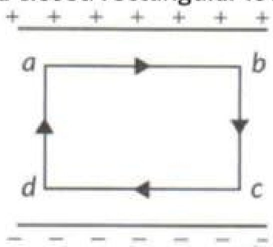
SURE SHOT QUESTIONS 2026

Chapter – 02 (Questions)

Electrostatic Potential and Capacitance

Question

1. The electric field inside a parallel plate capacitor is E. Find the amount of work done in moving a charge q over a closed rectangular loop abcda.



2. Establish the relation between electric field and electric potential at a point. Draw the equipotential surface for an electric field pointing in +Z direction with its magnitude increasing at constant rate along -Z direction.

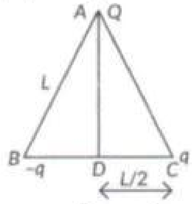
3. Define an equipotential surface. Draw equipotential surfaces:
   (i) In the case of a single point charge and
   (ii) In a constant electric field in Z – direction. Why the equipotential surface about a single charge are not equidistant?
   (iii) Can electric field exist tangential to an equipotential surface? Give reason.

4. (a) Two point charges $+Q_1$ and $-Q_2$ are placed r distance apart. Obtain the expression for the amount of work done to place a third charge Q_3 at the midpoint of the line joining the two charges.

   (b) At what distance from charge $+Q_1$ on the line joining the two charges (in terms of Q_1, Q_2 and r) will this work done be zero.

5. Obtain an expression for electrostatic potential energy of a system of three charges q, 2q and -3q placed at the vertices of an equilateral triangle of side a.

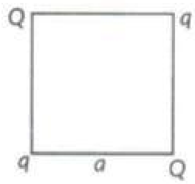
6. Three point charges Q, q and -q are kept at the vertices of an equilateral triangle of side L as shown in figure. What is
   (i) The electrostatic potential energy of the arrangement? And
   (ii) The potential at point D?



7. N small conducting liquid droplets, each of radius r, are charged to a potential V each. These droplets coalesce to form a single large drop without any charge leakage. Find the potential of the large drop.

8. Two point charges q and -2q are kept 'd' distance apart. Find the location of point relative to charge 'q' at which potential due to this system of charges is zero.

9. Four point charges Q, q, Q and q are placed at the corners of a square of side 'a' as shown in the figure. Find the



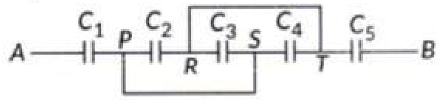
   (a) Resultant electric force on a charge Q, and
   (b) Potential energy of this system.

10. (a) Three point charges q, -4q and 2q are placed at the vertices of an equilateral triangle ABC of side 'l' as shown in the figure. Obtain the expression for the magnitude of the resultant electric force acting on the charge q.
    (b) Find out the amount of the work done to separate the charges at infinite distance.

11. In a parallel plate capacitor with air between the plates, each plate has an area of 6×10^{-3} m^2 and the separation between the plates is 0.3 mm.
    (i) Calculate the capacitance of the capacitor.
    (ii) If this capacitor is connected to 100 V supply, what would be the charge on each plate?

(iii) How would charge on the plates be affected, if a 3 mm thick mica sheet of K = 6 is inserted between the plates while the voltage supply remains connected?

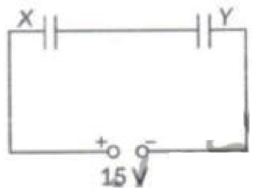
12. (i) Find the equivalent capacitance between A and B in the combination given below. Each capacitor is of 2 μF capacitance.



(i) If a dc source of 7 V is connected across AB, how much charge is drawn from the source and what is the energy stored in the network?

13. A 12 pF capacitor is connected to a 50 V battery. How much electrostatic energy is stored in the capacitor? If another capacitor of 6 pF is connected in series with it with the same battery connected across the combination, find the charge stored and potential difference across each capacitor.

14. Two parallel plate capacitors X and Y have the same area of plates and same separation between them. X has air between the plates while Y contains a dielectric of $\varepsilon_r = 4$.



(i) Calculate capacitance of each capacitor if equivalent capacitance of the combination is 4 μF.

(ii) Calculate the potential difference between the plates of X and Y.

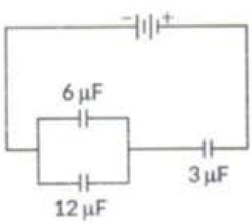
(iii) Estimate the ratio of electrostatic energy stored in X and Y.

15. In the following arrangement of capacitors, the energy stored in the 6 μF capacitor is E. Find the value of the following

(i) Energy stored in 12 μF capacitor

(ii) Energy stored in 3 μF capacitor

(iii) Total energy drawn from the battery

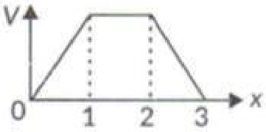


16. The magnitude of electric field (in N C^{-1}) in a region varies with the distance r (in m) as

$E = 10r + 5$

By how much does the electric potential increase in moving from point at r = 1 m to a point at r = 10 m.

17. The electric potential as a function of distance 'x' is shown in the figure. Draw a graph of the electric field E as a function of x.



18. Derive an expression for the potential energy of an electric dipole in a uniform electric field. Explain conditions for stable and unstable equilibrium.

19. If two similar large plates, each of area A having surface charge densities $+\sigma$ and $-\sigma$ are separated by a distance d in air, find the expressions for

(a) Field at points between the two plates and on outer side of the plates. Specify the direction of the field in each case.

(b) The potential difference between the plates.

(c) The capacitance of the capacitor so formed.

20. (a) Define an ideal electric dipole. Give an example.

(b) Derive an expression for the torque experienced by an electric dipole in a uniform electric field. What is net force acting on this dipole?

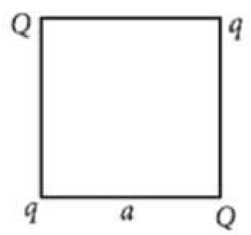
(c) An electric dipole of length 2 cm is placed with its axis making an angle of 60^0 with respect to uniform electric field of 10^5 N/C. If it experiences a torque of $8\sqrt{3}$ N/m, calculate the magnitude of charge on the dipole, and its potential energy.

21. Four point charges Q, q, Q *and* q are placed at the corners of a square of side 'a' as shown in the figure.

Find the

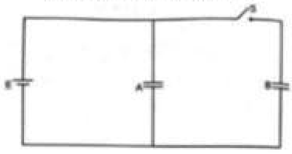
(a) resultant electric force on a charge Q, and

(b) potential energy of this system.



