

ARIHANT

JEE/NEET/CBSE/PRE-FOUNDATION

For Physics

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ELECTROSTATIC

1 ELECTRIC CHARGE

Charge is the property associated with matter due to which it produces and experiences electrical and magnetic effects.

All bodies consist of atoms, which contain equal amount of positive and negative charges in the form of protons and electrons respectively. The number of electrons being equal to the number of protons as an atom is electrically neutral. If the electrons are removed from a body, it gets positively charged. If the electrons are transferred to a body, it gets negatively charged.

“Similar charges (charges of the same sign) repel one another; and dissimilar charges (charges of opposite sign) attract one another.”

1.1 WAYS OF CHARGING A BODY

(i) Charging by friction

When two bodies are rubbed together, a transfer of electrons takes place from one body to another. The body from which electrons have been transferred is left with an excess of positive charge, so it gets positively charged. The body which receives the electrons becomes negatively charged.

“The positive and negative charges produced by rubbing are always equal in magnitude.”

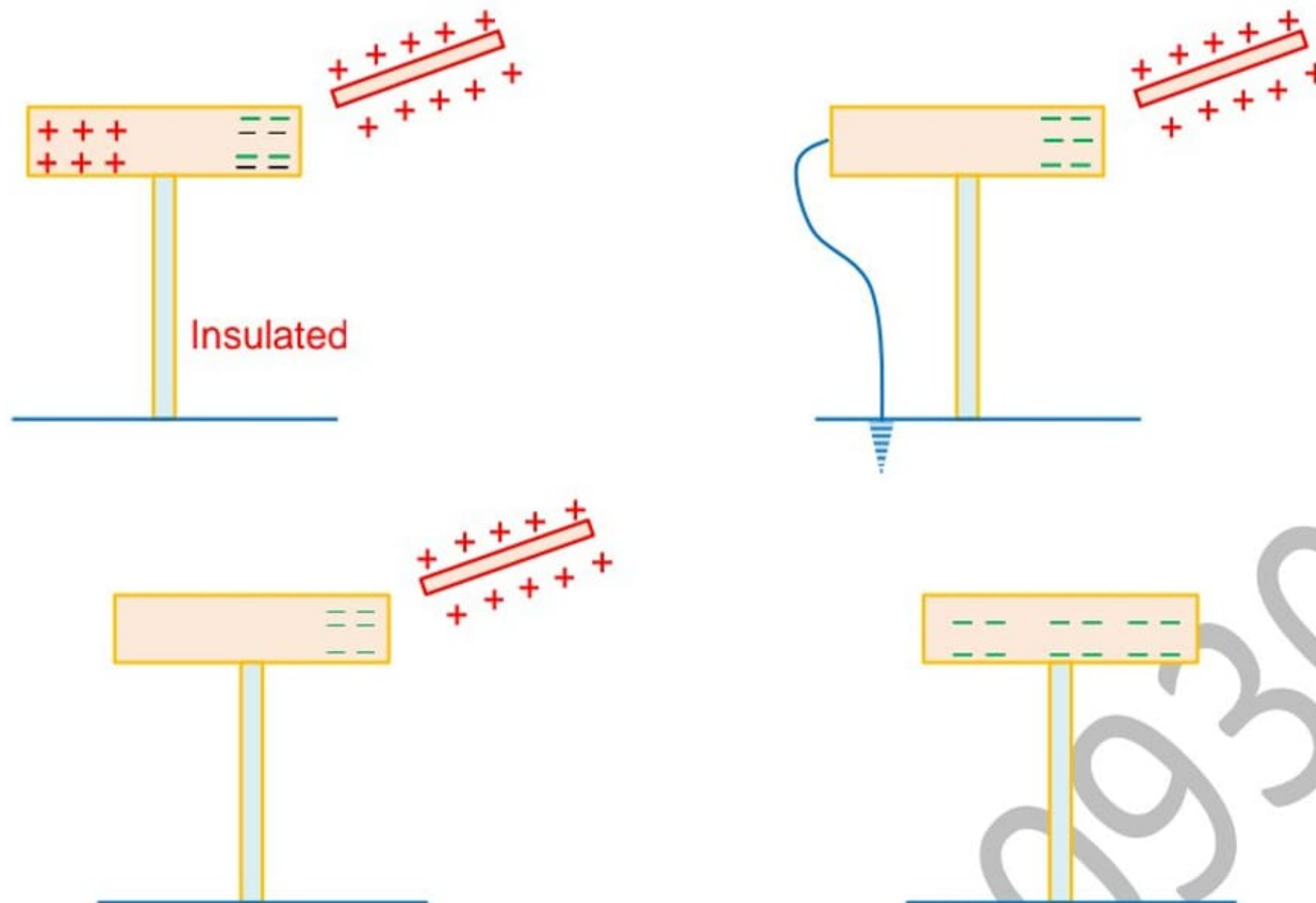
When a glass rod is rubbed with silk, it loses its electrons and gets a positive charge, while the piece of silk acquires equal negative charges.

An ebonite rod acquires a negative charge, if it is rubbed with wool (or fur). The piece of wool (or fur) acquires an equal positive charge.

(ii) Charging by electrostatic induction

If a positively charged rod is brought near an insulated conductor, the negative charges (electrons) in the conductor will be attracted towards the rod. As a result, there will be an excess of negative charge at the end of the conductor near the rod and the excess of positive charge at the far end. This is known as ‘electrostatic induction’.

The charges thus induced are found to be equal and opposite to each other. Now if we touch the far end with a conductor connected to the earth, the positive charges here will be cancelled by negative charges coming from the earth through the conducting wire. Now, if we remove the wire first and then the rod, the induced negative charges which were held at the outer end will spread over the entire conductor. It means that the conductor has become negatively charged by induction. In the same way one can induce a positive charge on a conductor by bringing a negative charged rod near it.



Important points regarding electrostatic induction

- (a) Inducing body neither gains nor loses charges.
- (b) The nature of induced charge is always opposite to that of inducing charge.
- (c) Induced charge can be lesser or equal to inducing charge but it is never greater than the inducing charge.
- (d) Induction takes place only in bodies (either conducting or non-conducting) and not in particles.

(iii) Charging by conduction

Let us consider two conductors, one charged and the other uncharged. We bring the conductors in contact with each other. The charge (whether negative or positive) under its own repulsion will spread over both the conductors. Thus the conductors will be charged with the same sign. This is called 'charging by conduction (through contact)'.

1.2 UNIT OF CHARGE

In SI units as current is assumed to be fundamental quantity and $I=q/t$, charge is a derived physical quantity with dimensions $[AT]$ and unit (ampere \times second) called 'coulomb (C)'.

The coulomb is related to CGS units of charge through the basic relation

$$1 \text{ coulomb} = 3 \times 10^9 \text{ esu of charge} = 1/10 \text{ emu of charge}$$

1.3 PROPERTIES OF CHARGE

(i) Charge is always associated with mass

The charge can not exist without mass though mass can exist without charge.

(ii) Charge is quantised

When a physical quantity can have only discrete values rather than any value, the quantity is said to be quantised.

