Capacitor charging and discharging

- **What is capacitor?**

  It is an electric component which stores electric charge. It consists of two plates, one for storing positive charge another for storing negative charge. The capacity of a capacitor to store charge is measured in terms of capacitance.

- **What is capacitance of a capacitor?**

  The capacitance of a capacitor is the measure of amount of charge it can store per unit voltage. Denoted C.

  $$\boxed{C = \frac{Q}{V}} \tag{1}$$

  SI unit: farad or F.

- **Define 1 farad of capacitance.**

  When potential difference (voltage) across the capacitor is 1 V and if it stores 1 C of charge then the capacitance is said to be 1 F.

- **What is a dielectric material?**

  Dielectric material or simply a dielectric is an insulating medium (does not have free charge carriers). When an electric field is applied to a dielectric, the charges in the material are displaced creating an electric dipole moment.

- **Define dielectric constant.**

  It is amount by which the capacitance of a capacitor increases when a dielectric material is introduced between the capacitor plates.

  If C is the capacitance without the dielectric. After the dielectric with dielectric constant ϵ_r is introduced the capacitance becomes $\epsilon_r C$.
  It is also called relative permittivity. It has no units.

- **What is the aim of the experiment?**

  To determine the capacitance of the capacitor and the dielectric constant of the material of the capacitor.

- **How is capacitance of a parallel plate capacitor related to its dimensions?**

  $$\boxed{C = \frac{\epsilon_r \epsilon_0 A}{d}}, \tag{2}$$

  where ϵ_r is dielectric constant,
  ϵ_0 is permittivity of free space,
  A is area of capacitor plate,
  d is the distance between plates.

  In the absence of any dielectric medium, the formula becomes

  $$C = \frac{\epsilon_0 A}{d}.$$

- **What does the introduction of dielectric do to capacitance?**

  It increases. $C = \epsilon_r C_0$, Capacitance without dielectric $C_0 = \frac{\epsilon_0 A}{d}$.

- **What does the introduction of dielectric do to voltage across capacitor?**

  It decreases. $\left(\frac{Q}{V\downarrow} = C\uparrow\right)$
- **What does the introduction of dielectric do to charge on the capacitor?**

  It increases. $\left(\frac{Q\uparrow}{V} = C\uparrow\right)$
- **Explain charging of a capacitor.**

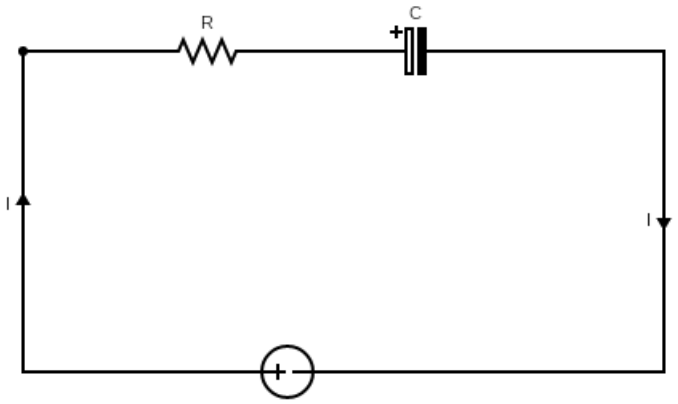

Figure 1: Circuit diagram showing charging of capacitor

When the battery (DC source) is connected to an uncharged capacitor, the electrons in the wire move from negative of the battery towards the positive of the battery (the direction of current is opposite to the flow of electrons). The electrons get deposited on one of the capacitor plates (shaded black). See figure (1). There is no conducting medium between one capacitor plate and the other. The other plate gets positive charge due to repulsion of electrons from the negatively charged plate. The electrons reach the positive of the battery from the positive plate of capacitor. As the capacitor charges, the charge on the capacitor increases, also the voltage across it. This process continues as long as capacitor can hold charges. Ones, the capacitor cannot store anymore charge, the capacitor stops charging and the current in the circuit becomes zero.

