

Class 12 Physics NCERT Solutions Electrostatic Potential and Capacitance Important Questions

Q 2.1) Two charges $5 \times 10^{-8} \text{ C}$ and $-3 \times 10^{-8} \text{ C}$ are the two charges located 16 cm apart from each other. At what point(s) on the line joining the two charges is the electric potential zero? Take the potential at infinity to be zero.

Soln.: Given,

$$q_1 = 5 \times 10^{-8} \text{ C}$$

$$q_2 = -3 \times 10^{-8} \text{ C}$$

The two charges are at a distance, $d = 16 \text{ cm} = 0.16 \text{ m}$ from each other.

As shown in the figure, let us consider a point P over the line joining charges q_1 and q_2 .

Let, distance of the considered point P from q_1 be 'r'

Let, point P has zero electric potential (V).

The electric potential at point P is the summation of potentials due to charges q_1 and q_2 .

$$\text{Therefore, } V = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1}{r} + \frac{1}{4\pi\epsilon_0} \cdot \frac{q_2}{d-r} \dots\dots\dots(1)$$

Here,

ϵ_0 = permittivity of free space.

Putting $V = 0$, in eqn. (1), we get,

$$0 = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1}{r} + \frac{1}{4\pi\epsilon_0} \cdot \frac{q_2}{d-r} \quad \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1}{r} = -\frac{1}{4\pi\epsilon_0} \cdot \frac{q_2}{d-r} \quad \frac{q_1}{r} = -\frac{q_2}{d-r} \quad \frac{5 \times 10^{-8}}{r} = -\frac{(-3 \times 10^{-8})}{0.16-r}$$

$$5(0.16 - r) = 3r$$

$$0.8 = 8r$$

$$r = 0.1 \text{ m} = 10 \text{ cm.}$$

Therefore, at a distance of 10 cm from the positive charge the potential is zero between the two charges.

Let us assume a point P at a distance 's' from the negative charge be outside the system, having potential zero.

So, for the above condition, potential is given by -

$$V = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1}{s} + \frac{1}{4\pi\epsilon_0} \cdot \frac{q_2}{s-d} \dots\dots\dots(2)$$

Here,

ϵ_0 = permittivity of free space.

For $V = 0$, eqn. (2) can be written as :

$$0 = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1}{s} + \frac{1}{4\pi\epsilon_0} \cdot \frac{q_2}{s-d} \quad \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1}{s} = -\frac{1}{4\pi\epsilon_0} \cdot \frac{q_2}{s-d} \quad \frac{q_1}{s} = -\frac{q_2}{s-d} \quad \frac{5 \times 10^{-8}}{s} = -\frac{(-3 \times 10^{-8})}{s-0.16}$$

$$5(s - 0.16) = 3s$$

$$0.8 = 2s$$

$$S = 0.4 \text{ m} = 40 \text{ cm.}$$

Therefore, at a distance of 40 cm from the positive charge outside the system of charges, the potential is zero.

Q 2.2) A regular hexagon of side 10 cm has a charge $5 \mu\text{C}$ at each of its vertices. Calculate the potential at the centre of the hexagon.

Soln.:

The figure shows, regular hexagon containing charges q , at each of its vertices.

Here

$$q = 5 \mu\text{C} = 5 \times 10^{-6} \text{ C.}$$

Length of each side of hexagon, $AB = BC = CD = DE = EF = FA = 10 \text{ cm.}$

Distance of the vertices from the centre O, $d = 10 \text{ cm.}$

Electric potential at point O,

$$V = \frac{1}{4\pi\epsilon_0} \cdot \frac{6xq}{d}$$

Here,

$$\epsilon_0 = \text{Permittivity of free space and } \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$$

$$V = \frac{9 \times 10^9 \times 6 \times 5 \times 10^{-6}}{0.1} = 2.7 \times 10^6 \text{ V.}$$

Q 2.3) Two charges $2 \mu\text{C}$ and $-2 \mu\text{C}$ are placed at points A and B 6 cm apart.

(1) Identify an equipotential surface of the system.

(2) What is the direction of the electric field at every point on this surface?

Soln.:

(1) An equipotential surface is defined as the surface over which the total potential is zero. In the given question this plane is normal to line AB. The plane is located at the mid – point of the line AB as the magnitude of the charges are same.

(2) At every point on this surface the direction of the electric field is normal to the plane in the direction of AB.

Q 2.4) A spherical conductor of radius 12 cm has a charge of $1.6 \times 10^{-7} \text{ C}$ distributed uniformly on its surface. What is the electric field

(1) inside the sphere.

(2) just outside the sphere.

(3) at a point 18 cm from the centre of sphere.

Soln.:

(1) Given,

Radius of spherical conductor, $r = 12 \text{ cm} = 0.12 \text{ m}$

Charge is distributed uniformly over the surface, $q = 1.6 \times 10^{-7} \text{ C.}$

Electric field inside a spherical conductor is zero.