Several experiments have established that the smallest charge that can exist in nature is the charge of an electron. If the charge of an electron ($= 1.6 \times 10^{-19} \text{C}$) is taken as the elementary unit, i.e., quanta of charge, and is denoted by e , the charge on any body will be some integral multiple of e , i.e.,

$$q = \pm ne ; n = 1, 2, 3, \dots \dots \dots \quad \dots (1)$$

charge on a body can never be $\left(\frac{2e}{3}\right)$, $(17.2)e$ or $(10^{-5})e$ etc.

(iii) Charge is conserved

A large number of experiments show that in an isolated system, total charge does not change with time, though individual charges may change, i.e., charge can neither be created nor be destroyed. This is known as the principle of conservation of charge.

(iv) Charge is invariant

This means that charge is independent of frame of reference, i.e., charge on a body does not change whatever be its speed.

1.4. CONDUCTORS AND INSULATORS

The conductors are materials, which allow electricity (electric charge) to pass through them due to the presence of free electrons. e.g., metals are good conductors.

The insulators are materials, which do not allow electric charge to pass through them as there is no free electrons in them. e.g. wood, plastics, glass etc.

Illustration 1

Question: How many electrons must be removed from a piece of metal so as to leave it with a positive charge of 3.2×10^{-17} coulomb?

Solution: From 'Quantization of charge', we know $Q = ne$

$$\therefore n = \frac{Q}{e} = \frac{3.2 \times 10^{-17} \text{ C}}{1.6 \times 10^{-19} \text{ C}} = 200$$

Illustration 2

Question: A copper penny has a mass of 32 g. Being electrically neutral, it contains equal amounts of positive and negative charges. What is the magnitude of these charges in μC . A copper atom has a positive nuclear charge of 3×10^{-26} C. Atomic weight of copper is 64g/mole and Avogadro's number is 6×10^{23} atoms/mole.

Solution: 1 mole i.e., 64 g of copper has 6×10^{23} atoms. Therefore, the number of atoms in copper penny of 32 g is

$$\frac{6 \times 10^{23}}{64} \times 32 \times 10^{-3} = 3 \times 10^{20}$$

One atom of copper has each positive and negative charge of 3×10^{-26} C. So each charge on the penny is

$$(3 \times 10^{20}) \times (3 \times 10^{-26}) = 9 \mu\text{C}.$$

2 COULOMB'S LAW

"Two stationary point charges repel or attract each-other with a force which is directly proportional to the product of the magnitudes of their charges and inversely proportional to the square of the distance between them."

Let 'r' be the distance between two point charges q_1 and q_2 .

According to **Coulomb's law**, we have $F \propto \frac{|q_1| |q_2|}{r^2}$

where F is the magnitude of the mutual force that acts on each of the two charges q_1 and q_2 . or,

$$F = \frac{K |q_1| |q_2|}{r^2}, \text{ where } K \text{ is a constant of proportionality}$$

The value of K depends upon the medium in which two point charges are placed.

In the SI system. $K = \frac{1}{4\pi\epsilon_0}$ for vacuum (or air)

The constant ϵ_0 ($= 8.85 \times 10^{-12} \text{ C}^2/\text{N}\cdot\text{m}^2$) is called "permittivity" of the free space. Thus

$$F = \frac{1}{4\pi\epsilon_0} \frac{|q_1| |q_2|}{r^2} \approx 9 \times 10^9 \frac{q_1 q_2}{r^2} \quad \dots (2)$$

2.1. PERMITTIVITY OF A MEDIUM



If the medium between the two point charges q_1 and q_2 is not a vacuum (or air). Then the electrostatic force between the two charges becomes

$$F = \frac{1}{4\pi\epsilon} \frac{|q_1||q_2|}{r^2} = \frac{1}{4\pi\epsilon_0\epsilon_r} \frac{|q_1||q_2|}{r^2} \quad \dots (3)$$

where $\epsilon = \epsilon_0\epsilon_r$ is called the 'absolute permittivity' or 'permittivity' of the medium and ϵ_r is a dimensionless constant called 'relative permittivity' of the medium which is a constant for a given medium. ϵ_r is also sometimes called "dielectric constant' or 'specific inductive capacity' of the medium.

2.2.COLOUMB'S LAW IN VECTOR FORM

The vector form of Coulomb's law is $\vec{F} = \frac{Kq_1q_2}{r^2} \hat{r}$... (4)

The unit vector \hat{r} has its origin at the 'source of the force". For example, to find the force on q_2 , the origin of \hat{r} is at q_1 . The signs of the charges must be explicitly included in equation (4). If F is the magnitude of the force, then $\vec{F} = + F\hat{r}$ means a repulsion, whereas $\vec{F} = -F\hat{r}$ means an attraction.



3 PRINCIPLE OF SUPERPOSITION

According to the principle of superposition, the force acting on one charge due to another is independent of the presence of charges. So, we can calculate the force separately for each pair of charges and then take their vector sum or find the net force on any charge.

The figure shows a charge q_1 interacting with other charges. Thus, to find the force on q_1 , we first calculate the forces exerted by each of the other charges, one at a time. The net force \vec{F}_1 on q_1 is

$$\text{simply the vector sum } \vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \dots \dots (5)$$

where \vec{F}_{12} is the force on the charge q_1 due to the charge q_2 and so on.

