Experiment No. 21(B)

Object : *To study the charge and discharge of a condenser through a high resistance and hence to determine the time constant of C-R circuit.*

Apparatus required : A d. c. power supply (0—300 volt), seven paper condensers (each of capacity 0·5 μF), six carbon resistances (each of resistance 1 MΩ), a neon bulb (which is used in a line tester), stop watch, connection wires.

Description of the Apparatus : Fig. 78 shows the electric circuit used in the experiment. It consists of all the condensers (of capacity 0·5 μF each) connected in parallel through switches

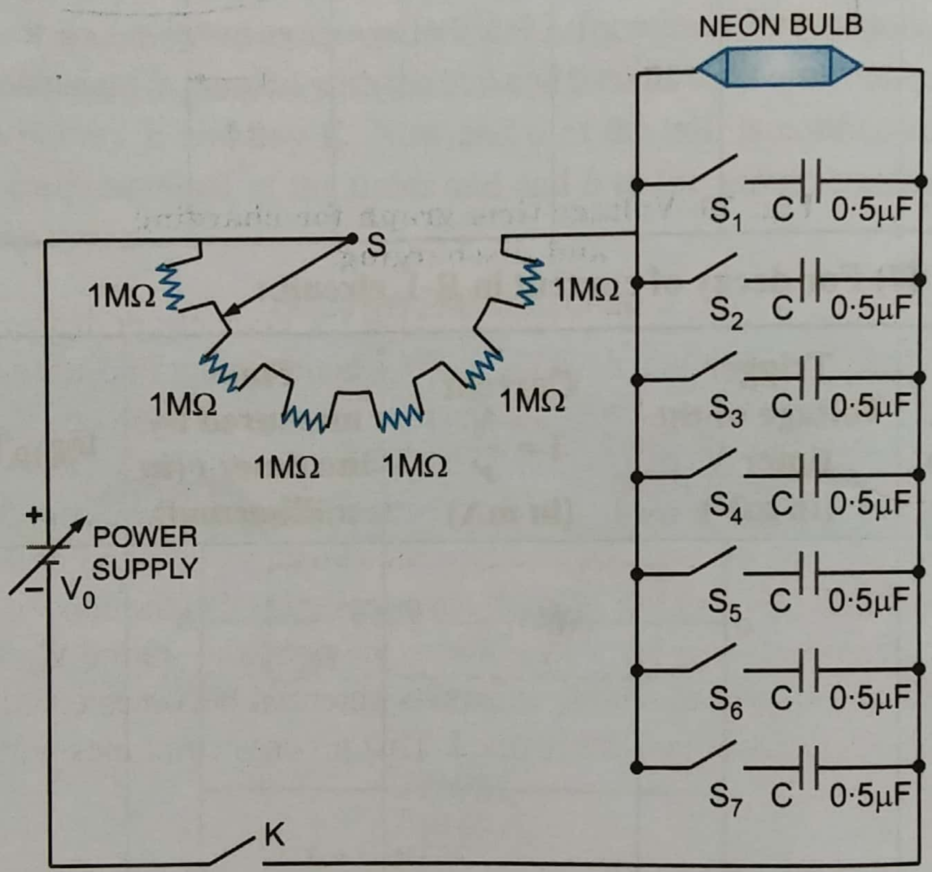

Fig. 78. Electric circuit for charging and discharging of a condenser

$S_1, S_2, ... S_7$. With these switches, the capacity in the circuit can be changed in steps of 0·5 μF. With this combination of condensers, all the resistances (each 1 MΩ) are connected in series. Through the dial switch S, the resistance in circuit can be changed in steps of 1 mega-ohm. Switch S is connected to the power supply. The output voltage of power supply can be changed from 0 to 300 volt. The other terminal of power supply is connected to the other terminals of condensers through a switch K. A neon bulb is connected across the two terminals of condensers.

Theory : When a condenser of capacity C is charged through a resistance R with a d. c. source of voltage V_0, the charge at any

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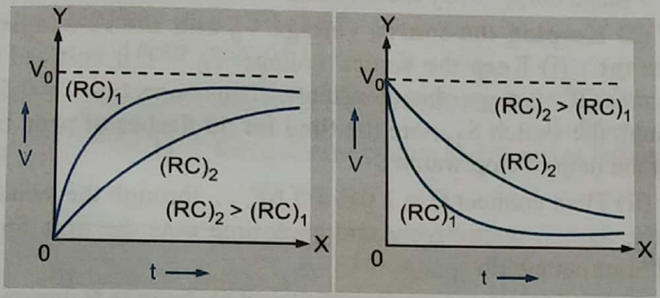
instant, on the plate of condenser is $Q = Q_0 (1 - e^{-t/RC})$ where Q_0 is the maximum charge ($= CV_0$).

