

Transient Response of RC circuit

Object. To study charging and discharging of a capacitor C through a resistor R and to find the time constant of the RC circuit.

Apparatus. Resistors and capacitors (of required values), ammeter and voltmeter (of required range), battery, power supply, stopwatch and connection leads.

Theory. A capacitor stores charge on it. The charging rate of capacitor C is controlled by a series resistor R. The product of R & C is called the time constant of the circuit. Such RC combinations are widely used in electronic circuits as for example filter circuits oscillators, integrators & differentiators etc.

On charging a capacitor C by a DC source of voltage V_0 through a series resistor R, the charge q on capacitor at time t is given by following exponential relation:

$$q = q_0 (1 - e^{-t/RC}) \dots\dots\dots (1)$$

where, RC is known as the time constant of the circuit and q_0 is the maximum charge on the capacitor. If instant voltage on capacitor at time t is V_t then $q = CV$ and $q_0 = CV_0$. Therefore, equation (1) in voltage form for experimental test becomes as given below:

$$V = V_0 (1 - e^{-t/RC}) \dots\dots\dots (A_1)$$

The instant current $i = dq/dt$, therefore the equation (1) gives the exponential variation of charging current by following relation:

$$i = i_0 e^{-t/RC} \dots\dots\dots (B_1)$$

where, $i_0 = V_0 / R$.

In the process of discharging the capacitor C through a resistor R, equations 1, A₁ & B₁ assume the following forms:

$$q = q_0 e^{-t/RC} \dots\dots\dots (2)$$

$$V = V_0 e^{-t/RC} \dots\dots\dots (A_2)$$

$$i = i_0 e^{-t/RC} \dots\dots\dots (B_2)$$

On the above basic relations, the exponential build up and the decay of voltage V and current i are experimentally studied by using circuits shown in fig. 1(a) and 1(b) respectively.

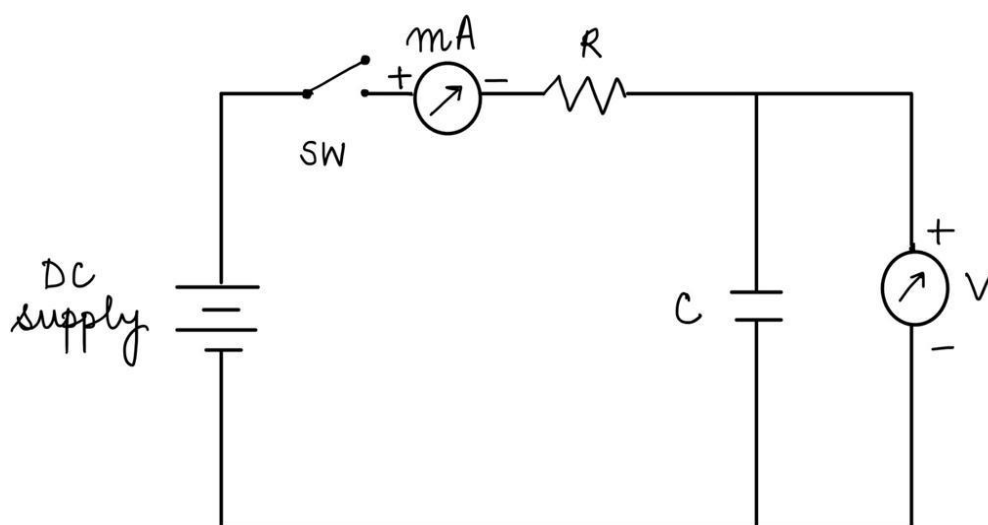


Fig. 1 (a) Transient (V, τ) response of C on charging.