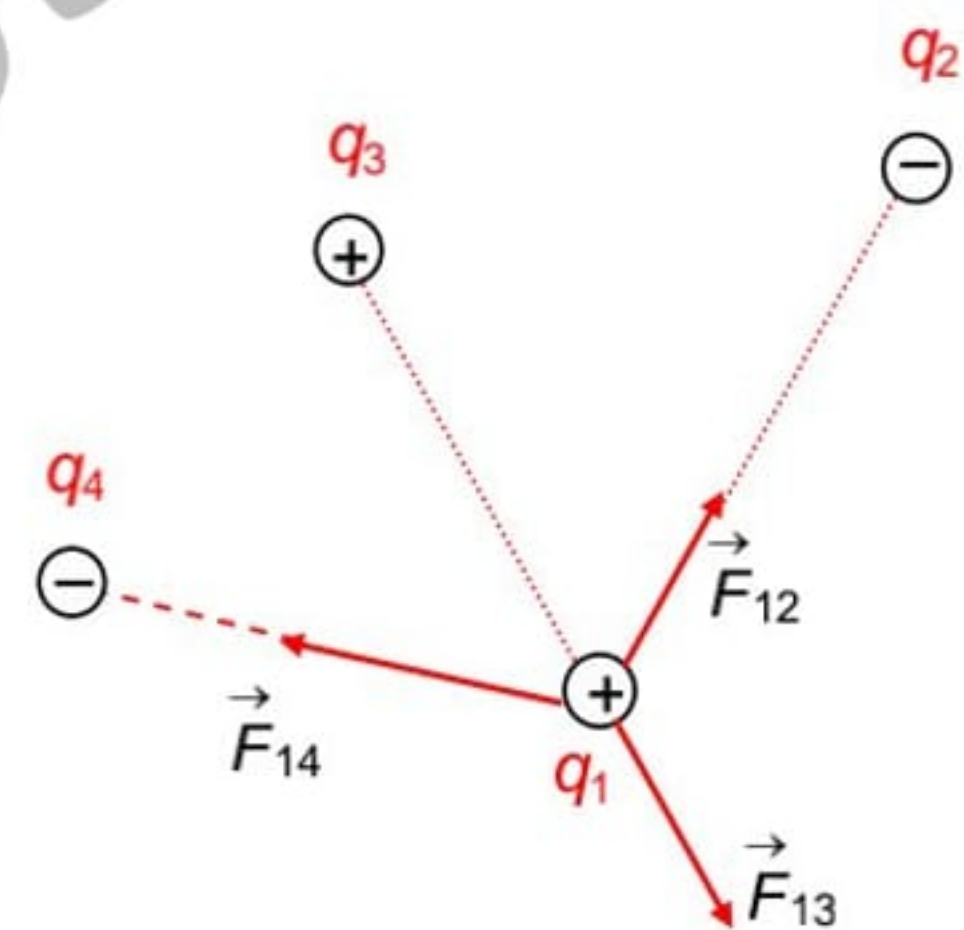


Illustration 3

Question:The electron and the proton in a hydrogen atom are 0.53×10^{-11} m apart. Compare the electrostatic and the gravitational forces between them in power of 10^{-41} .

Solution:The magnitude of the electrostatic force is

$$\begin{aligned} F_E &= \frac{1}{4\pi\epsilon_0} \frac{e^2}{r^2} \\ &= \frac{(9 \times 10^9 \text{ N-m}^2/\text{C}^2) \times (1.6 \times 10^{-19} \text{ C})^2}{(5.3 \times 10^{-11} \text{ m})^2} \\ &= 8.2 \times 10^{-8} \text{ N} \end{aligned}$$

The magnitude of the gravitational force is

$$F_G = G \frac{m_e m_p}{r^2}$$

$$= \frac{(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(9.11 \times 10^{-31} \text{ kg})(1.67 \times 10^{-27} \text{ kg})}{(5.3 \times 10^{-11} \text{ m})^2}$$

$$= 3.6 \times 10^{-47} \text{ N}$$

The ratio of the forces

$$\frac{F_G}{F_E} = 44$$

The $\frac{F_G}{F_E}$ is extremely small. So when we deal with the electrical interaction between elementary particles, gravity may safely be ignored.

Illustration 4

Question: Three charges lie along the x-axis as $q_1 = 15.0 \mu\text{C}$ is at $x = 2.0 \text{ m}$, and the positive charge $q_2 = 6.00 \mu\text{C}$ is at $x = 0$ on the x-axis such that the resultant force on it is zero? (in mm)

Solution: Since q_3 is negative and both q_1 and q_2 are positive, the forces \vec{F}_{31} and \vec{F}_{32} are both attractive. Let x be the co-ordinate of q_3

We have

$$F_{31} = \frac{K |q_3| |q_1|}{(2-x)^2}; F_{32} = \frac{K |q_3| |q_2|}{x^2}$$

Since the net force on the charge q_3 is zero,

$$\text{we have, } \frac{K |q_3| |q_2|}{x^2} = \frac{K |q_3| |q_1|}{(2-x)^2}$$

$$\text{or, } (4 - 4x + x^2) (6 \times 10^{-6} \text{ C}) = x^2 (15 \times 10^{-6} \text{ C})$$