Similarly when a charged condenser is discharged through a resistance R, the charge at any instant is $Q = Q_0 e^{-t/RC}$.

Thus the rate of charging and discharging both depend on the value of the quantity RC. This quantity is called *time constant* of the circuit.

If t = RC, then during the charging $Q = Q_0 (1 - e^{-1}) = 0{\cdot}63 Q_0$ and during the discharge $Q = Q_0 e^{-1} = 0{\cdot}37\ Q_0$. Larger the time constant of a circuit, slower is the rate of charging or discharging.

Since V = Q/C, hence during the charging, potential difference across the ends of condenser is $V = V_0 (1 - e^{-t/RC})$, while during the discharging, the potential difference across the ends of condenser is $V = V_0 e^{-t/RC}$. Fig. 79. (a) shows the variation of potential with time during charging and Fig. 79. (b) shows the variation of potential with time during discharging.



(a) (b)

Fig. 79. Voltage-time graph for charging and discharging

Now if a neon bulb is connected at the ends of condenser as shown in Fig. 80, then during charging as the potential difference across the condenser becomes equal to the striking voltage V_s of the neon bulb, the condenser gets discharged through the neon bulb and in time interval T_0, its potential reduces to the extinction voltage V_E of the neon bulb. Since the resistance of neon bulb is very high (≈ 2000 ohm), hence it can be assumed that the condenser discharges very rapidly. Again due to the potential source V_0, the condenser begins to charge and as its potential becomes equal to V_s, the condenser gets discharged. This process continues with a time interval T.

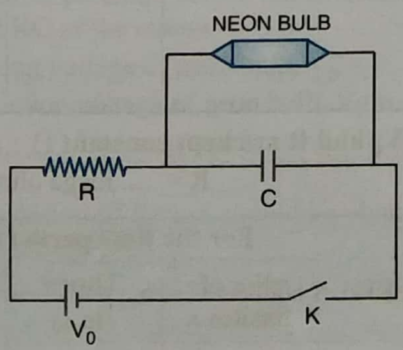


Fig. 80. C-R circuit with a d.c. source

Fig. 81 shows the charging and discharging of the condenser. Here the following two cases are possible :

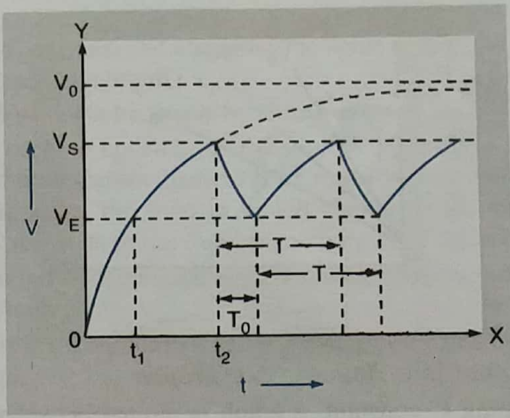


Fig. 81. Charging and discharging of condenser through a neon bulb

Case (1) : When the source voltage V_0 is constant and the time constant RC of the circuit is variable

If t_1 and t_2 be the time in which the potential difference across the condenser rises to V_E and V_S respectively, during charging then

$$V_E = V_0 (1 - e^{-t_1/RC})$$

and $$V_S = V_0 (1 - e^{-t_2/RC}) \quad \text{...(i)}$$

$$\therefore \quad -\log_e\left(\frac{V_0 - V_E}{V_0}\right) = \frac{t_1}{RC}$$

and $$-\log_e\left(\frac{V_0 - V_S}{V_0}\right) = \frac{t_2}{RC}$$

or $$\frac{t_2 - t_1}{RC} = -\log_e\left(\frac{V_0 - V_S}{V_0}\right) + \log_e\left(\frac{V_0 - V_E}{V_0}\right)$$

$$= \log_e\left(\frac{V_0 - V_E}{V_0 - V_S}\right)$$

But from Fig. 81, $t_2 - t_1 = T - T_0$

Hence $$T - T_0 = RC \log_e\left(\frac{V_0 - V_E}{V_0 - V_S}\right) \quad \text{...(ii)}$$

or $$T = KRC + T_0$$

where $$K = \log_e\left(\frac{V_0 - V_E}{V_0 - V_S}\right) \quad \text{...(iii)}$$