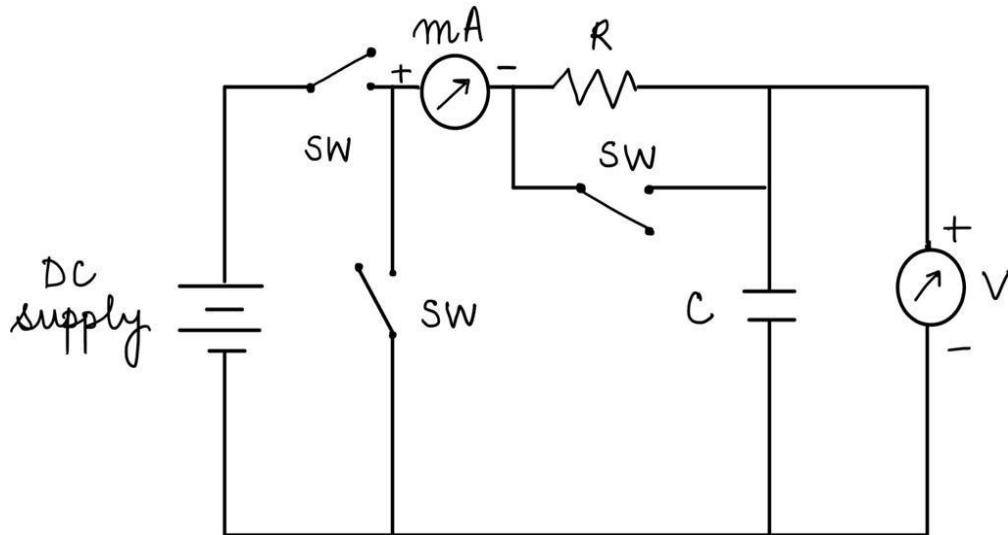


Fig. 1 (b) Transient (V, τ) response of C on discharging.

The condition $t = RC$ on substitution in relation (A_1) gives:

$$\frac{V}{V_0} = 1 - \frac{1}{e} = 1 - \frac{1}{2.718} = 0.63 \dots\dots (a_1)$$

This means that in process of charging V becomes 0.63 of V_0 in time $t = RC$. Similarly, relation (B_1) for condition $t = RC$ gives:

$$\frac{i}{i_0} = \frac{1}{e} = \frac{1}{2.718} = 0.37 \dots\dots (b_1)$$

This means that transient current $i = 0.37$ of i_0 in time $t = RC$ seconds. The relations (A_1, B_1) and the resulting relations (a_1, b_1) at $t = RC$ further show that while transient voltage increases exponentially the transient current decreases exponentially. In this way, the two variations are complementary.

However, relations A_2 & B_2 for exponential discharge of C through R gives following values at $t = RC$:

$$\frac{V}{V_0} = \frac{1}{e} = \frac{1}{2.718} = 0.37 \dots\dots (a_2) \text{ (From relation } A_2)$$

$$\frac{-i}{i_0} = -\frac{1}{e} = -\frac{1}{2.718} = -0.37 \dots\dots (b_2) \text{ (From relation } B_2)$$

The relation (a_2) shows that V becomes 0.37 of V_0 in time $t = RC$ and relation (b_2) shows that i becomes -0.37 of i_0 in time $t = RC$. Note the reverse direction of current i indicated by -ve sign.

The product $RC = \text{time constant}$ in seconds for R in Ω and C in F . Thus, knowing the values of R & C , the value of RC is calculated in seconds by the following relation:

$$R (\Omega) \cdot C (F) = RC (\text{seconds})$$

These values are experimentally tested by plotting graphical variation between V & t and i & t and using relations a_1 , b_1 and a_2 , b_2 .

Procedure. (Not to be written in copy)

In this experiment only the variation of voltage V with time t has been studied with respect to charging of capacitor C through resistor R and discharging of capacitor C through resistor R .

A. The charging of C through R: Variation of voltage V with time t

- **Keep the power switch and switches from SW1 to SW5 in off position.**
- **The press switch SW6 is meant to discharge a capacitor (C_1 or C_2). For this process switch off SW2 and press SW6 for about 5 seconds before taking a fresh reading.**

1. Connect terminals 1-1, 2-2_{R1}, 3_{R1}-3_{C1}, 4-4_{C1} and 5-5 (for $R_1 = 10\text{ k}\Omega$ and $C_1 = 2000\text{ }\mu\text{F}$). Now switch on the power supply.
2. Set the switch SW1 at 10 V. Keep a stopwatch ready to record time t in seconds for suitable increasing readings in voltmeter.
3. Switch on SW2 and keep **SW4 in off position**. Start the stopwatch at the same instant. This gives the voltage reading $V = 0$ at $t = 0$. Record the values of voltage V at suitable intervals of time t (say 10 sec) as shown in table given below.
4. Repeat steps 1-3 for other values of resistance and capacitance (for $R_2 = 20\text{ k}\Omega$ and $C_1 = 2000\text{ }\mu\text{F}$) by connecting terminals 2-2_{R2} and 3_{R2}-3_{C1}.

Least count of stopwatch = sec

Least count of voltmeter = V

S. No.	$R_1 = 10\text{ k}\Omega$, $C_1 = 2000\text{ }\mu\text{F}$		$R_2 = 20\text{ k}\Omega$, $C_1 = 2000\text{ }\mu\text{F}$	
	Time t (sec)	Voltage V (V)	Time t (sec)	Voltage V (V)

5. Take time t seconds on X-axis and voltage V on Y-axis and plot variations by using above table on the same graph as shown.

