CHAPTER 2

ELECTRIC POTENTIAL AND CAPACITANCE

CLASS 12TH

NCERT EXERCISE AND SOLUTIONS - PHYSICS

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

SOLUTION:

Given – Charges $q_1 = 5 \times 10^{-8}$ C and $q_2 = -3 \times 10^{-8}$ C, distance between charges (r) = 16 cm = 0.16 m

Need to fine – At what point on the line joining the charges is the potential zero?

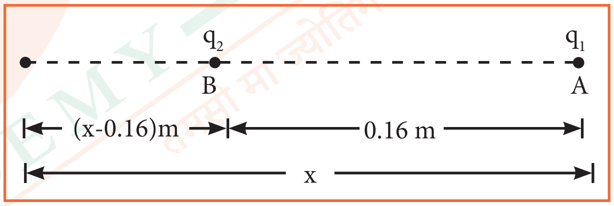
Case 1: From figure, consider a point P outside the system along the line joining the two charges.

Potential at P due to charge q_1 is,

$$V_1 = \frac{1}{4\pi\epsilon_0}\frac{q_1}{x} \quad \ldots\ldots \text{(i)} \qquad \left(\because \frac{1}{(4\pi\epsilon_0)} = 9\times10^9\ \text{Nm}^2/\text{C}^2\right)$$

Similarly, Potential at P due to charge q_2 is,

$$V_2 = \frac{1}{4\pi\epsilon_0}\frac{q_2}{(x-0.16)} \quad \ldots\ldots\ldots \text{(ii)}$$



Net Potential V is the sum of potential V_1 and V_2 from equation (i) and (ii) we get,

$$V = (V_1 + V_2) = \left(\frac{1}{4\pi\epsilon_0}\frac{q_1}{x}\right) + \left(\frac{1}{4\pi\epsilon_0}\frac{q_2}{(x-0.16)}\right)$$

According to question, net potential at P is zero.

$$\text{i.e., } \frac{1}{4\pi\epsilon_0}\frac{q_1}{x} = \frac{1}{4\pi\epsilon_0}\frac{q_2}{(x-0.16)}$$

$$\frac{q_1}{x} = \frac{-q_2}{(x-0.16)}$$

$$\frac{5\times10^{-8}}{x} = -\frac{\left(-3\times10^{-8}\right)}{(x-0.16)}$$

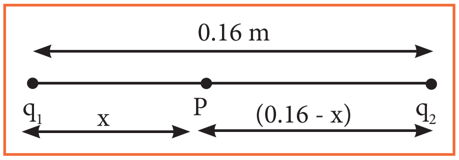
$$1-\frac{0.16}{x} = \frac{3}{5}$$

$$\frac{0.16}{x} = \frac{2}{5}$$

$$x = 0.4\,\text{m} = 40\,cm$$

Therefore, the potential is zero at 40 cm from the positive charge between the charges.

Case 2: From figure, consider point P is inside the system along the line joining the two charges. Potential at P due to charge q1 is,



$$V_1 = \frac{1}{4\pi\epsilon_0}\frac{q_1}{x} \quad \ldots\ldots \text{(i)} \qquad (\because \frac{1}{(4\pi\epsilon_0)} = 9\times10^9\ \text{Nm}^2/\text{C}^2)$$

Similarly, Potential at P due to charge q_2 is,

$$V_2 = \frac{1}{4\pi\epsilon_0}\frac{q_2}{(0.16-x)} \quad \ldots\ldots\ldots \text{(ii)}$$

Net Potential V is the sum of potential V_1 and V_2 from equation (i) and (ii) we get,

$$V = (V_1 + V_2) = \left(\frac{1}{4\pi\epsilon_0}\frac{q_1}{x}\right) + \left(\frac{1}{4\pi\epsilon_0}\frac{q_2}{(0.16-x)}\right)$$

According to question, net potential at P is zero.

$$\text{i.e., } \frac{1}{4\pi\epsilon_0}\frac{q_1}{x} = \frac{1}{4\pi\epsilon_0}\frac{q_2}{(0.16-x)}$$

$$\frac{q_1}{x} = \frac{-q_2}{(0.16-x)}$$

$$\frac{5\times10^{-8}}{x} = -\frac{(-3\times10^{-8})}{(0.16-x)}$$

$$\frac{0.16}{x} - 1 = \frac{3}{5}$$

$$\frac{0.16}{x} = \frac{8}{5}$$

$$x = 0.1\,\text{m} = 10\,cm$$

Therefore, the potential is zero at 10 cm from the positive charge between the charges.

2.2 A regular hexagon of side 10 cm has a charge 5 μC at each of its vertices. Calculate the potential at the centre of the hexagon.