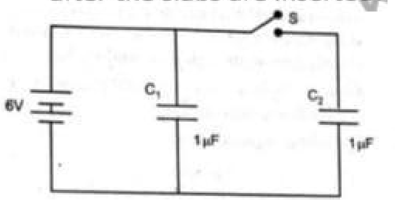
22. Show that the capacitance of a spherical conductor is $4\pi\varepsilon_0$ times the radius of the spherical conductor

23. Two identical parallel plate capacitors A and B are connected to battery of V volts with the switch S closed. The switch is now opened and the free space between the plates of the capacitors is filled with a dielectric of dielectric constant K. find the ratio of the total electrostatic energy stored in both capacitors before and after the introduction of the dielectric.



24. A 100 μF parallel plate capacitor having plate separation of 4 mm is charged by200 V dc. The source is now disconnected. When the distance between the plates is doubled and dielectric slab of thickness 4 mm and dielectric constant 5 is introduced between the plates, how will (i) its capacitance, (ii) the electric field between the plates, and (iii) energy density of the capacitor get affected? Justify your answer in each case.

25. Figure shows two identical capacitors, C_1 and C_2 each of 1 μF capacitance connected to a battery of 6 V. Initially switch 'S' is closed. After sometime 'S' is left open and dielectric slabs of dielectric constant K = 3 are inserted to fill completely the space between the plates of the capacitors. How will the (i) charge and (ii) potential difference between the plates of the capacitors be affected after the slabs are inserted?



26. Two tiny spheres carrying charges 1.5 μC and 2.5 μC are located 30 cm apart. Find the potential and the electric field

a. At the mid-point of the line joining the two charges, and
b. At a point 10 cm from this mid-point in a plane normal to the line and passing through the mid-point.

27. Define an equipotential surface. Draw equipotential surfaces :

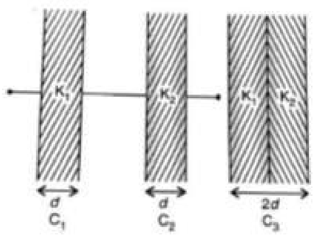
i. In the case of the single point charge and
ii. In a constant electric field in Z-direction. Why the equipotential surfaces about a single charge are not equidistant ?
iii. Can electric field exist tangential to an equipotential surface? Give reason.

28. Derive a relation between electric field & potential & explain significance of –ve sign.

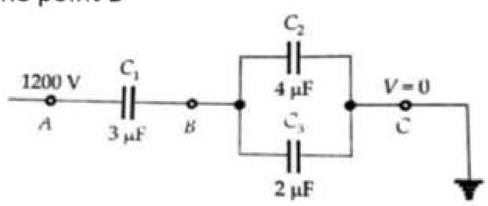
29. An electric dipole of length 4 cm, when placed with its axis making an angle of 60 with a uniform electric field experiences a torque of $4\sqrt{3}$ Nm. Calculate (i) magnitude of the electric field, (ii) potential energy of the dipole, if the dipole has charges of $\pm 8\ nC$.

30. Two particles have equal masses of 5.0 g each and opposite charges of +4 x 10^{-5} C and -4 x 10^{-5} C. They are released from rest with a separation of 1.0 m between them. Find the speeds of the particles when the separation is reduced to 50 cm.

31. The capacitors C_1 and C_2 having plates of area A each, are connected in series, as shown. Compare the capacitance of this combination with the capacitor C_3, again having plates of area A each, but 'made up' as shown in the figure.



32. In the circuit shown in the Fig., if the point C is earthed and point A is given a potential of +1200 V, find the charge on each capacitor and the potential at the point B



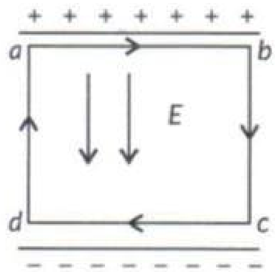
SURE SHOT QUESTIONS 2026

Chapter – 02 (Solutions)

Electrostatic Potential and Capacitance

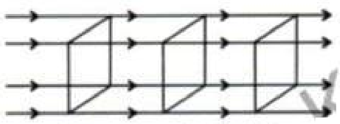
Question

1. Ans. Electric field inside a parallel plate capacitor = E



Here, electric field is conservative. Work done by the conservative force in closed loop is zero.
So, required work done = 0.

2. Ans. Equipotential surfaces in a constant electric field in Z – direction.



For constant electric field

Electric field as gradient of potential consider a point charge +q placed at point O. Suppose that V and $V+\delta V$ are electrostatic potential at points A and B, where distance from the charge +q are r and $r-\delta r$ respectively.

$(V+\delta V) = V + \frac{\delta W}{q_0}$

$\delta V = \frac{\delta W}{q_0}$ ....(i)

If $\vec{E}$ is electric field at point P due to charge +q placed at point O, then the test charge q_0 experiences a force equal to $q_0\vec{E}$ and the external force required to move the test charge against the electric field $\vec{E}$ is given by

$\vec{F} = -q_0\vec{E}$

Therefore, work done to move the test charge through an infinitesimally small displacement $\overrightarrow{PQ} = \overrightarrow{\delta l}$ is given by

$\Delta W = \vec{F}.\overrightarrow{\delta l} = (-q\vec{E}).\vec{\delta l} = -q_0 E\delta l \cos 180^0 = q_0 E\delta l$

As the distance r decreases in the direction of δl, then

$\delta W = -q_0 E\delta r$

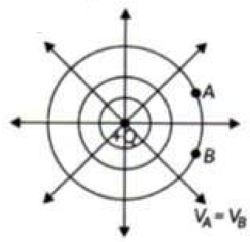
$\frac{\delta W}{q_0} = -E\delta r$ ....(ii)

From equations (i) and (ii), we get

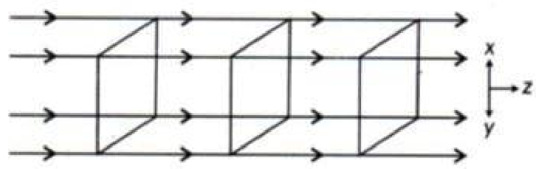
$\delta V = -E\delta r; E = -\frac{\delta V}{\delta r}$ (1)

3. Ans. Equipotential surface is the surface with a constant value of potential at all points on the surface.

(i) Equipotential surface for single point charge.