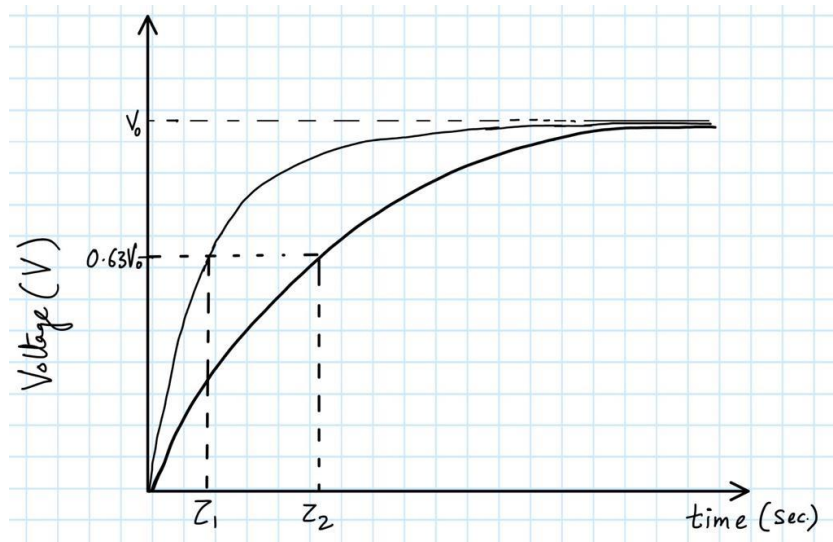


Fig. 2 (a) Charging of a capacitor through R.

6. Calculate the value of time constant RC in seconds by substituting R in Ω and C in F for different RC combinations used. Experimentally determine the value of time constant in seconds from graphic variations. For this note the value of t corresponding to 0.63 of V_0 . In present case, $V_0 = 10 \text{ V}$.

7. To find the value of time constant, label the voltage $V = 0.63$ of V_0 on Y- axis and note the corresponding value of time ($t = \tau_1$ & τ_2) in seconds on X-axis. This gives the value of time constant for the variations.
8. Record calculated values of time constant RC and the corresponding experimental values as per steps 6 & 7 in the following tabular form.

S. No.	Calculated time constant τ_{cal}			Experimental time constant τ_{exp}	Difference $\Delta =$ $\tau_{cal} - \tau_{exp}$
	R (Ω)	C (F)	RC (sec)		

B. The discharging of C through R: Variation of voltage V with time t

- Keep the power switch and switches from SW1 to SW5 in off position.
 - The press switch SW6 is meant to discharge a capacitor (C_1 or C_2). For this process switch off SW2 and press SW6 for about 5 seconds before taking a fresh reading.
1. Connect terminals 1-1, 2-2_{R1}, 3_{R1}-3_{C1}, 4-4_{C1} and 5-5 (for $R_1 = 10\text{ k}\Omega$ and $C_1 = 2000\text{ }\mu\text{F}$). Now switch on the power supply.
 2. Set the switch SW1 at 10 V. Keep a stopwatch ready to record time t in seconds for suitable increasing readings in voltmeter.

- Record the maximum voltage reading (about 10 V) and then switch off SW2 and SW4. Now switch on SW3 and start the stopwatch at the same instant. This gives the voltage reading $V = 10 \text{ V}$ at $t = 0$. Record the values of decreasing voltage V at suitable intervals of time t (say 10 sec) as shown in table given below.

- Least count of stopwatch = sec**

Least count of voltmeter = V

[illegible]

5. Take time t seconds on X-axis and voltage V on Y-axis and plot variations by using above table on the same graph as shown.

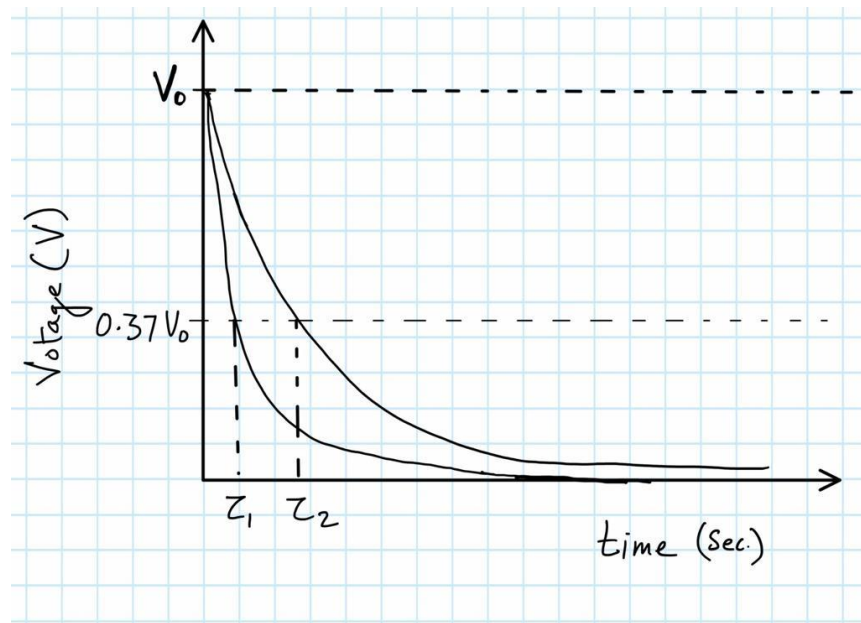


Fig. 2 (b) Discharging of a capacitor through R .