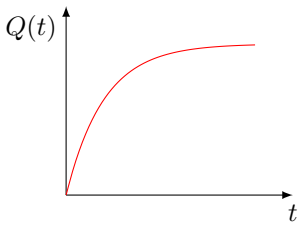

Figure 2: Graph of charge on capacitor versus time during charging.

The equations for charge Q and voltage V during charging are

$$Q(t) = CV(0)(1 - e^{-t/RC}),$$

$$V(t) = V(0)(1 - e^{-t/RC}).$$

- **Explain discharging of a capacitor.**

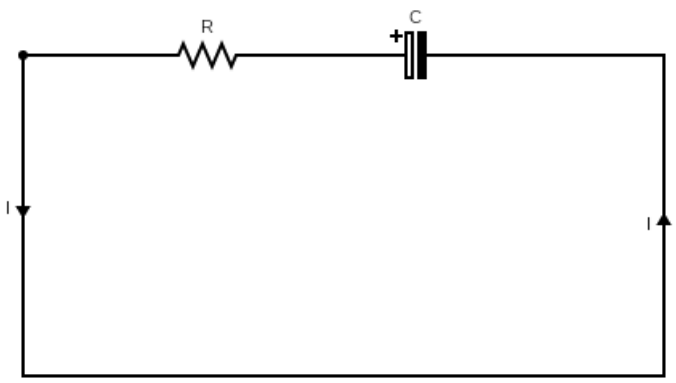

Figure 3: Circuit diagram showing discharging of capacitor

A fully charged capacitor in a closed circuit starts discharging(without battery connected to capacitor). The electrons from negative plate of capacitor flow towards positive plate (the current direction is reversed). This continues till all the charge on the capacitor discharges. Charge and voltage on the capacitor decreases during discharging.

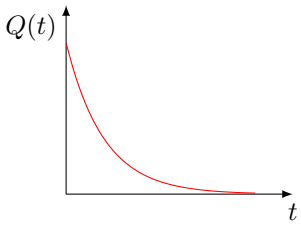

Figure 4: Graph of charge on capacitor versus time during discharging.

The equations for charge Q and voltage V during discharging are

$$Q(t) = CV(0)e^{-t/RC},$$

$$V(t) = V(0)e^{-t/RC}.$$

- **What is the principle used in the experiment?**

$$V(t) = V(0)\left(1 - e^{-t/RC}\right) \quad \text{charging} \tag{3}$$

$$V(t) = V(0)e^{-t/RC} \quad \text{discharging} \tag{4}$$

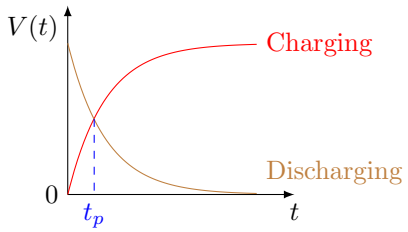

Figure 5: Graph of charging and discharging of capacitor.

Let us say, the two curves meet at $t = t_p$.

$$
\begin{aligned}
& V(t_p) = V(0)\left(1 - e^{-t_p/RC}\right) = V(0)e^{-t_p/RC}. \\
\implies & 1 - e^{-t_p/RC} = e^{-t_p/RC} \\
\implies & 1 = 2e^{-t_p/RC} \\
\implies & \frac{1}{2} = e^{-t_p/RC} \\
\implies & \log_e\left(\frac{1}{2}\right) = \frac{-t_p}{RC} \\
\implies & \log_e 2 = \frac{t_p}{RC} \\
\implies & \boxed{C = \frac{t_p}{R\ln 2}}.
\end{aligned}
$$

The dielectric constant (ϵ_r) of the material of the capacitor is calculated from the formula (rearrangement of equation (2)):

$$\boxed{\epsilon_r = \frac{dC}{\epsilon_0 A} \times 10^{-6}}.$$

The factor 10^{-6} is a correction factor.

- **Do capacitors charge when connected to AC source?**