(ii) Equipotential surfaces in a constant electric field in Z – direction.



For constant electric field

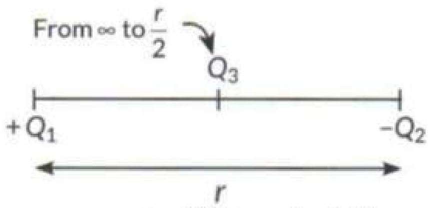
Equipotential surfaces about a single charge are not equidistant because electric potential, $V \propto \frac{1}{r}$

(iii) Electric field cannot exist tangential to an equipotential surface.

If the field lines are tangential, work will be done in moving a charge on the surface whereas on equipotential surface but we know that

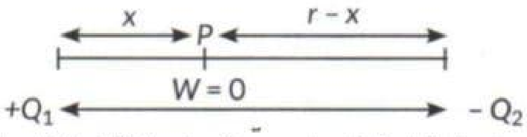
$W_{AB} = q_0(V_B - V_A) = 0$

4. Ans. (a) The work done to bring the charge Q_3 from infinity to $\frac{r}{2}$,



$$W = U = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{\frac{r}{2}} - \frac{1}{4\pi\varepsilon_0}\frac{Q_2Q_3}{\frac{r}{2}}$$
$$= \frac{1}{4\pi\varepsilon_0}\frac{2Q_3}{r}[Q_1 - Q_2]$$

(b) Consider a point P at a distance x from Q_1 where work done is zero. Then



$\therefore$ Potential at P due to Q_1 = potential at P due to Q_2

$\frac{kQ_1}{x} = \frac{kQ_2}{(r-x)} \Rightarrow (r-x)Q_1 = xQ_2$

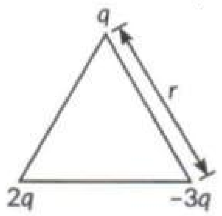
$rQ_1 - xQ_1 = xQ_2 \Rightarrow rQ_1 = x(Q_1 + Q_2)$

$\Rightarrow x = \frac{rQ_1}{Q_1+Q_2}$

5. Ans. Electrostatic potential energy,

$$U = \frac{1}{4\pi\varepsilon_0}\cdot\sum_{i=1,2}\frac{q_1q_2}{r_{12}}$$

Given an equilateral triangle,
Let side of triangle is r.
There are three pair of charges. Potential energy,



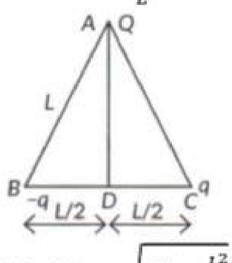
$$U = \frac{1}{4\pi\varepsilon_0}\left[\frac{q(2q)}{r} + \frac{2q(-3q)}{r} + \frac{(-3q)(q)}{r}\right]$$
$$U = \frac{1}{4\pi\varepsilon_0}\left(\frac{2q^2}{r} - \frac{6q^2}{r} - \frac{3q^2}{r}\right)$$
$$U = \frac{1}{4\pi\varepsilon_0}\left[\frac{-7q^2}{r}\right]$$
$$U = -\frac{1}{4\pi\varepsilon_0}\frac{7q^2}{r}$$

6. Ans. (i) $PE = \sum\frac{kq_iq_j}{r_{ij}}$

Potential energy of the arrangement is given by

$U = \frac{kQ(-q)}{L} + \frac{kQq}{L} + \frac{k(-q)q}{L}$

$\therefore U = -\frac{kq^2}{L}$



(ii) $AD = \sqrt{L^2 - \frac{L^2}{4}} = \frac{\sqrt{3}}{2}L$

Potential at D

$V = \frac{k(-q)\times 2}{L} + \frac{kq\times 2}{L} + \frac{kQ\times 2}{\sqrt{3}L}$

$\therefore V = \frac{2kQ}{\sqrt{3}L}$

7. Ans. Let q be the charge on each droplet.

Then $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$ ....(i)

Volume of big drop = N x volume of small drop

$$\frac{4}{3}\pi R^3 = N \times \frac{4}{3}\pi r^3$$

Where R is the radius of the big drop.

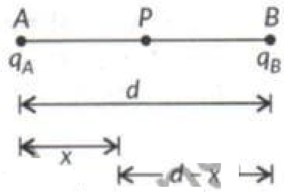
$\Rightarrow R = N^{1/3}r$ ....(ii)

And Q = Nq, where Q is the charge of bigger drop

$\therefore$ Potential of larger drop,

$$V' = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R} = \frac{1}{4\pi\varepsilon_0}\frac{Nq}{N^{1/3}r} = \frac{N}{N^{1/3}}V = N^{2/3}V$$

8. Ans. $q_A = q and q_B = -2q$



$V_{PA} = \frac{kq_A}{x}$

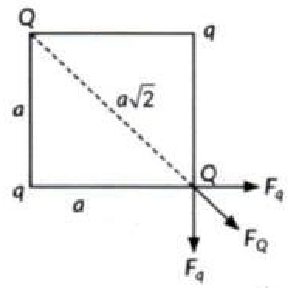
$V_{PB} = \frac{kq_B}{(d-x)}$

$V_{PA} + V_{PB} = 0$

$\frac{kq}{x} = \frac{2kq}{(d-x)}; d - x = 2x$

$$3x = d; x = \frac{d}{3}$$

9. Ans. (a) Force on charge Q due to charge q.



$$F_q = \frac{1}{4\pi\varepsilon_0}\times\frac{qQ}{a^2}$$

Force on charge Q due to another charge Q.

