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ELECTRIC POTENTIAL AND CAPACITORS

ELCTRIC POTENTIAL AND POTENTIAL DIFFERENCE

An electric charge placed at a point in an electric field has potential energy.

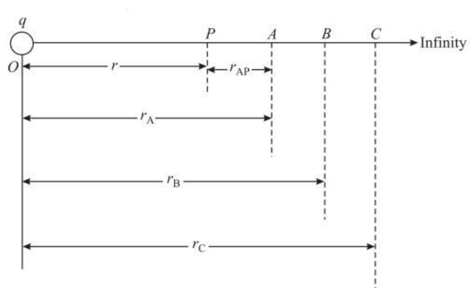
The electric potential at any point in an electric field is equal to the work done against the electric force in moving a unit positive charge from outside the electric field to that point

The SI unit of potential and potential difference is volt

If one joule of work is done in taking a test charge of one coulomb from one point to the other in an electric field, the potential difference between these points is said to be one volt.

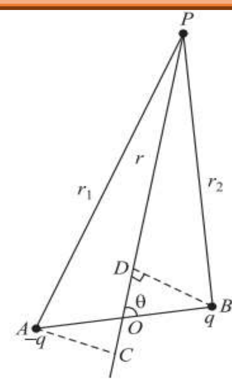
$$\boldsymbol{V_{AB} = V_B - V_A = \frac{W_{AB}}{q_0}}$$

Potential at a point due to a Point Charge



$$V_p = \frac{1}{4\pi\varepsilon_0} \times \frac{q}{r}$$

Potential at a Point due to an Electric Dipole



$$V_1 = \frac{1}{4\pi\varepsilon_0} \times \frac{q}{r_1}$$

$$V_2 = \frac{1}{4\pi\varepsilon_0} \times \frac{q}{r_2}$$

$V = \frac{q}{4\pi\varepsilon_0} \times \left[\frac{1}{r_2} - \frac{1}{r_1}\right],$

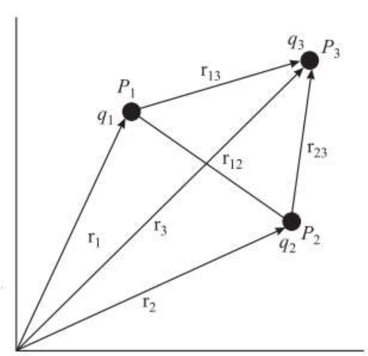
$r_1 = r + l\cos\theta, r_2 = r - l\cos\theta$

$V = \frac{q \times 2l\cos\theta}{4\pi\varepsilon_0 r^2}$

Potential Energy of a System of Point Charges

$$\boldsymbol{U} = \frac{\boldsymbol{q_1 \times q_2}}{4\pi\varepsilon_0 \|r_{12}\|}$$

$\mathbf{U} = \frac{\mathbf{1}}{4\pi\varepsilon_0}\left(\frac{\boldsymbol{q_1 q_2}}{\boldsymbol{r_{12}}} + \frac{\boldsymbol{q_1 q_3}}{\boldsymbol{r_{13}}} + \frac{\boldsymbol{q_2 q_3}}{\boldsymbol{r_{23}}}\right)$



The total amount of work done in bringing various point charges of the system to their respective positions from infinitely large mutual separations.

RELATION BETWEEN ELECTRIC FIELD AND POTENTIAL

At any point, the electric field is equal to negative rate of change of potential with distance (called potential gradient) at that point in the direction of field.

$$E = -\frac{\Delta V}{\Delta d}$$

CAPACITANCE

Two conductors having equal but opposite charges +Q and – Q on them. There is a potential difference V between them. Such a system of conductors is called a capacitor.

C = Q / V

1 farad = 1coulomb/ 1 volt

Capacitance of a Spherical Conductor

$$\boldsymbol{C} = 4\pi\varepsilon_0$$

Types of Capacitors

Capacitance of an insulated conductor can be increased by bringing near it an uncharged earthed conductor. This is the basic principle of a capacitor.

A Parallel Plate Capacitor

A parallel plate capacitor is one of the simplest capacitors in which two parallel metallic plates, each of area A, are separated from one another by a small distance d. An insulating medium like air, paper, mica, glass etc separates the plates. The plates are connected to the terminals of a battery