6. Calculate the value of time constant RC in seconds by substituting R in Ω and C in F for different RC combinations used. Experimentally determine the value of time constant in seconds from graphic variations. For this note the value of t corresponding to 0.63 of V_0 . In present case, $V_0 = 10 \text{ V}$.
7. To find the value of time constant, label the voltage $V = 0.63$ of V_0 on Y- axis and note the corresponding value of time ($t = \tau_1$ & τ_2) in seconds on X-axis. This gives the value of time constant for the variations.

8. Record calculated values of time constant RC and the corresponding experimental values as per steps 6 & 7 in the following tabular form.

S. No.	Calculated time constant τ_{cal}			Experimental time constant τ_{exp}	Difference $\Delta =$ $\tau_{cal} - \tau_{exp}$
	R (Ω)	C (F)	RC (sec)		

Result. The variation of voltage V with time t has been shown graphically.

The difference in the time constant Δ is:

- i. ($R_1 = 10 \text{ k}\Omega$, $C_1 = 2000 \text{ }\mu\text{F}$)
- ii. ($R_2 = 10 \text{ k}\Omega$, $C_1 = 2000 \text{ }\mu\text{F}$)

Precautions.

- The switches used for charging and discharging the capacitor should be pressed carefully.
- Make sure to discharge the capacitor fully while taking the readings for charging. In the same way, charge the capacitor fully while taking the readings for discharging.
- The stopwatch should be used with precision.
- Readings should be taken at small intervals and large no. of readings should be taken.

Viva – Voce

Q. Define capacitor.

Ans. A capacitor is a two terminal device that store energy in the form of electric field.

Q. Define electric charge.

Ans. Electric charge is the physical property of particles such as electrons and protons which causes them to experience attractive or repulsive force.

Q. Define capacitance.

Ans. The ability of an object to store electric charge is called capacitance.

Q. What is the SI unit of capacitance?

Ans. Farad (F)

Q. What is the basic construction of a capacitor?

Ans. A basic capacitor is made of two electrodes separated by a dielectric medium or material. The electrodes or conductive plates are good conductors of electricity. Hence, they easily allow electric current through them. The dielectric medium or material present between the conductive plates is poor conductor of electricity. Hence, it does not allow electric current through it. The electric charges that try to move from one plate to another plate will be trapped within the electrode or plate because of the strong opposition from the dielectric. As a result, electric charge is builds up on the electrodes.

Q. When does the capacitor starts charging?

Ans. When voltage is applied to the capacitor, it starts charging.

Q. When does the capacitor stops charging?

Ans. When external voltage source is removed from the circuit, the capacitor stops charging. However, the electric charge stored in the capacitor cannot be removed unless it is connected to an external device.

Q. When does the capacitor starts discharging?

Ans. When capacitor is connected to any device such as electric bulb, it starts discharging.

Q. What is discharging of a capacitor?

Ans. The charge stored within the capacitor being released during discharging.

Q. What is the role of a dielectric in a capacitor?

Ans. When a dielectric is placed between the two conducting plates of the capacitor it will decrease the effective potential on the two plates and hence the capacitance of the capacitor increases.

Q. What is the form of energy that gets stored in a capacitor?

Ans. Electric potential energy is stored in a capacitor.

Q. What does the rate of charging and discharging of a capacitor depend upon?

Ans. The rate of charging and discharging of a capacitor depends upon the capacitance of the capacitor and the resistance of the circuit through which it is charged.

Q. What do you mean by time constant?

Ans. Time constant of the circuit is the time in which charge on the condenser rises to 0.63 times its maximum value during charging or the time in which charge on the condenser falls to 0.37 times its initial maximum charge during discharging.

Q. What is the unit of time constant? What is the value?

Ans. The unit of time constant is second. Time constant = RC .

Q. How does the rate of charging or discharging of condenser depend on time constant?

Ans. Smaller the time constant of the circuit, faster is the rate of charging or discharging of condenser. i.e., the rate of charging or discharging of condenser is inversely proportional to the time constant of the circuit.

Q. How are the condensers connected in your experiment?

Ans. The condensers are connected in parallel (because the capacity must be increased one by one).

Q. How are the resistances connected?

Ans. The resistances are connected in series (because the resistance must be increased one by one).

Q. In your experiment, the charging of condenser is with which resistance and discharging is with which resistance?

Ans. The charging of condenser is with the resistance connected in the circuit while discharging is with the resistance of load.