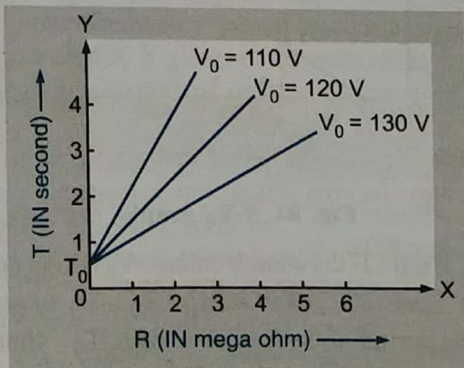


Fig. 82. T–R graph

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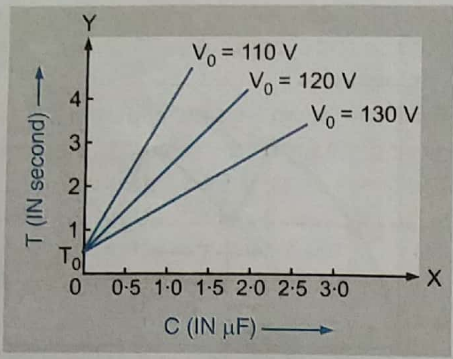

Fig. 83. T–C graph

If keeping C constant, a graph is plotted between R and T (Fig. 82) or keeping R constant, a graph is plotted between C and T (Fig. 83), the graph in both cases will be a straight line, the length of intercept by which on T-axis is T_0. [Remember that if $T_0 = 0$, it implies that the resistance of neon bulb is nearly infinite]. The slope of the straight line depends on the source voltage V_0. Larger the value of V_0, less is the slope.

Case (2) : When the time constant of the circuit RC is constant and the source voltage V_0 is variable

From eqn. (ii),

$$e^{(T-T_0)/RC} = \left(\frac{V_0 - V_E}{V_0 - V_S}\right) = 1 + \frac{V_S - V_E}{V_0 - V_S}$$

$$\therefore \quad V_0 - V_S = (V_S - V_E)\,[e^{(T-T_0)/RC} - 1]^{-1}$$

Let $K' = V_S - V_E$ and $Y = [e^{(T-T_0)/RC} - 1]^{-1}$

Then $\quad V_0 - V_S = K'Y$

or $\quad V_0 = K'Y + V_S$

or $$Y = \frac{1}{K'} V_0 - \frac{V_S}{K'} \qquad \text{...(iv)}$$

It is clear from eqn. (iv) that if a graph is plotted between V_0 and Y, we get a straight line (Fig. 84). The length of intercept on V_0 axis by the straight line is V_S and slope of the straight line is

$$s = \frac{1}{K'} = \frac{1}{V_S - V_E}$$

Thus the values of V_S and V_E can be calculated.

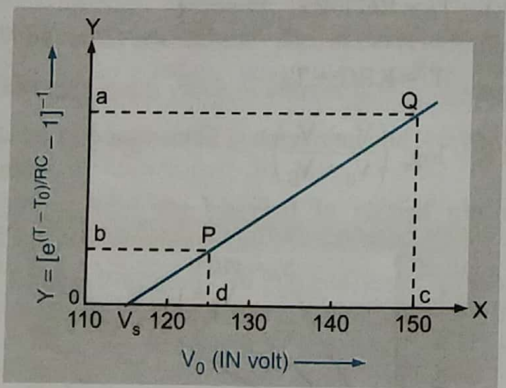

Fig. 84. Y-V_0 graph

Formula Used : If the source voltage V_0 is kept constant, then

$$T = KRC + T_0$$

where T = time period of flash of neon bulb, T_0 = time interval of discharge of condenser, C = capacity of condenser, R = resistance, and K is a constant.

If the source voltage V_0 is variable, then

$$V_0 = K'Y + V_S \text{ or } Y = \frac{1}{K'}(V_0 - V_S)$$

where $K' = V_S - V_E$ and $Y = [e^{(T-T_0)/RC} - 1]^{-1}$

Here V_S = striking voltage of neon bulb and V_E = extinction voltage of neon bulb.