$F_Q = \frac{1}{4\pi\varepsilon_0}\times\frac{Q^2}{(a\sqrt{2})^2} = \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{2a^2}$

Net force on charge Q is

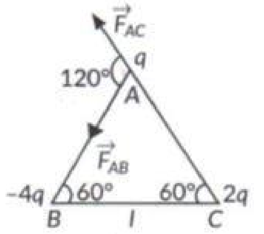
$$F_{net} = F_Q + \sqrt{F_q^2 + F_q^2} = F_Q + F_q\sqrt{2}$$
$$= \frac{1}{4\pi\varepsilon_0}\times\frac{Q^2}{2a^2} + \frac{1}{4\pi\varepsilon_0}\times\frac{qQ}{a^2}\sqrt{2}$$

$= \frac{Q}{4\pi\varepsilon_0 a^2}\left[\frac{Q}{2} + \sqrt{2}q\right]$ along diagonal

(b) Potential energy of the given system

$U = U_{qQ} + U_{Qq} + U_{qQ} + U_{qq} + U_{QQ}$
$= 4U_{qQ} + U_{qq} + U_{QQ}$
$= \frac{4qQ}{4\pi\varepsilon_0 a} + \frac{q^2}{4\pi\varepsilon_0(\sqrt{2}a)} + \frac{Q^2}{4\pi\varepsilon_0(\sqrt{2}a)}$
$= \frac{1}{4\pi\varepsilon_0 a}\left[4qQ + \frac{q^2}{\sqrt{2}a} + \frac{Q^2}{\sqrt{2}a}\right]$

10. Ans. (a) $F_{AB} = \frac{1}{4\pi\varepsilon_0}\frac{q(4q)}{l^2}$



$= \frac{1}{4\pi\varepsilon_0}\frac{4q^2}{l^2}$

$F_{AC} = \frac{1}{4\pi\varepsilon_0}\frac{q(2q)}{l^2} = \frac{1}{4\pi\varepsilon_0}\frac{2q^2}{l^2}$

Angle between forces $\vec{F}_{AB}$ and $\vec{F}_{AC}$ is 120^0.

Magnitude of resultant force,

$F = \sqrt{F_{AB}^2 + F_{AC}^2 + 2F_{AB}F_{AC}\cos 120^0}$

$= \frac{1}{4\pi\varepsilon_0}\left(\frac{q^2}{l^2}\right)\sqrt{(4)^2 + (2)^2 + 2\times 4\times 2\times\left(\frac{-1}{2}\right)}$

$= \frac{1}{4\pi\varepsilon_0}\frac{q^2}{l^2}\sqrt{16+4-8} = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{l^2}(2\sqrt{3})$

(b) Required work done =Change in potential energy of the system = $U_f - U_i$

$= 0 - (U_{AB} + U_{BC} + U_{CA})$

$= \frac{-1}{4\pi\varepsilon_0 l}[q(-4q) + (-4q)(2q) + (q)(2q)]$

$= \frac{-1}{4\pi\varepsilon_0 l}[-4q^2 - 8q^2 + 2q^2] = \frac{10q^2}{4\pi\varepsilon_0 l}$

11. Ans. (i) Capacitance $C = \frac{\varepsilon_0 A}{d}$

$= \frac{8.85\times10^{-12}\times6\times10^{-3}}{3\times10^{-4}} = 17.7\times10^{-11}F$

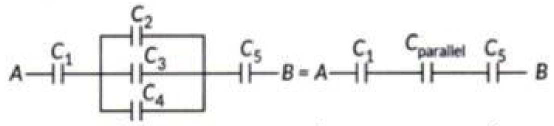
(ii) Charge Q = CV = $17.7 \times 10^{-11} \times 100$
$= 17.7 \times 10^{-9}$ C

(iii) C′ = KC

$\therefore Q' = KQ = 10.62\times10^{-8}C$

12. Ans. (i) In the circuit C_2, C_3 and C_4 are in parallel

$\therefore C_{parallel} = C_2 + C_3 + C_4 = 2+2+2 = 6\mu F$



$\therefore$ Equivalent capacitance between A and B is

$\frac{1}{C_{equivalent}} = \frac{1}{C_1} + \frac{1}{C_{parallel}} + \frac{1}{C_5}$

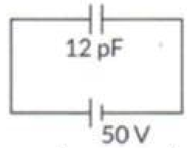
$= \frac{1}{2} + \frac{1}{6} + \frac{1}{2} = \frac{3+1+3}{6} = \frac{7}{6}$

$\therefore C_{equivalent} = \frac{6}{7} = 0.86\mu F$

(ii) $Q = C_{equivalent}V = 0.86\times7 = 6\mu C$

$\therefore Energy, E = \frac{1}{2}QV = \frac{1}{2}\times6\times7 = 21J$

13. Ans. Electrostatic energy stored in the capacitor,



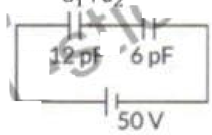
$U = \frac{1}{2}CV^2 = \frac{1}{2}\times12\times10^{-12}\times(50)^2$

(As C = 12 pF, V = 50V)

U = 1.5×10^{-8} J

When 6 pF is connected in series with 12 pF, charge stored across each capacitor,

$Q = \frac{C_1C_2}{C_1+C_2}V$



$= \frac{12\times6\times10^{-24}}{(12+6)\times10^{-12}}\times50 = 200pC$

Now, potential difference across 12 pF is,

$= \frac{Q}{C_1} = \frac{200\times10^{-12}}{12\times10^{-12}} = 16.67V$

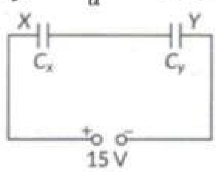
Potential difference across 6 pF is,

$= \frac{Q}{C_2} = \frac{200\times10^{-2}}{6\times10^{-12}} = 33.33V$

14. Ans. Here,

$C_x = \frac{\varepsilon_0 A}{d}$

$C_y = \frac{\varepsilon_0\varepsilon_r A}{d} = \varepsilon_r C_x = 4C_x$



(i) C_x and C_y are in series, so equivalent capacitance is given by

$C = \frac{C_x\times C_y}{C_x+C_y}$

$\Rightarrow 4 = \frac{C_x\times4C_x}{C_x+4C_x}(\because C = 4\mu F)$

$\Rightarrow 4 = \frac{4C_x}{5} \therefore C_x = 5\mu F$

And $C_y = 4\,C_x = 20\,\mu F$

(ii) Charge on each capacitor, Q = CV

$$Q = 4\times10^{-6}\times15 = 60\times10^{-6}C$$

Potential difference between the plates of X,

$$V_x = \frac{Q}{C_x} = \frac{60\times10^{-6}}{5\times10^{-6}} = 12V$$

Potential difference between the plates of Y,

$$V_y = V - V_x = 15 - 12 = 3V$$

(iii) Ratio of electrostatic energy stored,

$$\frac{U_x}{U_y} = \frac{\frac{Q^2}{2C_x}}{\frac{Q^2}{2C_y}} = \frac{C_y}{C_x} = \frac{4C_x}{C_x} = 4$$

15. Ans. (i) Given that energy of the 6 μF capacitor is E

Let V be the potential difference along the capacitor of capacitance 6 μF.