(2) Electric field E, just outside the conductor is given by the relation,

$$E = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{r^2}$$

Here,

$$\epsilon_0 = \text{permittivity of free space and } \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$$

Therefore,

$$E = \frac{9 \times 10^9 \times 1.6 \times 10^{-7}}{(0.12)^2}$$

Therefore, just outside the sphere the electric field is $4.4 \times 10^4 \text{ NC}^{-1}$.

(3) From the centre of sphere the electric field at a point 18m = E_1 .

From the centre of sphere the distance of point d = 18 cm = 0.18m.

$$E_1 = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{d^2} = \frac{9 \times 10^9 \times 1.6 \times 10^{-7}}{((1.8 \times 10)^{-2})^2} = 4.4 \times 10^4 \text{ NC}^{-1}$$

So, from the centre of sphere the electric field at a point 18 cm away is $4.4 \times 10^4 \text{ NC}^{-1}$.

Q 2.5) A parallel plate capacitor with air between the plates has a capacitance of 8pF ($1\text{pF} = 10^{-12} \text{ F}$). What will be the capacitance if the distance between the plates is reduced by half, and the space between them is filled with a substance of dielectric constant 6?

Soln.: Given,

Capacitance, $C = 8\text{pF}$.

In first case the parallel plates are at a distance 'd' and is filled with air.

Air has dielectric constant, $k = 1$

$$\text{Capacitance, } C = \frac{k \times \epsilon_0 \times A}{d} = \frac{\epsilon_0 \times A}{d} \quad \dots \text{eq(1)}$$

Here,

A = area of each plate

ϵ_0 = permittivity of free space.

Now, if the distance between the parallel plates is reduced to half, then $d_1 = d/2$

Given, dielectric constant of the substance, $k_1 = 6$

Hence, the capacitance of the capacitor,

$$C_1 = \frac{k_1 \times \epsilon_0 \times A}{d_1} = \frac{6\epsilon_0 \times A}{d/2} = \frac{12\epsilon_0 \times A}{d} \quad \dots (2)$$

Taking ratios of eqns. (1) and (2), we get,

$$C_1 = 2 \times 6 C = 12 C = 12 \times 8 \text{ pF} = 96\text{pF}.$$

Hence, capacitance between the plates is 96pF.

Q 2.6) Three capacitors connected in series have capacitance of 9pF each.

(1) What is the total capacitance of the combination?

(2) What is the potential difference across each capacitor if the combination is connected to a 120 V supply?

Soln.:

(1) Given,

The capacitance of the three capacitors, $C = 9 \text{ pF}$

Equivalent capacitance (C_{eq}) is the capacitance of the combination of the capacitors given by

$$\frac{1}{C_{eq}} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C} = \frac{3}{C} = \frac{3}{9} = \frac{1}{3} \quad \frac{1}{C_{eq}} = \frac{1}{3} = C_{eq} = 3 \text{ pF}$$

Therefore, the total capacitance = 3pF.

(2) Given, supply voltage, $V = 100\text{v}$

The potential difference (V_1) across the capacitors will be equal to one – third of the supply voltage.

$$\text{Therefore, } V_1 = \frac{V}{3} = \frac{120}{3} = 40\text{V}$$

Hence, the potential difference across each capacitor is 40V.

Q 2.7) Three capacitors of capacitances 2 pF, 3 pF and 4 pF are connected in parallel.

(1) What is the total capacitance of the combination?

(2) Determine the charge on each capacitor if the combination is connected to a 100 V supply.

Soln.:

(1) Given, $C_1 = 2\text{pF}$, $C_2 = 3\text{pF}$ and $C_3 = 4\text{pF}$.

Equivalent capacitance for the parallel combination is given by C_{eq} .

Therefore, $C_{eq} = C_1 + C_2 + C_3 = 2 + 3 + 4 = 9\text{pF}$

Hence, total capacitance of the combination is 9pF .

(2) supply voltage, $V = 100\text{v}$

The three capacitors are having the same voltage, $V = 100\text{v}$

$q = VC$

where,

q = charge

c = capacitance of the capacitor

v = potential difference

for capacitance, $c = 2\text{pF}$

$q = 100 \times 2 = 200\text{pC} = 2 \times 10^{-10}\text{C}$

for capacitance, $c = 3\text{pF}$

$q = 100 \times 3 = 300\text{pC} = 3 \times 10^{-10}\text{C}$

for capacitance, $c = 4\text{pF}$

$q = 100 \times 4 = 400\text{pC} = 4 \times 10^{-10}\text{C}$

Q 2.8) In a parallel plate capacitor with air between the plates, each plate has an area of $6 \times 10^{-3} \text{ m}^2$ and the distance between the plates is 3 mm . Calculate the capacitance of the capacitor. If this capacitor is connected to a 100 V supply, what is the charge on each plate of the capacitor?