Procedure : First the electric circuit shown in Fig. 78 is completed and the least count of stop watch is noted.

Now the experiment is performed in following three steps :

(1) Keeping the source voltage V_0 and capacitance C constant : (i) The source (power supply) voltage V_0 is kept at 110 volt and the value of C is kept 0·5 μF through the switch S_1 (by connecting the banana plug). Then the value of R is kept 1 mega ohm by the switch S and time for 50 flashes of neon bulb is noted with the stop watch.

(ii) The experiment is repeated by increasing the resistance R in steps of 1 mega ohm *i.e.,* by keeping R = 2 mega ohm, R = 3 mega ohm, ... by the switch S.

(2) Keeping the source voltage V_0 and the resistance R constant : (i) Keep the source voltage V_0 = 110 volt and the resistance R = 2 mega ohm (constant). Then connecting C = 0·5 μF through the switch S_1, note the time for 50 flashes of neon bulb with the help of stop watch.

(ii) Then connect C = 1 μF, 1·5 μF, ... through the switches S_2, S_3, S_4, ... respectively and each time note the time for 50 flashes of neon bulb.

(3) Keeping the capacitance C and resistance R constant: (i) First keep the resistance R = 4 mega ohm and C = 2 μF (constant). Now keep the source voltage V_0 = 110 volt, note the time for 50 flashes of neon bulb with the help of stop watch.

(ii) Then keep V_0 = 120 volt, 130 volt, ... respectively and each time note the time for 50 flashes of neon bulb.

Observations : Least count of stop watch = ... s.

(1) When V_0 and C are kept constant :

C = ... μ F, V_0 = ... volt

S. No.	R (in mega ohm)	For the time period of flashes		
		No. of flashes *n*	Time *t* (in s)	Time period T = *t*/*n* (in s)
1.				
2.				
3.				

(2) When V_0 and R are kept constant :

R = ... mega ohm, V_0 = ... volt

S. No.	C (in μ F)	For the time period of flashes		
		No. of flashes *n*	Time *t* (in s)	Time period T = *t*/*n* (in s)
1.	0·5			
2.	1·0			
3.	1·5			

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(3) When R and C are kept constant :

R = ... mega ohm, C = ... μF

S. No.	V_0 (in volt)	For the time period of flashes		
		No. of flashes *n*	Time *t* (in s)	Time period $T = t/n$ (in s)
1.	110			
2.	120			
3.	130			

Calculations : (1) From the first observation table, a graph is plotted by taking T on Y-axis and R on X-axis which is a straight line as shown in Fig. 82. The length of intercept of straight line on the T-axis is noted.

Intercept on T-axis, T_0 = ... s

(2) From the second observation table, a graph is plotted by taking T on Y-axis and C on X-axis which is a straight line as shown in Fig. 83. The length of intercept of straight line on the T-axis is noted.

Intercept on T-axis, T_0 = ... s

Mean value of T_0 = ... s

(3) From the third observation table, calculate RC, $\frac{T - T_0}{RC}$ and $Y = [e^{(T - T_0)/RC} - 1]^{-1}$ for each observation and record as follows :

RC = ...S

S. No.	V_0 (in volt)	T (in s)	$\frac{T - T_0}{RC}$	$Y = [e^{(T - T_0)/RC} - 1]^{-1}$
1.	110			
2.	120			
3.	130			

Now a graph is plotted between Y and V_0 which is a straight line as shown in Fig. 84. The length of intercept of the straight line on V_0 axis is noted and the slope of straight line is found.

Intercept on V_0 axis, V_S = ... volt

Slope of straight line $s = \frac{ab}{cd}$ = ...

Hence $V_S - V_E = \frac{1}{s}$ = ... volt.

∴ $V_E = V_S - \frac{1}{s}$ = ... volt

Result : (1) From the third observation table, it is clear that the rate of growth of potential across the condenser depends on the time constant RC of the circuit.

(2) The striking voltage of neon bulb, V_S = ... volt.

(3) The extinction voltage of neon bulb, V_E = ... volt.

Precautions : (1) The stop watch should be sensitive up to 0·1 s.

(2) The time period of flashes should be obtained by noting the time for at least 50 flashes.

(3) The time constant of the circuit must be in between 0·5 s and 15·0 s.

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