Since, $\frac{1}{2}CV^2 = E \quad \therefore \frac{1}{2}\times6\times10^{-6}\times V^2 = E$

$\Rightarrow V^2 = \frac{E}{3}\times10^6$ ....(i)

Since potential is same for parallel connection, the potential through 12 μF capacitor is also V. Hence, energy of 12 μF capacitor is

$$E_{12} = \frac{1}{2}\times12\times10^{-6}\times V^2 = \frac{1}{2}\times12\times10^{-6}\times\frac{E}{3}\times10^6 = 2E$$

(ii) Since charge remains constant in series, the charge on 6 μF and 12 μF capacitors combined will be equal to the charge on 3 μF capacitor. Using the formula, Q = CV.

We can write

$$(6+12)\times10^{-6}\times V = 3\times10^{-6}\times V'$$

$$V' = 6V$$

Using (i) and squaring both sides, we get

$$V'^2 = 12E\times10^6$$

$$\therefore E_3 = \frac{1}{2}\times3\times10^{-6}\times12E\times10^6 = 18E$$

(iii) Total energy drawn from battery is

$$E_{total} = E + E_{12} + E_3 = E + 2E + 18E = 21E$$

16. Ans. Given E = 10r + 5

Now the electric potential, $V = -\int E.dr$

$$= -\int_1^{10}(10r+5)\,dr = -\left[\frac{10r^2}{2} + 5r\right]_1^{10}$$

$$= -1[5r^2 + 5r]_1^{10} = -[(5\times100+50)-(5+5)]$$

$$= -540V$$

17. Ans. Electric field $E = -\frac{dV}{dx}$

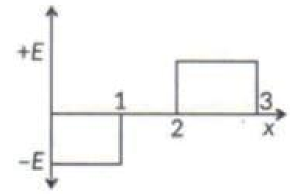
$For x = 0 to 1, V = kx$ ....(i)

$x = 1 to 2, V = k$

$x = 2 to 3, V = -kx$

Where k is some constant

So, using (i) the variation of electric field is shown in figure.



18. Ans. Since net force on electric dipole in uniform electric field is zero, so no work is done in moving the electric dipole in uniform electric field, however some work is done in rotating the dipole against the torque acting on it. So, small work done in rotating the dipole by an angle dθ in uniform electric field E is

$$dW = \tau d\theta = pE\sin\theta\,d\theta$$

Hence, net work done in rotating the dipole from angle θ_i to θ_f in uniform electric field is

$$W = \int_{\theta_i}^{\theta_f} pE\sin\theta\,d\theta = pE[-\cos\theta]_{\theta_i}^{\theta_f}$$

Or $W = pE[-\cos\theta_f + \cos\theta_i] = pE[\cos\theta_i - \cos\theta_f]$

If initially, the dipole is placed at an angle $\theta_i = 90^0$ to the direction of electric field, and is then rotated to the angle $\theta_f = \theta$, then net work done is

$$W = pE[\cos 90^0 - \cos\theta]$$

$$or W = -pE\cos\theta$$

This gives the work done in rotating the dipole through an angle θ in uniform electric field, which gets stored in it in the form of potential energy i.e.,

$$U = -pE\cos\theta$$

This gives potential energy stored in electric dipole of moment p when placed in uniform electric field at an angle θ with its direction.

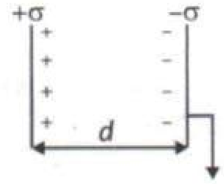
(i) When $\theta = 0^0$, then $U_{min} = -pE$

So, potential energy of an electric dipole is minimum, when it is placed with its dipole moment p parallel to the direction of electric field E and so it is called its most stable equilibrium position.

(ii) When $\theta = 180^0, then\,U_{max} = +pE$

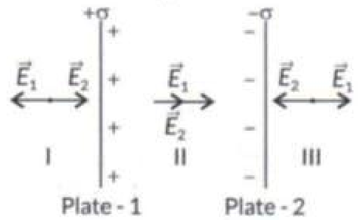
So, potential energy of an electric dipole is maximum, when it is placed with its dipole moment p anti-parallel to the direction of electric field E and so it is called its most unstable equilibrium position.

19. Ans. Capacitor is based on the principle of electrostatic induction. The capacitance of an insulated conductor increases significantly by bringing an uncharged earthed conductor near to it. This combination forms parallel plate capacitor.



(a) Magnitude of electric field intensities

$E_1 = E_2 = \frac{\sigma}{2\varepsilon_0}$



(i) In region I (outside)

$$E_1 = E_2 - E_1 = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = 0$$

(ii) In region II (inside)

$$E_{II} = E_1 + E_2 = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0}$$

(iii) In region III (outside)

$$E_{III} = E_1 - E_2 = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = 0$$

In the region II i.e., in the space between the plates, resultant electric field $\vec{E}_{II}$ is directed normal to plates, from positive to negative charge plate.

(b) The potential difference between the plates is

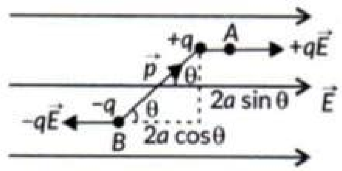
$$V = E_{II}.d = \frac{\sigma}{\varepsilon_0} d or V = \frac{Q}{A\varepsilon_0} d$$

(c) Capacitance of the capacitor so formed is

$$C = \frac{Q}{V} = \frac{Q}{Qd/A\varepsilon_0} or C = \frac{\varepsilon_0 A}{d}$$

20. Ans. (a) A pair of equal and opposite charges separated by a small vector distance is called an electric dipole. An ideal dipole consist of two very very large charges +q and -q separated by a very very small distance. An ideal dipole has almost no size.

Water molecule is an example of electric dipole.
(b) Torque on a dipole in uniform electric field:
When electric dipole is placed in a uniform electric field, its two charges experience equal and opposite forces, which cancel each other and hence net force on an electric dipole in a uniform electric field is zero.



However these forces are not collinear, so they give rise to some torque on the dipole given by
Torque = Magnitude of either force x Perpendicular distance between them

$$\tau = Fr_1 = qE.2a\sin\theta = q2a.E\sin\theta$$

Or $\tau = pE\sin\theta$

Where θ is the angle between the directions of $\vec{p}$ and $\vec{E}$.

In vectorial form, $\vec{\tau} = \vec{p} \times \vec{E}$

(i) When $\theta = 0^0$ or 180^0 then τ_{min}

(ii) When $\theta = 90^0 then \tau_{max}$

Thus, torque on a dipole tends to align it in the direction of uniform electric field.