Solving this quadratic equation for x , we get $x = 775$

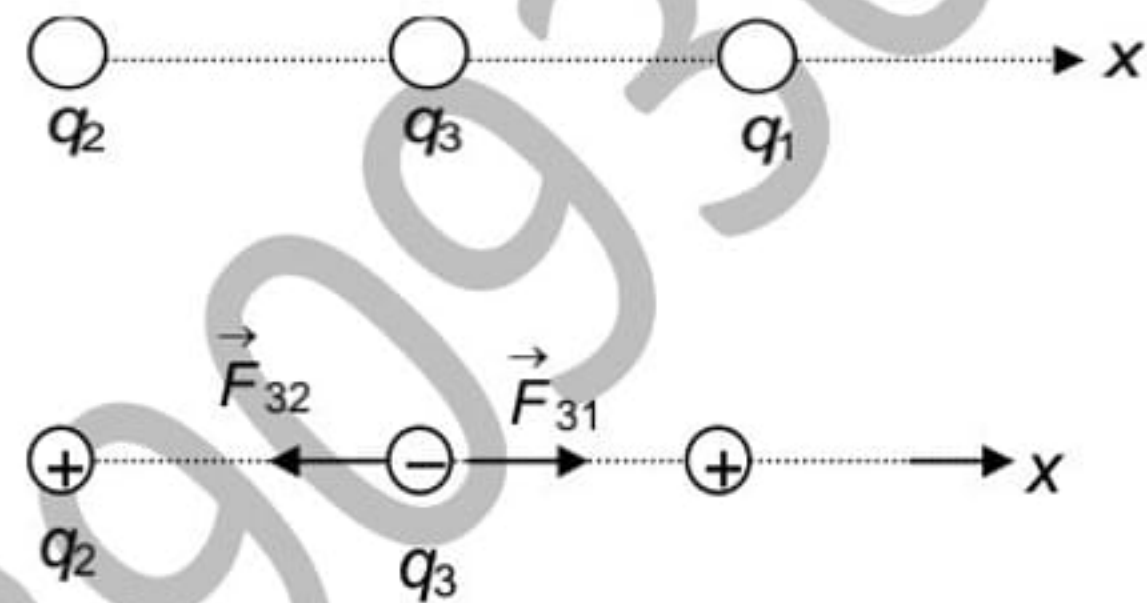


Illustration 5

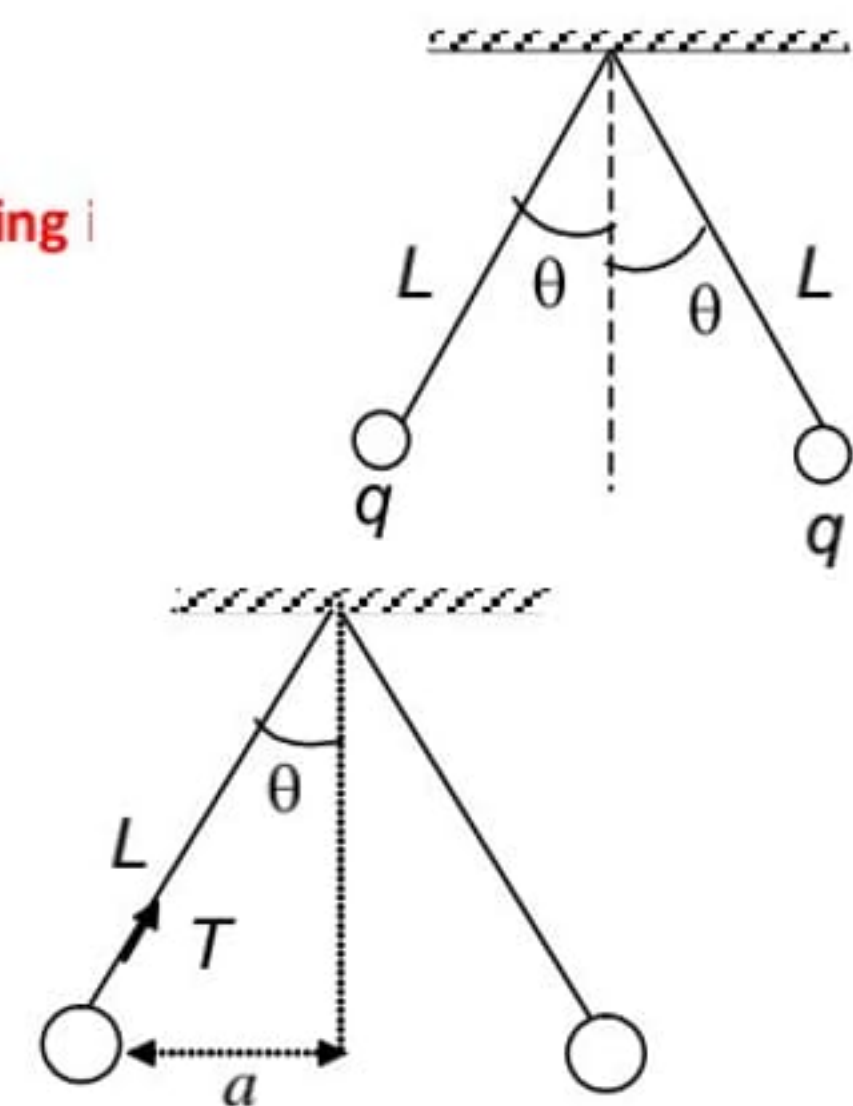
Question: Two identical small charged spheres, each having a mass of $3.0 \times 10^{-2} \text{ kg}$, hang in equilibrium as shown below. If the length of each string is 15 m and the strings make an angle of 45° with the vertical, find the magnitude of the charge on each sphere in nC. ($g = 10 \text{ m/s}^2$)

Solution: From the right angled triangle, we have $\sin \theta = \frac{a}{L}$

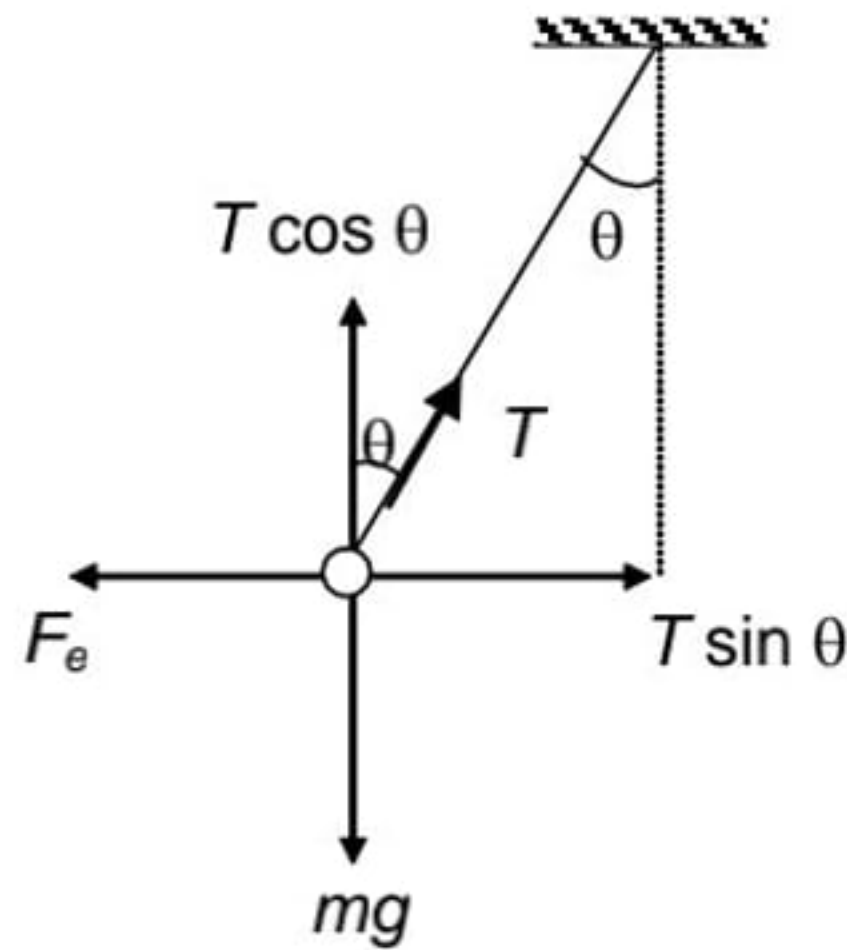
$$\text{or, } a = L \sin \theta = (15 \text{ m}) \sin 45^\circ = 10.6 \text{ m}$$

Hence, the separation of the spheres is

$$2a = 21.2 \text{ m}$$



F.B.D. of one of the spheres:-



Since the sphere is in equilibrium, the resultants of the forces in the horizontal and vertical directions must separately add up to zero. thus

$$\begin{aligned} T \sin \theta - F_e &= 0 \\ \Rightarrow T \sin \theta &= F_e && \dots (i) \\ \text{and } T \cos \theta - mg &= 0 \\ \Rightarrow T \cos \theta &= mg && \dots (ii) \end{aligned}$$

Dividing equation (i) by equation (ii), we get

$$\begin{aligned} \tan \theta &= \frac{F_e}{mg} \quad \text{or, } F_e = mg \tan \theta \\ &= (3 \times 10^{-2} \text{ kg}) \times (10 \text{ m/s}^2) (\tan 45^\circ) \\ &= 0.3 \text{ N} \end{aligned}$$

Let q be charge on each sphere.
According to Coulomb's law

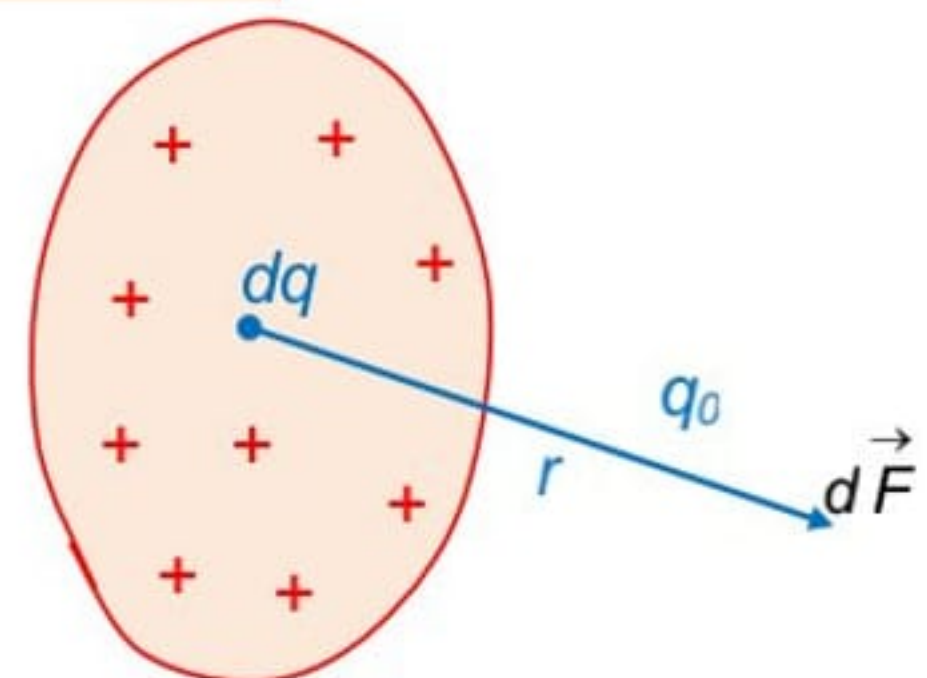
$$F_e = \left(\frac{1}{4\pi\epsilon_0} \right) \frac{|q||q|}{r^2}$$

$\therefore q = 15 \mu\text{C}$

4

FORCE DUE TO CONTINUOUS CHARGE

To find the force exerted by a continuous charge distribution on a point charge, we divide the charge into infinitesimal charge elements. Each infinitesimal charge element is then considered as a point charge.



