

Dielectrics & capacitors



Disclaimer : This PPT is intended only as a quick revision of formulas, definitions, theorems and theory concepts before examinations. No physics can be learnt just by watching a few videos or going through a few slides of PPT.

Take active participation in your regular classes where you can enjoy learning physics through discussions, interactions, simulations, live demonstrations, derivations and problem solving

Dielectric & capacitor

Dielectric types

Behaviour of dielectric in E

When cell remains connected

When cell is disconnected

Partial filling of dielectric

Additional cases

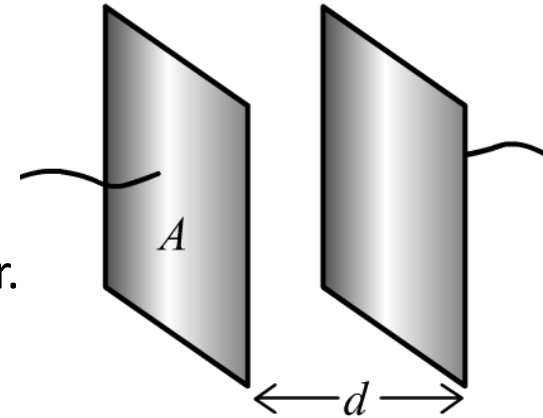
Dielectrics

A dielectric is an insulating material.

Dielectrics do not contain mobile or *free* charge carriers.

Dielectrics are used to increase the capacitance of a capacitor.

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



Based on polarization of each atom/molecule, dielectric may be classified as

- (a) Polar dielectrics
- (b) Non-polar dielectrics

Polar dielectrics

- Centre of positive charge does not coincide with the centre of negative charge.
- Examples : HCl , H_2O etc.
- Dipole moment of each molecule is not zero
- Dipole moment of a bulk sample is zero (figure I)
- In the presence of external electric field the dipoles are realigned resulting in a non zero net dipole moment per unit volume (figure II) .
- Electric field intensity due to the induced dipoles results in decrease in the net electric field intensity in the region of the dielectric.

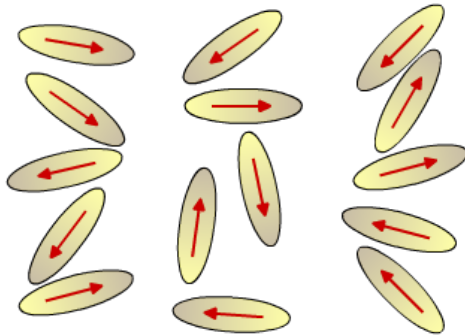


figure I

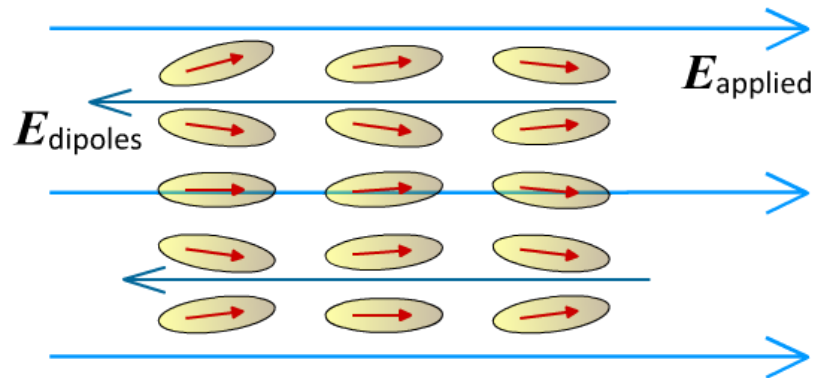


figure II

Non-polar dielectrics

- Centre of positive charge coincides with the centre of negative charge.
- Examples : H_2 , CO_2 etc.
- Dipole moment of each molecule is zero
- Dipole moment of a bulk sample is also zero (figure I)
- In the presence of external electric field, the molecules are polarized resulting in non zero net dipole moment per unit volume (figure II) .
- Electric field intensity due to the induced dipoles results in decrease in the net electric field intensity in the region of the dielectric.