If the field is not uniform in that condition the net force on electric dipole is not zero.

When $\theta = 0$: $\tau = 0$ and $\vec{p}$ and $\vec{E}$ are parallel and the dipole is in a position of stable equilibrium.

(c) Torque $\tau = PE\sin\theta = Q/\sin\theta$ ...(i)

Here l is the length of the dipole, Q is the charge and E is the electric field.

Therefore Q = Torque/Esin (θ)

$$= 8\sqrt{3}/(2\times10^{-2})(10^5)\frac{\sqrt{3}}{2} = 8\times10^{-3}C$$

Potential energy, $U = -PE\cos\theta = -Ql\cos\theta$ ...(ii)

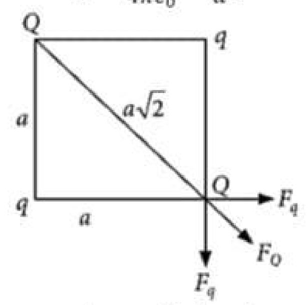
Divide equation (i) by (ii),

$$\frac{\tau}{U} = \frac{Q/\sin\theta}{-Q/\cos\theta} (where P = Ql)$$

$$\frac{\tau}{U} = -\tan\theta \Rightarrow U = \frac{\tau}{-\tan 60^0} = \frac{-8\sqrt{3}}{\sqrt{3}} = -8J$$

21. Soln. (a) Force on charge Q due to charge q.

$$F_q = \frac{1}{4\pi\varepsilon_0} \times \frac{qQ}{a^2}$$



Force on charge Q due to another charge Q,

$F_Q = \frac{1}{4\pi\varepsilon_0} \times \frac{Q^2}{(a\sqrt{2})^2}$

$= \frac{1}{4\pi\varepsilon_0} \frac{Q^2}{2a^2}$

Net force on charge Q is

$$F_{net} = F_Q + \sqrt{F_q^2 + F_q^2} = F_Q + F_q\sqrt{2}$$

$$= \frac{1}{4\pi\varepsilon_0} \times \frac{Q^2}{2a^2} + \frac{1}{4\pi\varepsilon_0} \times \frac{qQ}{a^2}\sqrt{2}$$

$$= \frac{Q}{4\pi\varepsilon_0 a^2}\left[\frac{Q}{2} + \sqrt{2}q\right] along diagonal$$

(b) Potential energy of the given system.

$$U = U_{qQ} + U_{Qq} + U_{qQ} + U_{Qq} + U_{qq} + U_{QQ}$$

$$= 4U_{qQ} + U_{qq} + U_{QQ}$$

$$= \frac{4qQ}{4\pi\varepsilon_0 a} + \frac{q^2}{4\pi\varepsilon_0(\sqrt{2}\,a)} + \frac{Q^2}{4\pi\varepsilon_0(\sqrt{2}\,a)}$$

$$= \frac{1}{4\pi\varepsilon_0 a}\left[4qQ + \frac{q^2}{\sqrt{2}a} + \frac{Q^2}{\sqrt{2}a}\right]$$

22. Soln. The potential at any point on the surface of the conductor having radius r and charge q is given by

$V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r}$

Where $\varepsilon_0 = 8.854 \times 10^{-12} C^2 N^{-1} m^{-2}$

The capacitance f the spherical conductor situated in vacuum is given by

$C = \frac{q}{V} = \frac{q}{\frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r}}$

$C = 4\pi\varepsilon_0 r$

Hence, the capacitance of an isolated spherical conductor situated in vacuum is $4\pi\varepsilon_0$ times its radius.

23. Soln. Energy stored = $\frac{1}{2}CV^2 = \frac{1}{2}\frac{Q_2}{C}$

Net capacitance with switch S closed = C + C = 2C

∴ Energy stored = $\frac{1}{2} \times 2C \times V^2 = CV^2$

After the switch S is opened, capacitance of each capacitor = KC

∴ Energy stored in capacitor $A = \frac{1}{2}KCV^2$

For capacitor B,

Energy stored

$$= \frac{1}{2}\frac{Q^2}{KC} = \frac{1}{2}\frac{C^2V^2}{KC} = \frac{1}{2}\frac{CV^2}{K}$$

∴ Total energy stored

$$= \frac{1}{2}KCV^2 + \frac{1}{2}\frac{CV^2}{K}$$

$$= \frac{1}{2}CV^2\left(K + \frac{1}{K}\right)$$

$$= \frac{1}{2}CV^2\left(\frac{K^2+1}{K}\right) \ldots\ldots (ii)$$

On dividing (i) and (ii)

∴ Required ratio = $\frac{2CV^2K}{CV^2(K^2+1)} = \frac{2K}{(K^2+1)}$

24. Soln. Given,

$c = 100\mu F$

$d = 4 \times 10^{-3} m$

$V = 200V$

$k = 5$

$Q = CV$

= 200 x 100 x 10^{-6}

= 2 x 10^{-2} Coulomb

As dielectric of 4 mm is inserted between the plates of capacitor and the spacing between the plates is doubled then it will acts as following fig-A and fig-B.

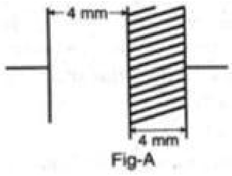


Fig-A

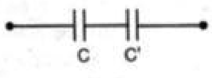


Fig-B

Here, C' will be capacitance with dielectric of 4 mm & 8 mm separation between the plates.

$C' = KC = 5 \times 100 \times 10^{-6} = 0.5 \times 10^{-3} F$

(i) Thus, equivalent capacitance

$\frac{1}{C_{eq}} = \frac{1}{C} + \frac{1}{C'} = \frac{1}{100\times10^{-6}} + \frac{1}{0.5\times10^{-3}}$

$= 10 \times 10^3 + 2 \times 10^3$

$= 12 \times 10^3$

$\frac{1}{C_{eq}} = 12 \times 10^3$

$C_{eq} = \frac{1}{12\times10^3}$

$= \frac{1}{12} \times 10^{-3}$

$C_{eq} = 83.33\mu F$

(ii) Electric field inside dielectric will be

$(E') = \frac{E}{K} = \frac{50}{5\times10^{-3}}$

$= \frac{50\times10^3}{5} = 10 \times 10^3$

$= 10000 v/m$

And Electric field inside capacitor but out of dielectric Area will be

$E = 50 \times 10^3 V/m$

(iii) Energy density f capacitor is given by:

$U = \frac{Q^2}{2C}$

$= U' + U$

$= \frac{Q^2}{2C} + \frac{Q^2}{2C'}$

$\Rightarrow \frac{Q^2}{2}\left[\frac{1}{C} + \frac{1}{C'}\right] = \frac{2\times10^{-2}\times2\times10^{-2}}{2}[12 \times 10^3]$

$\left(\because \frac{1}{C} + \frac{1}{C'} = \frac{1}{C_{eq}}\right)$

$= 2 \times 10^{-1} \times 12$

$= 2.4J$

25. Soln. When S is closed:

P.d. across C_1 = P.d. across C_2 = 6 V

$$V_1 = V_2 = 6V [\because q = CV]$$

$\therefore q_1 = q_2 = 1\mu F \times 6V = 6\mu C$

When S is open:

When dielectric slab (K = 3) are inserted,

$$C_1 = 3 \times 1\mu F = 3\mu F$$

$$C_2 = 3 \times 1\mu F = 3\mu F$$

P.d. across C_1,

$$V_1' = 6V$$

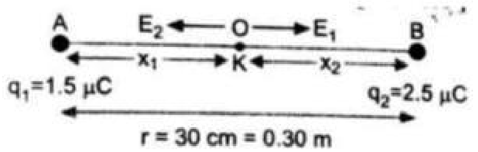
$\therefore q_1' = 3\mu F \times 6V = 18\mu C$

P.d. across C_2,

$$V_2' = \frac{q_2}{C_2} = \frac{6\mu C}{3\mu F} = 2V$$

$\therefore V_2' = 2V$

26. Soln. The potential due to similar charges is additive while electric field at a point due to individual charges are added vectorially.



(a) The electric potential at mid point O.

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1}{x_1} + \frac{q_2}{x_2}\right)$$

Here $x_1 = x_2 = \frac{0.30}{2} = 0.15m$

$$V = 9 \times 10^9 \left[\frac{1.5\times10^{-6}}{0.15} + \frac{2.5\times10^{-6}}{0.15}\right] = 9 \times 10^9 \left[10 \times 10^{-6} + \frac{50}{3} \times 10^{-6}\right]$$

$$= 9 \times 10^9 \times \frac{80}{3} \times 10^{-6} = 2.4 \times 10^4 volt$$

Electric field at O due to q_1 is towards $\vec{AB}$ and that due to q_2 is towards $\vec{BO}$ is net electric field at mid point O,

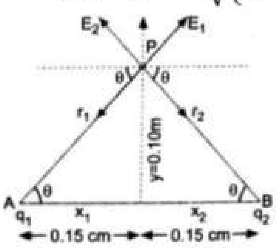
$$E = E_2 - E_1 = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_2}{x_2^2} - \frac{q_1}{x_1^2}\right)$$

$$= 9 \times 10^9 \left[\frac{2.5 \times 10^{-6}}{(0.15)^2} - \frac{1.5 \times 10^{-6}}{(0.15)^2}\right]$$

$$= 4.0 \times 10^5 N/C Charge from q_2 to q_1.$$

(b) Let P be a point at distance 10 cm = 0.10 m from O, in a plane normal to line AB.

$$AP = BP = \sqrt{(0.15)^2 + (0.10)^2} = 0.18m$$



Electric potential at P

$$V_P = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1}{(AP)} + \frac{q_2}{(BP)}\right]$$

$$= 9 \times 10^9 \left[\frac{1.5\times10^{-6}}{0.18} + \frac{2.5\times10^{-6}}{0.18}\right]$$

$$= \frac{9\times10^9\times4.0\times10^{-6}}{0.18} = 2.0 \times 10^5 volt.$$

Electric field at P due to q_1,

$$\vec{E_1} = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_1^2} along \vec{PQ} = 9 \times 10^9 \times \frac{1.5\times10^{-6}}{(0.18)^2} along \vec{PQ}$$

Electric field at P due to q_2

$$\vec{E_2} = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_2^2} along \vec{PR}$$

$$= 9 \times 10^9 \times \frac{2.5\times10^{-6}}{(0.18)^2} along \vec{PR}$$

Resolving E_1 and E_2 along and normal to AB.

Net electric field along $\vec{BA}$, $E_x = E_2 \cos\theta - E_1 \cos\theta$

$$= (E_2 - E_1)\cos\theta = (E_2 - E_1)\frac{x_1}{r_1}$$

$$= 9 \times 10^9 \left[\frac{2.5\times10^{-6} - 1.5\times10^{-6}}{(0.18)^2}\right] \times \left(\frac{0.15}{0.18}\right)$$

$$= \frac{9 \times 10^9 \times 1.0 \times 10^{-6}}{(0.18)^2} \times \left(\frac{0.15}{0.18}\right)$$

$$= 2.3 \times 10^5 N/C$$

Net electric field normal to AB, $E_y = (E_2 + E_1)\sin\theta$

$$= 9 \times 10^9 \left[\frac{2.5\times10^{-6} + 1.5\times10^{-6}}{(0.18)^2}\right] \times \frac{0.10}{0.18}$$

$$= 9 \times 10^9 \times \frac{4.0 \times 10^{-6}}{(0.18)^2} \times \frac{10}{18} = 6.2 \times 10^5 N/C$$

Net electric field $E = \sqrt{E_x^2 + E_y^2} = \sqrt{(2.3 \times 10^5)^2 + (6.2 \times 10^5)^2} = 6.6 \times 10^5 N/C$

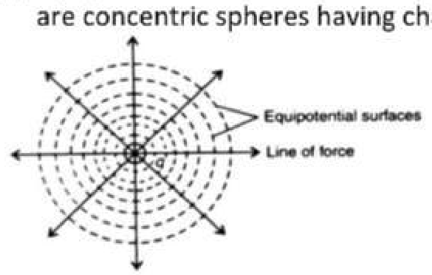
If α is the angle made by resultant field with AB, then

$$\tan\alpha = \frac{E_y}{E_x} = \frac{6.2\times10^5}{2.3\times10^5} = 2.69$$

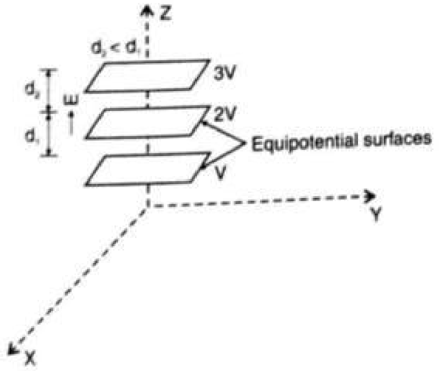
$$\Rightarrow \alpha = \tan^{-1}(2.69) = 69.6^0$$

27. Soln. Equipotential surface is a surface which has equal potential at every point on it.

(i) Equipotential surfaces due to single point charge are concentric spheres having charge at the centre.