The magnitude of the force dF exerted by the charge dq on the charge q_0 is given by

$$dF = \frac{1}{4\pi\epsilon_0} \frac{|dq||q_0|}{r^2}$$

where r is the distance between dq and q_0 . The total force is then found by adding all the infinitesimal force elements, which involves the integral

$$\vec{F} = \int d\vec{F}$$

Taking $d\vec{F} = dF_x \hat{i} + dF_y \hat{j} + dF_z \hat{k}$, we have

$$\left. \begin{aligned} F_x &= \int dF_x \\ F_y &= \int dF_y \\ F_z &= \int dF_z \end{aligned} \right\} \dots (6)$$

Because of the vector nature of the integration, the mathematical procedure must be carried out with care. The symmetry of charge distribution will usually result in a simplified calculation.

Each type of charge distribution is described (in the table given below) by an appropriate Greek letter parameter: λ , σ or ρ .

How we choose the charge element dq depends upon the particular type of the charge distribution.

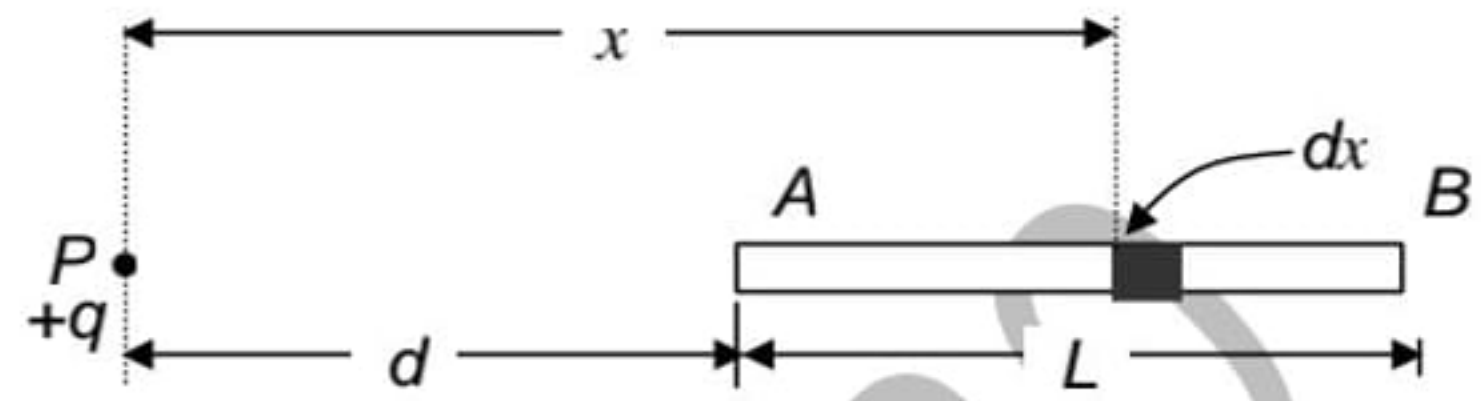
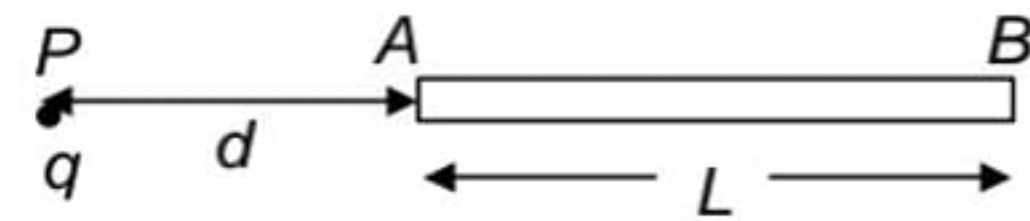
Charge distribution	Relevant parameter	SI units	Charge element dq
Along a line	λ , charge per unit length	C/m	$dq = \lambda dx$
On a surface	σ , charge per unit area	C/m ²	$dq = \sigma dA$
Throughout a volume	ρ , charge per unit volume	C/m ³	$dq = \rho dV$

Illustration 6

Question: A point charge q is situated at a distance ' d ' from one end of a thin non-conducting rod of length L having a charge Q (uniformly distributed along its length) as shown. Find the magnitude of the electric force between the two. (in N)

(take, $q=10^{-6}\text{C}$, $Q=9\times 10^{-3}\text{C}$, $d = 1\text{m}$, $L = 2\text{m}$)

Solution: Consider an element of rod of length ' dx ' at a distance x from the point charge q . Treating the element as a point charge, the force between q and the charge element will be



$$dF = \frac{1}{4\pi\epsilon_0} \frac{qdQ}{x^2}$$

But $dQ = \left(\frac{Q}{L}\right) dx$

So, $dF = \frac{1}{4\pi\epsilon_0} \frac{qQdx}{Lx^2}$

$\therefore F = \frac{1}{4\pi\epsilon_0} \frac{qQ}{L} \int_d^{d+L} \frac{dx}{x^2}$

$$= \frac{1}{4\pi\epsilon_0} \left[-\frac{1}{x} \right]_d^{d+L}$$

$$= \frac{1}{4\pi\epsilon_0} \frac{qQ}{L} \left[\frac{1}{d} - \frac{1}{d+L} \right]$$

$$= \frac{1}{4\pi\epsilon_0} \frac{qQ}{d(d+L)}$$

$$= 27$$

Illustration 7

Question: A thin non-conducting rod of length L and having a charge Q (uniformly distributed along its length) is placed along x -axis, as shown. Find the force (in N) exerted by the rod on the point charge q_0 located on the perpendicular bisector of the rod (the positive y -axis) at a distance y from the centre (take $y=1\text{m}$, $L=2\text{m}$, $q_0 = \sqrt{2} \times 10^{-6}\text{C}$, $q = 9 \times 10^{-3}\text{C}$.)