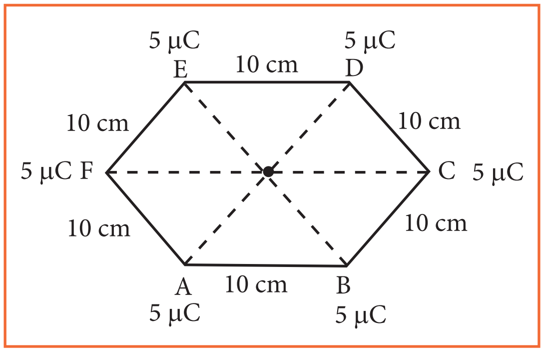
SOLUTION:

Given – side of regular hexagon (a) = 10 cm = 0.1 m, charge on vertices (q) = 5 μC = 5 × 10^{-6} C.

Need to find – Potential at the centre of the hexagon.

From figure, distance of each vertex from centre O is, r = 10 cm = 0.1 m

Electric potential at centre O is given by,



$$V = 6\frac{1}{4\pi\epsilon_0}\frac{q}{r} \qquad (\because \frac{1}{(4\pi\epsilon_0)} = 9\times10^9\ \text{Nm}^2/\text{C}^2)$$

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

Therefore, the potential at the centre of the hexagon is 2.7×10^6 V.

2.3 Two charges 2 μC and –2 μC are placed at points A and B 6 cm apart.

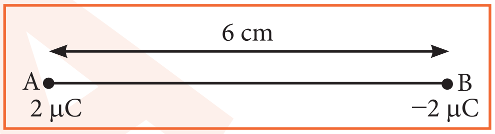
(a) Identify an equipotential surface of the system.

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

SOLUTION:

Given – Two charges q_1 = 2 C and q_2 = –2 μC, distance between them (r) = 6 cm = 0.06 m

(a) From the figure, the arrangement resembles a dipole.



For a dipole, the electric potential is zero at points on the equatorial plane, which is the plane perpendicular to the line joining A and B at its midpoint.

This plane acts as an equipotential surface.

(b) The direction of the electric field at every point on this equipotential surface is normal to the plane, pointing along the line joining the charges A and B (i.e., in the direction of AB).

2.4 A spherical conductor of radius 12 cm has a charge of 1.6 × 10⁻⁷ C distributed uniformly on its surface. What is the electric field

(a) inside the sphere

(b) just outside the sphere

(c) at a point 18 cm from the centre of the sphere?

SOLUTION:

Given – Charge distributed (q) = 1.6×10^{-7} C, radius of the sphere (r) = 12 cm = 0.12 m.

Need to find – Electric field

(a) Electric field inside the conducting sphere is zero because the electric field inside a spherical conductor is zero because any internal field would cause charges to move, redistributing until the field is neutralized.

(b) The electric field E just outside the sphere is given by,

$$E = \frac{1}{4\pi \epsilon_0} \frac{q}{r^2} \quad \left(\therefore \frac{1}{4\pi \epsilon_0} = 9 \times 10^9 \text{ Nm}^2/\text{C}^2 \right)$$

$$E = \frac{1.6 \times 10^{-7} \times 9 \times 10^{-9}}{(0.12)^2} = 10^5 \text{ N/C}$$

Therefore, the electric field just outside the sphere is 10^5 N/C.

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(c) The electric field E at a point 18 cm from the centre of the sphere is given by,

$$E = \frac{1}{4\pi \in_0} \frac{q}{r^2}$$

Where, r = 18 cm = 0.18 m

$$E = \frac{(9\times10^9)\times(1.6\times10^{-7})}{\left(18\times10^{-2}\right)^2}$$

$$E = 4.4\times10^4 \text{ N/C}$$

Therefore, the electric field at a point 18 cm from the centre of the sphere is 4.4×10^4 N/C.

2.5 A parallel plate capacitor with air between the plates has a capacitance of 8 pF (1pF = 10^{-12} 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?

SOLUTION:

Given – Capacitance (C) = 8 pF = F, Dielectric constant (K) = 6,

Let, initial distance between the plates = d

Need to find – Capacitance of parallel plate capacitor if distance between the plates reduced by half.

Capacitance of a parallel plate capacitor is given by,

$$C = \frac{\in_0 A}{d} = 8 \times 10^{-12} \text{ F} \qquad \text{(if air/vacuum between the plates)}$$

Capacitance of a parallel plate capacitor is given by,

$$C' = \frac{K\in_0 A}{d'} \qquad \text{(if dielectric medium filled between the plates)}$$

where, $\in_0 = 8.85 \times 10^{-11}$ C²/Nm² d' = d/2.

Now, $$C' = \frac{6\in_0 A}{d/2} = 12\text{ C} \qquad (\therefore \text{C} \frac{\in_0 A}{\text{d}})$$

$$C' = 12 \times (8 \times 10^{-12}) \text{ F}$$

$$= 96 \text{ pF.}$$

Therefore, the capacitance between the plates is 96 pF .

2.6 Three capacitors each of capacitance 9 pF are connected in series.

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

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

SOLUTION:

Given – Capacitance of 3 capacitors connected in series $C_1 = C_2 = C_3 = C = 9$ pF.