$$\boldsymbol{C} = \frac{\varepsilon_0 A}{\boldsymbol{d}}$$

Relative Permittivity or Dielectric Constant

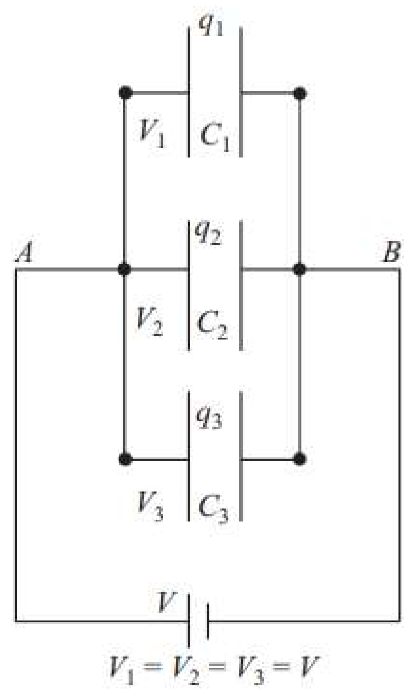
$$\frac{\boldsymbol{\varepsilon}}{Permitivity\ of\ free\ space\ (\varepsilon_0)} = \varepsilon_r$$

$$K = \frac{Capacitance\ with\ dielectric\ between\ the\ plate}{Capacitance\ with\ vacuume\ between\ the\ plate}$$

$$\mathbf{K} = \frac{C_m}{C_0}$$

GROUPING OF CAPACITORS

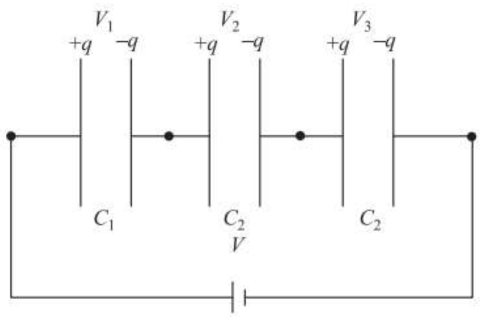
Parallel Grouping of Capacitors



equivalent capacitance of a number of capacitors joined in parallel is equal to the sum of the individual capacitances. Remember that in parallel combination, all the capacitors have the same potential difference between their plates but charge is distributed in proportion to their capacitances

$$C_p = C_1 + C_2 + C_3 = \sum_{i=1}^{n} C_i$$

Series Grouping of Capacitors



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The second plate of the first capacitor is connected to the first plate of the second capacitor. The second plate of second capacitor is connected to first plate of the next capacitor of the combination and so on. The second plate of last capacitor of the combination is connected to the electrical source

In series combination of capacitors, the equivalent capacitance is less than the least of any of the individual capacitances.

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \sum_{i=1}^{n} \frac{1}{C_i}$$

Energy Stored in a Capacitor

The stored energy is directly proportional to the capacitance. It also increases as potential difference increases.

$$\boldsymbol{U = \frac{1}{2}qV = \frac{1}{2}CV^2}$$

DIELECTRICS AND DIELECTRIC POLARIZATION

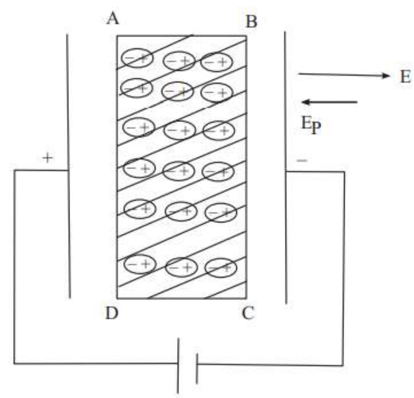
Dielectrics are insulating materials, which transmit electric effects without conducting. Dielectrics are of two types : non-polar and polar

Non-polar dielectrics

In the molecules of non–polar dielectrics, the centre of positive charge coincides with the centre of negative charge. Each molecule has zero dipole moment in its normal state. These molecules are mostly symmetrical such as nitrogen, oxygen, benzene, methane, $CO2$, etc.

Polar dielectrics

P = $\boldsymbol{\alpha \varepsilon_0 E}$



Check Yourself

1. A test charge is moved from lower potential point to a higher potential point. The potential energy of test charge will
   (a) remain the same
   (b) increase
   (c) decrease
   (d) become zero
2. Dielectric constant for a metal is
   (a) zero
   (b) infinite
   (c) 1
   (d) 10
3. 1 volt is equivalent to
   (a) $\frac{\text{newton}}{\text{second}}$ (b) $\frac{\text{newton}}{\text{coulomb}}$
   (c) $\frac{\text{joule}}{\text{coulomb}}$ (d) $\frac{\text{joule}}{\text{second}}$

4. Equi potential surfaces
(a) are closer in regions of large electric fields compared to regions of lower electric fields.
(b) will be more crowded near sharp edges of a conductor.
(c) will always be equally spaced.
(d) both (a) and (b) are correct.

5. The capacitance of a capacitor will decrease if we introduce a slab of:
(a) copper
(b) aluminium
(c) zinc
(d) None of these

Stretch Yourself

1. Derive an expression for electric potential energy of charge distribution
2. The total capacitance of two capacitor is 4 F when connected in series and 18 F when connected in parallel. Find the capacitance of each capacitor
3. Why is an insulator called a dielectric.

Hint to Check Yourself

1 C 2 B 3C 4D 5D