Solution: Consider an element of rod of length ' dx ' at a distance x from the centre. Treating the element as a point charge, the force between q and the charge element will be

$$dF = \frac{1}{4\pi\epsilon_0} \frac{q_0 dq}{r^2}$$

The direction of $d\vec{F}$ is shown in the figure. But $dq = \lambda dx$

$$\text{So, } dF = \frac{1}{4\pi\epsilon_0} \frac{q_0 \lambda dx}{r^2}$$

For every charge element dq located at position $+x$, there is another charge element dq located at $-x$. When we add the forces due to the charge elements at $+x$ and $-x$, we find the x components have equal magnitudes but point in opposite directions. So their sum is zero, i.e., $F_x = 0$

$$\begin{aligned} \text{Now, } dF_y &= dF \sin \theta \\ &= \frac{1}{4\pi\epsilon_0} \frac{q_0 \lambda dx}{x^2 + y^2} \frac{y}{\sqrt{x^2 + y^2}} \end{aligned}$$

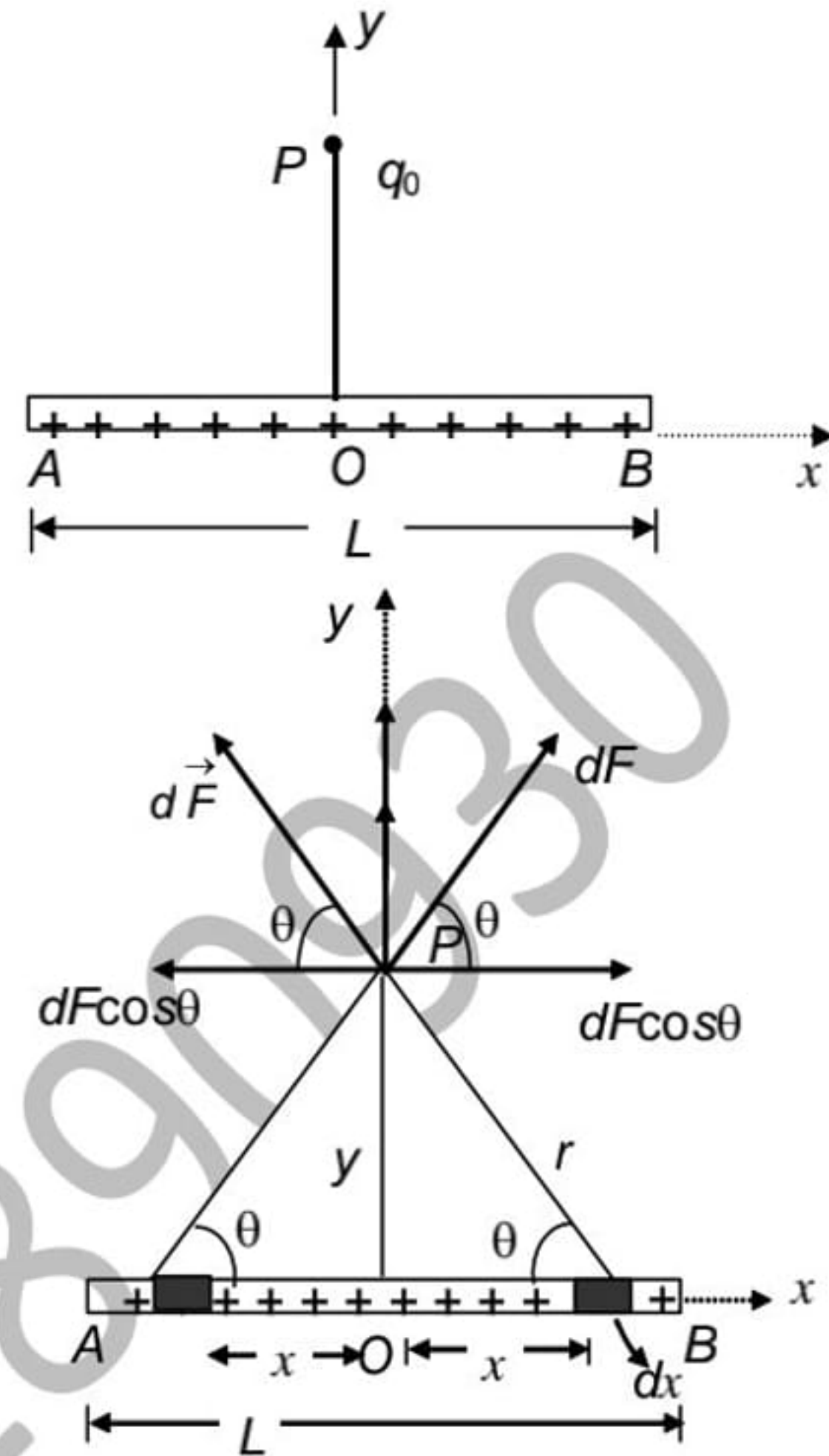
$$(\because r^2 = x^2 + y^2; \sin \theta = \frac{y}{\sqrt{x^2 + y^2}})$$

$$\text{or, } dF_y = \frac{1}{4\pi\epsilon_0} \frac{q_0 \lambda y dx}{(x^2 + y^2)^{3/2}}$$

$$\therefore F_y = \int dF_y = \frac{1}{4\pi\epsilon_0} q_0 \lambda y \int_{-\frac{L}{2}}^{+\frac{L}{2}} \frac{dx}{(x^2 + y^2)^{3/2}}$$

Evaluating the integral, we obtain

$$F_y = \frac{1}{4\pi\epsilon_0} \frac{q_0 q}{y \sqrt{y^2 + \frac{L^2}{4}}} = 81$$



5 ELECTRIC FIELD

An electric field is defined as a region in which there should be a force on a charge brought into that region. Whenever a charge is being placed in an electric field, it experiences a force.

Electric fields that we will study are usually produced by different types of charged bodies – point charges, charged plates. Charged sphere etc. We can also define the electric field of a charged body as its region of influence within which it will exert force on other charges.



If two point charges are placed as shown, we describe the forces on them in two ways

(i) The charge q_2 is in the electric field of charge q_1 . Thus the electric field of charge q_1 exerts force on q_2 .

(ii) The charge q_1 is in the electric field of charge q_2 . Hence the electric field of charge q_2 exerts a force on q_1 .

Electric field $\xrightarrow{\text{exerts force on}}$ charges inside it.

Electric field $\xrightarrow{\text{is created by}}$ charged bodies.

5.1 ELECTRIC INTENSITY OR ELECTRIC FIELD STRENGTH (\vec{E})

The electric field intensity at a point in an electric field is the force experienced by a unit positive charge placed at that point, it is being assumed that the unit charge does not affect the field.

Thus, if a positive test charge q_0 experiences a force \vec{F} at a point in an electric field, then the electric field intensity \vec{E} at that point is given by

$$\vec{E} = \frac{\vec{F}}{q_0} \quad \dots (7)$$

Important points regarding electric Intensity

(i) It is a vector quantity. The direction of the electric field intensity at a point inside the electric field is the direction in which the electric field exerts force on a (unit) positive charge.