(a) In series connection the net capacitance of combination is given by,

$$\frac{1}{C_{net}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$= \frac{1}{9} + \frac{1}{9} + \frac{1}{9} = \frac{3}{9} = \frac{1}{3}$$

$$C_{net} = 3pF$$

Therefore, net capacitance is 3 pF.

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(b) Supply voltage (V) = 120 V.

In series connection the potential difference (V') across each capacitor is equal to one-third of the supply voltage.

i.e., V' = = 40 V

Therefore, potential difference across each capacitor is 40 V.

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

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

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

SOLUTION:

Given – C_1 = 2pF, C_2 = 3 pF, C_3 = 4 pF connected in parallel combination.

(a) In parallel connection the net capacitance of combination is given by,

$$C_{net} = C_1 + C_2 + C_3$$

$$Cnet = 2 \text{ pF} + 3 \text{ pF} + 4 \text{ pF} = 9 \text{ pF}$$

Therefore, the net capacitance is 9 pF.

(b) In parallel combination the potential difference across each capacitor is same V = 100 volt.

Charge on each capacitor is given by: Q = CV

$Q_1 = C_1V = (2pF) \times (100V) = 2 \times 10^{-10}$ C

$Q_2 = C_2V = (3pF) \times (100V) = 3 \times 10^{-10}$ C

$Q_3 = C_3V = (4pF) \times (100V) = 4 \times 10^{-10}$ C

2.8 In a parallel plate capacitor with air between the plates, each plate has an area of 6×10^{-3} m² 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?

SOLUTION:

Given – Area of plates (A) = 6×10^{-3} m², Distance between plates (d) = 3 mm = 3×10^{-3}m,

Supply voltage (V) = 100V.

Need to find – Capacitance of the capacitor and charge on each conductor plate.

Capacitance of the parallel plate capacitor is given by,

$$C = \frac{\epsilon_0 A}{d} \qquad (\therefore \epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2/\text{Nm}^2)$$

$$C = \frac{\left(8.854\times10^{-12}\right)\times\left(6\times10^{-3}\right)}{\left(3\times10^{-3}\right)}$$

$$= 17.71\times10^{-12}\,\text{F} = 17.71pF$$

Therefore, the capacitance is 17.71 pF.

Charge on each plate of the capacitor is given by,

Q = CV

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$Q = (17.71 \times 10^{-12} F)(100 V)$

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

Therefore, the charge on each capacitor plate is 1.771×10^{-9} C.

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.

SOLUTION:

Given – Dielectric constant (k) = 6, Thickness of mica sheet (t) = 3 mm = 3×10^{-3} m,

Initial capacitance (C) = $17.71 \times 10^{-12} F = 17.71 pF$.

(a) When voltage supply remains connected then the change in capacitance due to dielectric is given by,

$$C' = kC$$

$$C' = 6\,(17.71 \times 10^{-12} F) = 106 \text{ pF}$$

Supply voltage (V) = 100 V then, ($\therefore$ Potential across the plates is constant)

New charge (Q) = C'V = (106 pF)(100 V) = 1.06×10^{-8} C

(b) If the supply voltage is disconnected, the amount of charge on the plates remains unaffected. The potential across the plates is given by the formula:

$$V' = \frac{q}{C'}$$

$$V' = \frac{1.771 \times 10^{-9}}{106 \times 10^{-12}} = 16.7V$$

Therefore, the potential across the plates when the supply was removed is 16.7 V.

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

SOLUTION:

Given – Capacitance (C) = 12 pF, Supply voltage (V) = 50 V.

Need to find – Electrostatic energy stored in the capacitor.

Electrostatic energy stored in the capacitor is given by,

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

$$= 1.5 \times 10^{-8} J$$

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

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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?

SOLUTION:

Given – Capacitance of first capacitor (C_1) = 600 pF, Supply voltage (V) = 200 V, Capacitance of second capacitor (C_2) = 600 pF.

Need to find – Loss in electrostatic energy in this process.

Electrostatic energy stored in the capacitor is given by,

$$E = \frac{1}{2}CV^2 = \frac{1}{2}\times(600\times10^{-12})\times(200)^2$$

$$= 1.2\times10^{-5}\,J$$

If the supply is disconnected from the capacitor and another capacitor with capacitance C = 600 pF is connected to it, the equivalent capacitance C' of the combination is given by:

$$\frac{1}{C'} = \frac{1}{C} + \frac{1}{C}$$

$$= \frac{1}{600} + \frac{1}{600} = \frac{2}{600} = \frac{1}{300}$$

$$C' = 300\text{ pF}$$

New electrostatic energy is given by,

$$E' = \frac{1}{2}\times C'\times V^2$$

$$= \frac{1}{2}\times 300\times(200)^2$$

$$= 0.6\times10^{-5}\,J$$

Loss in electrostatic energy is given by,

$$\Delta E = (E - E') = (1.2\times10^{-5}\,J) - (0.6\times10^{-5}\,J)$$

$$\Delta E = 0.6\text{ J}$$

Therefore, the loss in energy is 0.6 J.

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