Soln.: Given,

The area of plate of the capacitor, $A = 6 \times 10^{-3} \text{ m}^2$

Distances between the plates, $d = 3\text{mm} = 3 \times 10^{-3} \text{ m}$

Voltage supplied, $V = 100\text{v}$

Capacitance of a parallel plate capacitor is given by, $C = \frac{\epsilon \times A}{d}$

Here,

ϵ = permittivity of free space = $8.854 \times 10^{-12} \text{ N}^{-1} \text{ m}^{-2} \text{ C}^{-2}$

$C = \frac{8.854 \times 10^{-12} \times 6 \times 10^{-3}}{3 \times 10^{-3}} = 17.81 \times 10^{-12} \text{ F} = 17.71 \text{ pF}$.

Therefore, each plate of the capacitor is having a charge of

$q = VC = 100 \times 17.81 \times 10^{-12} \text{ C} = 1.771 \times 10^{-9} \text{ C}$

Q 2.9: Explain what would happen if, in the capacitor given in Exercise 2.8, a 3 mm thick mica sheet (of dielectric constant = 6) were inserted between the plates,

(a) while the voltage supply remained connected.

(b) after the supply was disconnected.

Answer 2.9:

(a) Dielectric constant of the mica sheet, $k = 6$

If voltage supply remained connected, voltage between two plates will be constant.

Supply voltage, $V = 100 \text{ V}$

Initial capacitance, $C = 1.771 \times 10^{-11} \text{ F}$

New capacitance, $C_1 = kC = 6 \times 1.771 \times 10^{-11} \text{ F} = 106 \text{ pF}$

New charge, $q_1 = C_1 V = 106 \times 100 \text{ pC} = 1.06 \times 10^{-8} \text{ C}$

Potential across the plates remains 100 V.

(b) Dielectric constant, $k = 6$

Initial capacitance, $C = 1.771 \times 10^{-11} \text{ F}$

New capacitance, $C_1 = kC = 6 \times 1.771 \times 10^{-11} \text{ F} = 106 \text{ pF}$

If supply voltage is removed, then there will be constant amount of charge in the plates.

Charge = $1.771 \times 10^{-9} \text{ C}$

Potential across the plates is given by,

$$V_1 = q/C_1 = \frac{1.771 \times 10^{-9}}{106 \times 10^{-12}}$$

$$= 16.7 \text{ V}$$

Q 2.10) A 12pF capacitor is connected to a 50V battery. How much electrostatic energy is stored in the capacitor?

Soln.: Given,

Capacitance of the capacitor, $C = 12 \text{ pF} = 12 \times 10^{-12} \text{ F}$

Potential difference, $V = 50 \text{ V}$

Electrostatic energy stored in the capacitor is given by the relation,

$$E = \frac{1}{2} CV^2 = \frac{1}{2} \times 12 \times 10^{-12} \times (50)^2 \text{ J} = 1.5 \times 10^{-8} \text{ J}$$

Therefore, the electrostatic energy stored in the capacitor is $1.5 \times 10^{-8} \text{ J}$.
was disconnected.

Q 2.11) A 600pF capacitor is charged by a 200V supply. It is then disconnected from the supply and is connected to another uncharged 600 pF capacitor. How much electrostatic energy is lost in the process?

Soln.: Given,

Capacitance, $C = 600 \text{ pF}$

Potential difference, $V = 200 \text{ v}$

Electrostatic energy stored in the capacitor is given by :

$$E_1 = \frac{1}{2} CV^2 = \frac{1}{2} \times (600 \times 10^{-12}) \times (200)^2 \text{ J} = 1.2 \times 10^{-5} \text{ J}$$

Acc. to the question, the source is disconnected to the 600pF and connected to another capacitor of 600pF, then equivalent capacitance (C_{eq}) of the combination is given by,

$$\begin{aligned} \frac{1}{C_{eq}} &= \frac{1}{C} + \frac{1}{C} = \frac{1}{600} + \frac{1}{600} \\ &= \frac{2}{600} = \frac{1}{300} \end{aligned}$$

$$C_{eq} = 300 \text{ pF}$$

New electrostatic energy can be calculated by:

$$E_2 = \frac{1}{2} CV^2 = \frac{1}{2} \times 300 \times (200)^2 \text{ J} = 0.6 \times 10^{-5} \text{ J}$$

Loss in electrostatic energy,

$$E = E_1 - E_2$$

$$E = 1.2 \times 10^{-5} - 0.6 \times 10^{-5} \text{ J} = 0.6 \times 10^{-5} \text{ J} = 6 \times 10^{-6} \text{ J}$$

Therefore, the electrostatic energy lost in the process is $6 \times 10^{-6} \text{ J}$.