(ii) Dimensions of the electric field intensity

$$E = \frac{F}{q_0} = \frac{[MLT^{-2}]}{[AT]} = [MLT^{-3}A^{-1}]$$

In S.I. systems, the unit of \vec{E} is N/C or V/m as

$$\frac{N}{C} = \frac{N \times m}{C \times m} = \frac{J}{C \times m} = \frac{V}{m}$$

5.2. FORCE EXERTED BY A FIELD ON A CHARGE INSIDE IT

By definition as $\vec{E} = \frac{\vec{F}}{q_0}$, i.e.,

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

If q_0 is a +ve charge, force \vec{F} on it is in the direction of \vec{E} . If q_0 is a -ve charge, \vec{F} on it is opposite to the direction of \vec{E}



Illustration 8

Question: An electron ($q = -e$) is placed near a charged body experiences a force in the positive y direction of magnitude 3.60×10^{-8} N.

- (a) The electric field at that location is $x \times 10^{-9}$, find x . (where x is in N)
(b) What would be the force exerted by the same charged body on an alpha particle ($q = +2e$) placed at the location initially occupied by the electron?

Solution: Using equation (7), we have

$$E_y = \frac{|F_y|}{|q_0|} = \frac{3.60 \times 10^{-8} \text{ N}}{1.60 \times 10^{-19} \text{ C}} = 225$$

The electric field is in the negative y direction.

(b) The force on the alpha particle is given by

$$F_y = q_0 E_y = 2(+1.60 \times 10^{-19} \text{ C})(2.25 \times 10^{11} \text{ N/C}) = 72$$

The force is in the negative y direction, the same direction as the electric field.

5.3. ELECTRIC FIELD INTENSITY DUE TO A POINT CHARGE

Let a positive test charge q_0 be placed at a distance r from a point charge q . The magnitude of force acting on q_0 is given by Coulomb's law,

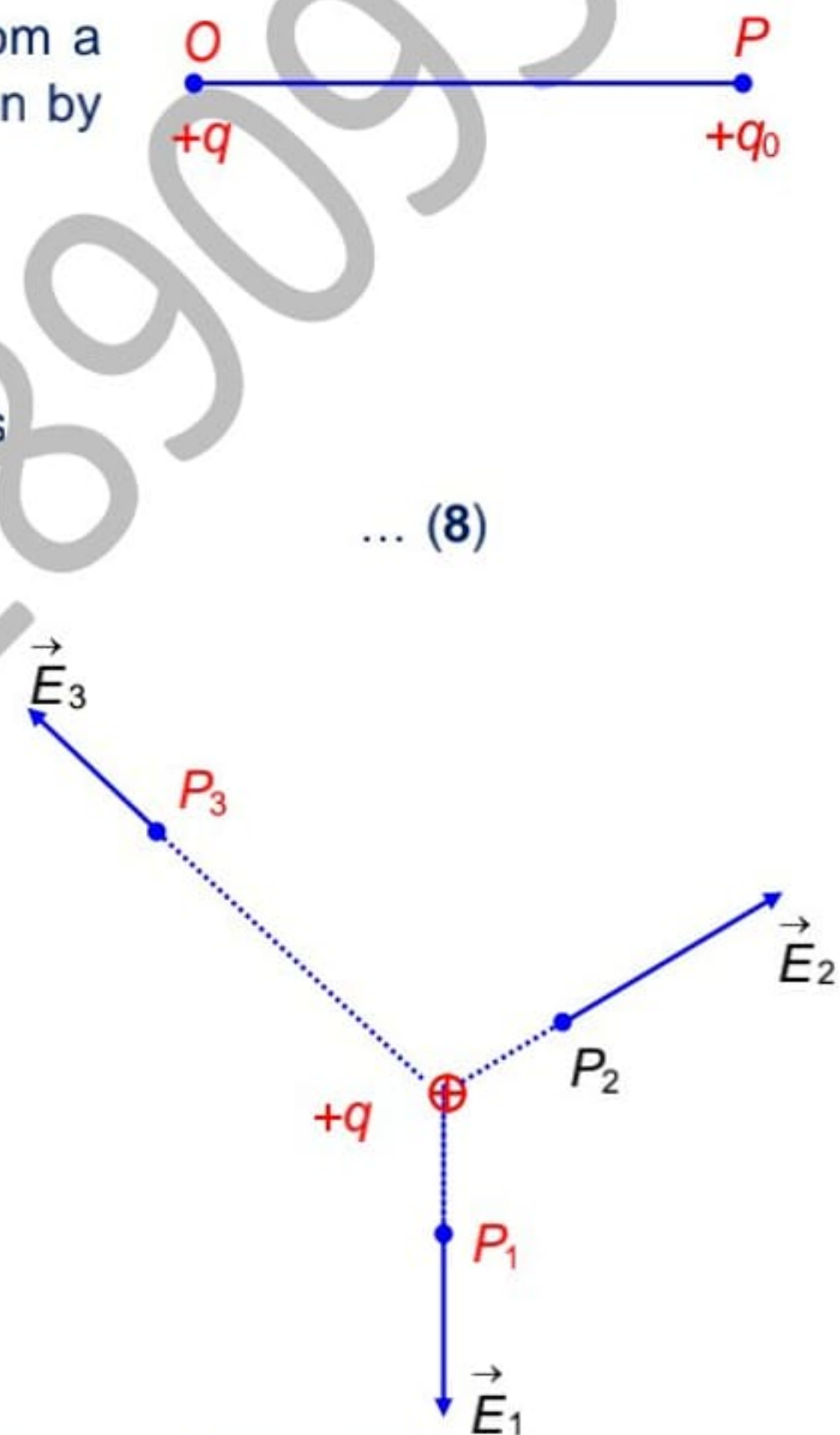
$$F = \frac{1}{4\pi\epsilon_0} \frac{q_0 q}{r^2}$$

The magnitude of the electric field at the site of the charge is

$$E = \frac{F}{q_0} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \quad \dots (8)$$

The direction of \vec{E} is the same as the direction of \vec{F} , along a radial line from q , pointing outward if q is positive and negative if q is negative.

The figure given below shows the direction of the electric field \vec{E} at various points near a positive point charge.



5.4. ELECTRIC FIELD INTENSITY DUE TO A GROUP OF POINT CHARGES

Since the principle of linear superposition is valid for Coulomb's law, it is also valid for the electric field. To calculate the electric field strength at a point due to a group of N point charges.

We first find the individual field strengths \vec{E}_1 due to Q_1 , \vec{E}_2 due to Q_2 , and so on

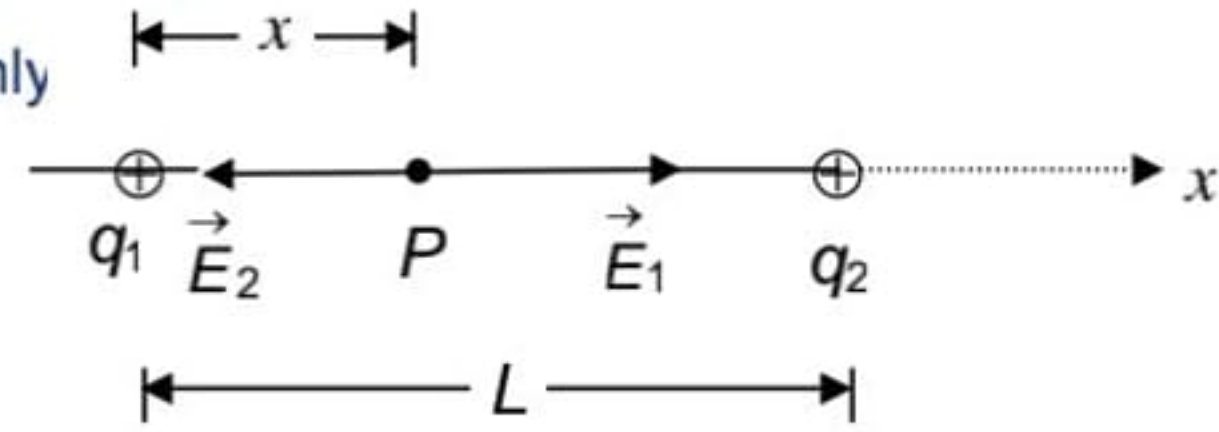
The resultant field strength is the vector sum of individual field strengths.