(ii) In constant electric field along z-direction, the perpendicular distance between equipotential surfaces remains same.



For single charge, equipotential surface will be series of concentric spherical shells with charge at centre,

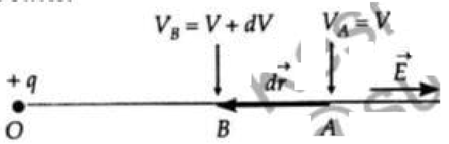
$dr \propto \frac{1}{E}$

The separation dr between equipotential surface will go on increasing with decrease in electric field.

(iii) No, because if the surface is not equipotential then it would mean that there is tangential component of electric field along surface.

This component will result in motion of electrons, but since we have static fields, this is not possible.

28. Soln. Computing electric field from electric potential. As shown in fig. consider the electric field due to charge +q located at the origin O. Let A and B be two adjacent points separated by distance dr. The two points are so close that electric field $\vec{E}$ between them remains almost constant. Let V and V + dV be the potentials at the two points.



The external force required to move the test charge q_0 (without acceleration) against the electric field $\vec{E}$ is given by

$\vec{F} = -q_0\vec{E}$

The work done to move the test charge from A to B is

$W = F.dr = -q_0 E.dr$

Also, the work in moving the test charge from A to B is

W = Charge x potential difference

$= q_0(V_B - V_A) = q_0\, d\, V$

Equating the two works done, we get

$-q_0 E.dr = q_0.dV$

$or E = -\frac{dV}{dr}$

The quantity $\frac{dV}{dr}$ is he rate of change of potential with distance and is called *potential gradient*. Thus *the electric field at any point is equal to the negative of the potential gradient at that point.* The negative sign shows that the direction of the electric field is in the direction of decreasing potential. Moreover, the field is in the direction where this decrease is steepest.

29. Soln. Here 2a = 4 cm = 0.04 m,

$\theta = 60^0$;

$\tau = 4\sqrt{3}Nm, q = 8nC = 8 \times 10^{-9}C$

Dipole moment,

$p = q \times 2a = 8 \times 10^{-9} \times 0.04 = 0.32 \times 10^{-9}Cm.$

(i) As $\tau = pE\, sin\, \theta$

$$\therefore E = \frac{\tau}{p\, sin\, \theta} = \frac{4\sqrt{3}}{0.32 \times 10^{-9} \times sin\, 60^0}$$

$$= \frac{4\sqrt{3} \times 10^9 \times 2}{0.32 \times \sqrt{3}} = 2.5 \times 10^{10}NC^{-1}.$$

(ii) $u = -pE\, cos\, \theta$

$= -0.32 \times 10^{-9} \times 2.5 \times 10^{10} \times cos\, 60^0 = -4J.$

30. Soln. Here m = 5.0 g = 5 x 10^{-3} kg,

$q = \pm 4 \times 10^{-5}C, r_1 = 1.0m, r_2 = 50cm = 0.50m$

Let v = speed of each particle at the separation of 50 cm.

From energy conservation principle,

K.E. of the two particles at 50 cm separation + P.E. of the two particles at 50 cm separation

= P.E. of the two particles at 1.0 m separation

$$\frac{1}{2}mv^2 + \frac{1}{2}mv^2 + \frac{1}{4\pi\varepsilon_0}.\frac{q_1q_2}{r_2} = \frac{1}{4\pi\varepsilon_0}.\frac{q_1q_2}{r_1}$$

$$mv^2 = \frac{q_1q_2}{4\pi\varepsilon_0}\left[\frac{1}{r_1} - \frac{1}{r_2}\right] or v^2 = \frac{q_1q_2}{4\pi\varepsilon_0 m}\left[\frac{r_2 - r_1}{r_1r_2}\right]$$

$\therefore v^2$

$$= \frac{4 \times 10^{-5} \times (-4 \times 10^{-5}) \times 9 \times 10^9}{5 \times 10^{-3}}\left[\frac{0.50 - 1.0}{1.0 \times 0.50}\right]$$

$= 2880 or v = 53.67ms^{-1}$

31. Soln. $\therefore C_{eq} = \frac{C_1C_2}{C_1+C_2} = \frac{A\varepsilon_0}{d}\left(\frac{K_1K_2}{K_1+K_2}\right)$

Now, capacitor C_3 can be considered as made up of two capacitors C_1 and C_2, each of plate area A and separation d, connected in series.

We have $C_1' = \frac{A\varepsilon_0 K_1}{d}$

And $C_2' = \frac{A\varepsilon_0 K_2}{d}$

$\Rightarrow C_3 = \frac{C_1'C_2'}{C_1'+C_2'} = \frac{A\varepsilon_0}{d}\left(\frac{K_1K_2}{K_1+K_2}\right)$

$\therefore \frac{C_3}{C_{eq}} = 1$

Hence, the net capacitance of the combination is equal to that of C_3.

32. Soln. Capacitors C_2 and C_3 form a parallel combination. Their equivalent capacitance is

$$C' = C_2 + C_3 = (4 + 2)\mu F = 6\mu F$$

Now C_1 and C' form a series combination, therefore, the equivalent capacitance of the entire network is

$$C = \frac{CC'}{C+C'} = \frac{3\times6}{3+6} = 2\mu F$$

The charge on the equivalent capacitor is

$$q = CV = 2 \times 10^{-6} \times 1200C = 2.4 \times 10^{-3}C$$

This must be equal to the charge on C_1 and also the sum of the charges on C_2 and C_3. Thus

$$V_A - V_B = \frac{q}{C_1} = \frac{2.4\times10^{-3}}{3\times10^{-6}} = 800V$$

$$V_A = 1200V$$

$$\therefore V_B = 1200 - 800 = 400V$$

Hence $V_C - V_B = 400 - 0 = 400V$

$q_2 = C_2(V_C - V_B) = 4 \times 10^{-6} \times 400C = 1.6 \times 10^{-3}C$

$$q_3 = C_3(V_C - V_B) = 2 \times 10^{-6} \times 400C = 0.8 \times 10^{-3}C$$

$q_1 = q = 2.4 \times 10^{-3}C.$