{R+r'}{KRr'}t}$$

Let
$$\frac{Vr'+v_0R}{R+r'}=Q$$

Then
$$v=Q+(a-Q)\varepsilon^{-\frac{R+r'}{KRr'}t}$$

When v falls to b,
$$t=T_2=\text{duration of light period.}$$

Therefore
$$b=Q+(a-Q)\varepsilon^{-\frac{R+r'}{KRr'}T_2}$$

or
$$T_2=\frac{KRr'}{R+r'}\log\frac{a-Q}{b-Q} \quad \ldots\ldots\ldots\ldots \quad (2)$$

where
$$Q=\frac{Vr'+v_0R}{R+r'}$$

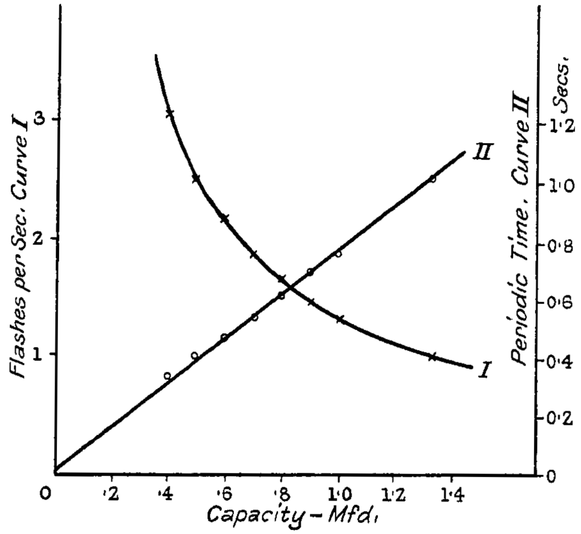

FIG. 7.—VARIATION OF FREQUENCY WITH CAPACITY.

In the case considered above the duration of the light period worked out at about 0·002 second.

The total time of one complete period is equal to the sum of the times of the dark and light periods respectively.

That is,
$$T=T_1+T_2$$
$$=KR\left\{\log\frac{V-b}{V-a}+\frac{r'}{Rr'}\log\frac{a-Q}{b-Q}\right\}$$

We see from the above that the time of one complete cycle is directly proportional to the capacity in parallel and the resistance in series with the lamp. This was proved experimentally, and in Fig. 7 curves are given showing how the periodic time and its reciprocal, the number of flashes per second, vary with change of capacity. Change of applied E.M.F. also affects the periodic time, and two curves are shown in Fig. 8. In both cases the series resistance was 1 megohm, but two different capacities, namely, 1 microfarad and 1·333 microfarads, were used. It will be noticed that the lower part of each curve is drawn dotted and made to meet the V-axis at 171 volts. This is obviously the case, for when the voltage is below 171, *i.e.*, below the critical starting voltage, no flashing can possibly occur.

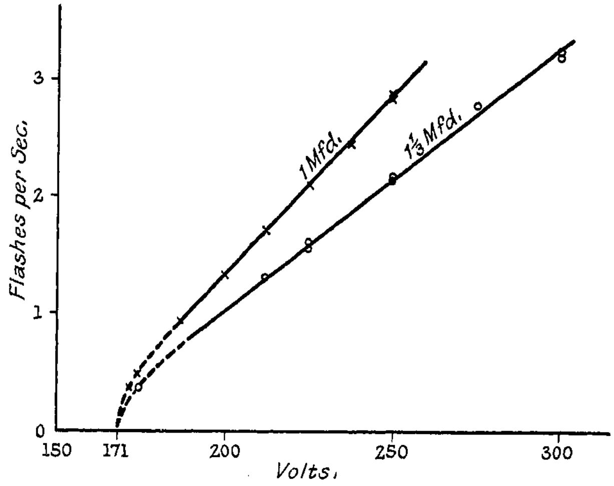

FIG. 8.—VARIATION OF FREQUENCY WITH APPLIED VOLTAGE.

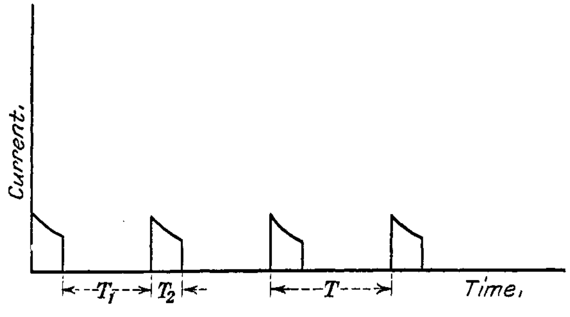

FIG. 9.—WAVE SHAPE OF INTERMITTENT CURRENT.

From a consideration of the laws of charge and discharge of a condenser, in conjunction with the characteristic curve of a neon tube, it follows that the wave-shape of the intermittent current obtained from such an arrangement will be somewhat as shown in Fig. 9. This may possibly be modified by insertion of inductance or by including a tuned or resonant circuit for any particular frequency.

The device which has been described here provides a very simple means of producing intermittent currents without the use of any moving mechanism or contacts, and should prove particularly useful over the audible range of frequencies.

There is no doubt that the three-electrode thermionic valve provides the most satisfactory means of generating very high or radio frequencies, but in order to get an audio frequency current from a thermionic valve, very costly apparatus is necessary, whereas, with the flashing neon lamp the apparatus is extremely simple and inexpensive.

Among the suggested possible uses of the arrangement are :—

(1) Audio frequency—Telephonic measurements.
Stroboscopic measurements.

(2) High frequency—Radio communication and measurements.