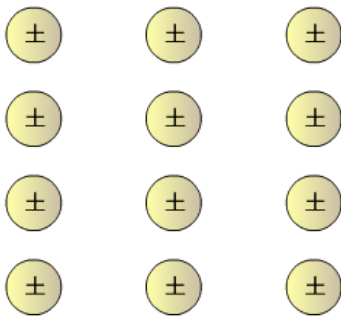


figure I

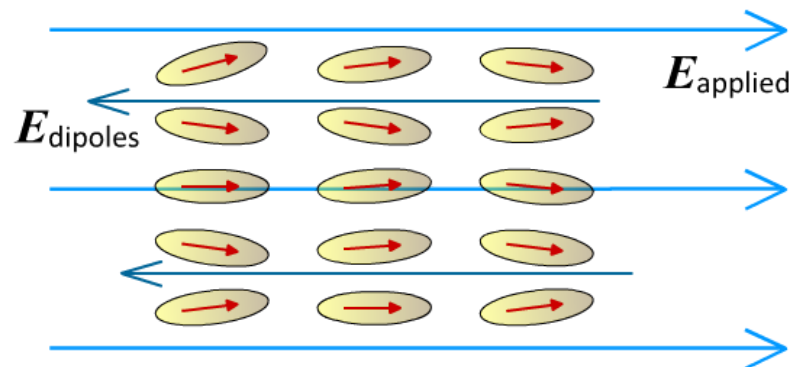


figure II

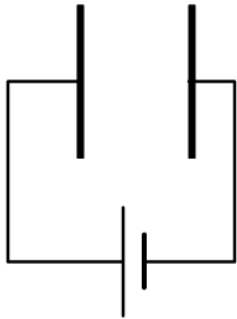
Inserting a dielectric in a capacitor when the cell is connected to it

A capacitor is charged using cell. A dielectric of constant K is introduced between the plates of the capacitor with cell still connected to it.

- Capacitance of capacitor increases as permittivity due to dielectric becomes $K\epsilon_0$
- Electric field existing between the plates of the capacitor causes polarization of the dielectric placed between the plates.
- Electric field of aligned dipoles tends to decrease the net electric field between the plates of the capacitor which in turn tends to decrease the potential difference between the plates.
- Supply of additional charges by the cell to the capacitor prevents any decrease on potential and hence potential difference across the plates remain same.
- Charge on the plates increases.
- Energy stored in the capacitor also increases

Electric potential and capacitance

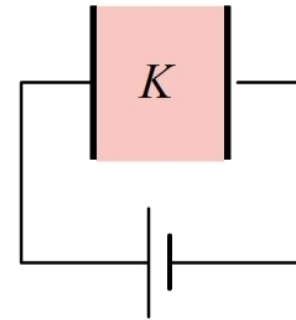
Before introduction of dielectric



- Capacitance $C_o = \frac{\epsilon_o A}{d}$
- P.D. across the plates V_o
- Charge $Q_o = C_o V_o$
- Electric field $E_o = V_o / d$
- Energy stored in the capacitor U_o

$$U_o = \frac{1}{2} C_o V_o^2$$

After introduction of dielectric



- Capacitance increases $C = \frac{\epsilon_o K A}{d}$
- P.D. remains same
- Charge on capacitor increases
 $Q = K C_o V_o$
- Electric field remains same $E = V_o / d$
- Energy stored increases

$$U = \frac{1}{2} K C V_o^2$$

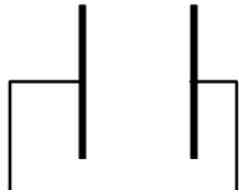
Inserting a dielectric in a capacitor when the cell is disconnected from it

A capacitor is charged using a cell. The cell is disconnected and then a dielectric of constant K is introduced between the plates of the capacitor.

- Capacitance of capacitor increases as permittivity due to dielectric becomes $K\epsilon_0$
- As the cell is not connected to the capacitor, charge on each plate of the capacitor remains constant.
- Electric field existing between the plates of the capacitor causes polarization of the dielectric placed between the plates.
- Electric field due to the aligned dipoles results in decrease of the net electric field between the plates of the capacitor which in turn decreases the potential difference between the plates.
- Energy stored in the capacitor decreases

Electric potential and capacitance

Before introduction of dielectric



- Capacitance of capacitor C_o

$$C_o = \frac{\epsilon_o A}{d}$$

- Charge on the capacitor $Q_o = C_o V_o$

- P.D. across the plates V_o

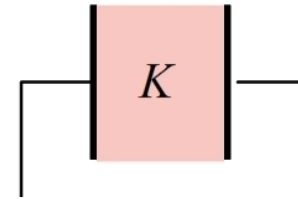
- Electric field E_o

$$E_o = V_o / d$$

- Energy stored in the capacitor U_o

$$U_o = \frac{1}{2} C_o V_o^2$$

After introduction of dielectric



- Capacitance of capacitor increases

$$C = \frac{\epsilon_o K A}{d}$$

- Charge on capacitor remains same

- P.D. across plates decreases

$$V = Q_o / KC_o$$

- Electric field decreases

$$E = V_o / d$$

- Energy stored in capacitor decreases

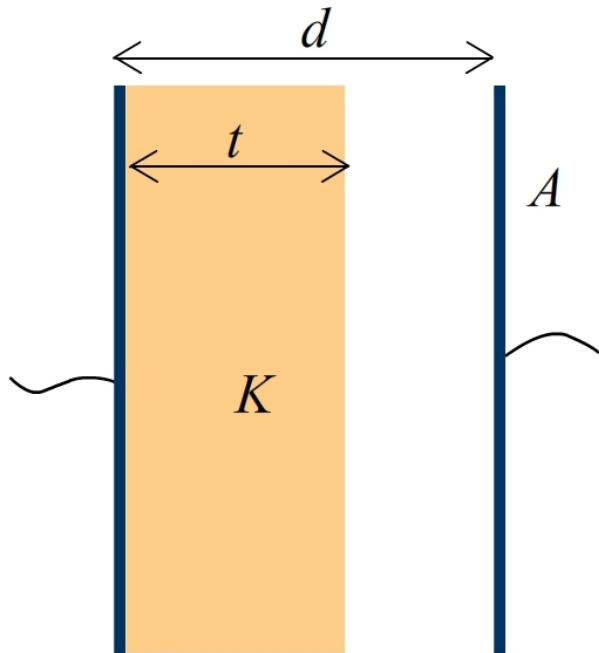
$$U = \frac{1}{2} \frac{C V_o^2}{K}$$

Effective capacitance of a capacitor filled partially with dielectric

Consider a parallel plate capacitor. Let A be the area of each plate and d be the distance between the plates.

Case – I

This arrangement may be treated as a combination of capacitors in series



$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$C_1 = \frac{\epsilon_0 K A}{t}$$

$$C_2 = \frac{\epsilon_0 A}{(d-t)}$$

$$\frac{1}{C} = \frac{t}{\epsilon_0 K A} + \frac{(d-t)}{\epsilon_0 A}$$

$$\frac{1}{C} = \frac{1}{\epsilon_0 A} \left(\frac{t}{K} + \frac{(d-t)}{1} \right)$$

$$\frac{1}{C} = \frac{1}{\epsilon_0 A} \left(\frac{t + K(d-t)}{K} \right)$$

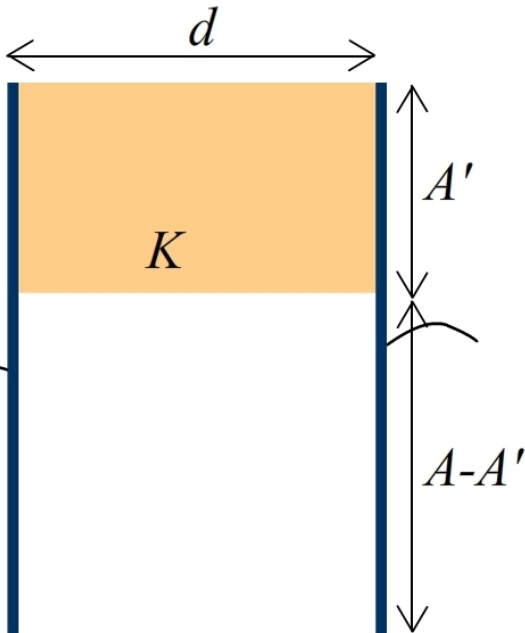
$$C = \frac{\epsilon_0 A K}{t + K(d-t)}$$

Effective capacitance of a capacitor filled partially with dielectric

Consider a parallel plate capacitor. Let A be the area of each plate and d be the distance between the plates.

Case – II

This arrangement may be treated as a parallel combination of capacitors



$$C = C_1 + C_2$$

$$C_1 = \frac{\epsilon_0 K A'}{d}$$

$$C_2 = \frac{\epsilon_0 (A - A')}{d}$$

$$C = \frac{\epsilon_0 K A'}{d} + \frac{\epsilon_0 (A - A')}{d}$$

$$C = \frac{\epsilon_0}{d} (A + A'(K - 1))$$