$$\begin{aligned} \vec{E} &= \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \dots \\ &= \sum \vec{E}_n \quad (n = 1, 2, 3, \dots N) \end{aligned}$$

Illustration 9

Question. A point charge q_1 of $+ 1.5 \mu\text{C}$ is placed at a origin of a co-ordinate system, and the second charge q_2 of $+ 2.3 \mu\text{C}$ is at a position $x = L$, where $L = 13 \text{ cm}$. At what point P along the x -axis is the electric field zero (in mm).

Solution: The point must lie between the charges because only



$$E_1 = E_2$$

We then have

$$\frac{1}{4\pi\epsilon_0} \frac{q_1}{x^2} = \frac{1}{4\pi\epsilon_0} \frac{q_2}{(L-x)^2}, \text{ where } x \text{ is the co-ordinate of the point } P.$$

Solving for x , we have

$$x = \frac{L}{1 \pm \sqrt{q_2/q_1}}$$

Substituting numerical values for L , q_1 and q_2 ,

We obtain

$$x = 5.8 \text{ cm and } x = -54.6 \text{ cm}$$

But the negative value of x is unacceptable

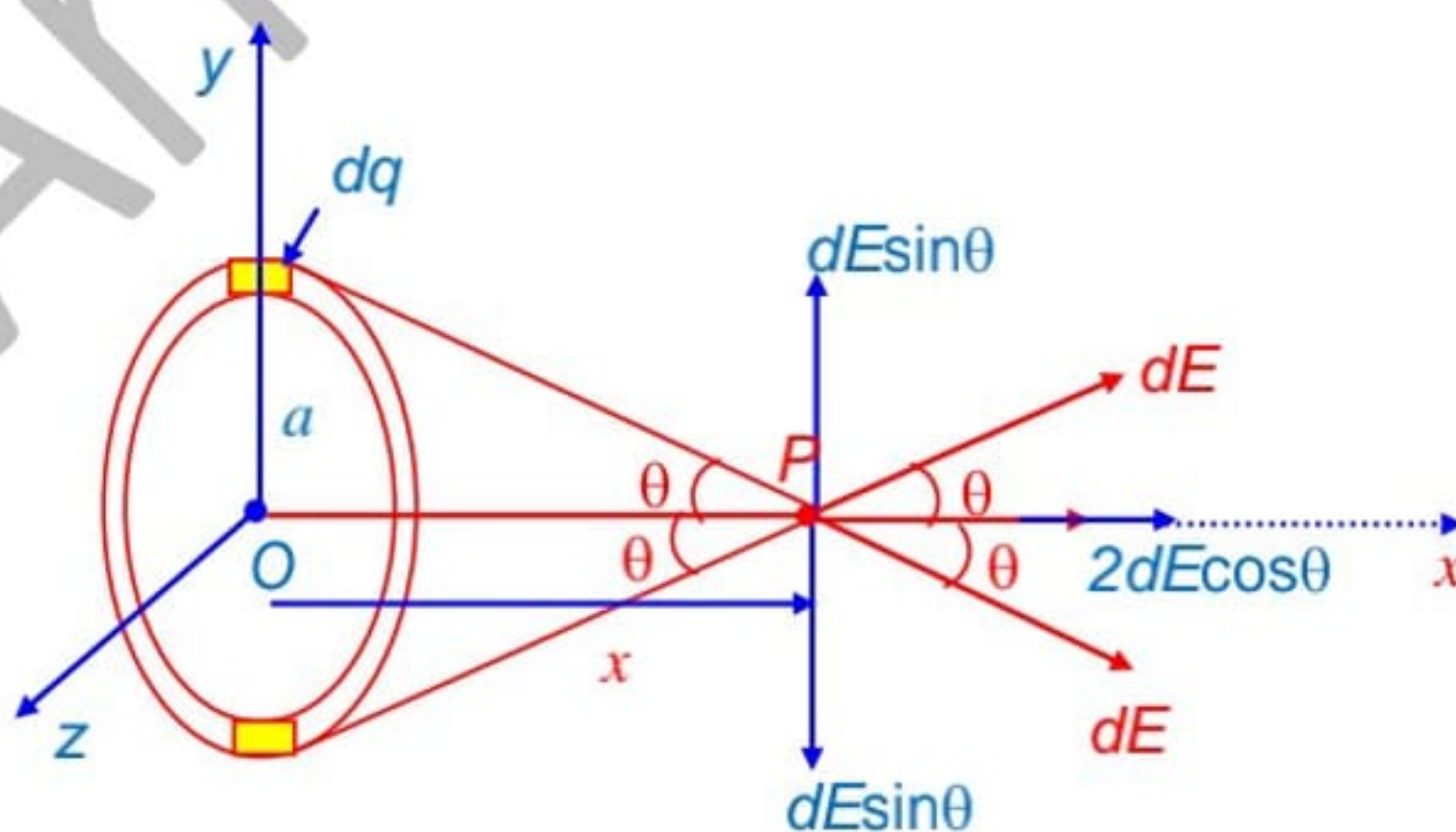
Hence, $x = 58 \text{ mm}$

6 ELECTRIC FIELD OF CONTINUOUS CHARGE DISTRIBUTIONS

6.1 ELECTRIC FIELD DUE TO A UNIFORMLY CHARGED RING AT A POINT ON THE AXIS OF THE RING

Let us consider a charge Q distributed uniformly on a thin, circular, non-conducting ring of radius a . We have to find electric field E at a point P on the axis of the ring, at a distance x from the centre.

From symmetry, we observe that every element dq can be paired with a similar element c $dE \sin\theta$ perpendicular to the x -axis is thus cancelled by a component $dE \sin\theta$ in the opp; perpendicular components add to zero. Thus we only add the dE_x components.



Now,
$$dE = \frac{1}{4\pi\epsilon_0} \frac{dq}{(d^2 + x^2)}$$

Hence, the resultant electric field at P is given by

$$\begin{aligned} E &= \int dE_x \\ &= \int dE \cos \theta \\ &= \frac{1}{4\pi\epsilon_0} \int \frac{dq}{(a^2 + x^2)} \left(\frac{x}{\sqrt{a^2 + x^2}} \right) \\ &= \frac{1}{4\pi\epsilon_0} \frac{x}{(a^2 + x^2)^{3/2}} \int dq \end{aligned}$$

As we integrate around the ring, all the terms remain constant and $\int dq = Q$

So, the total field is

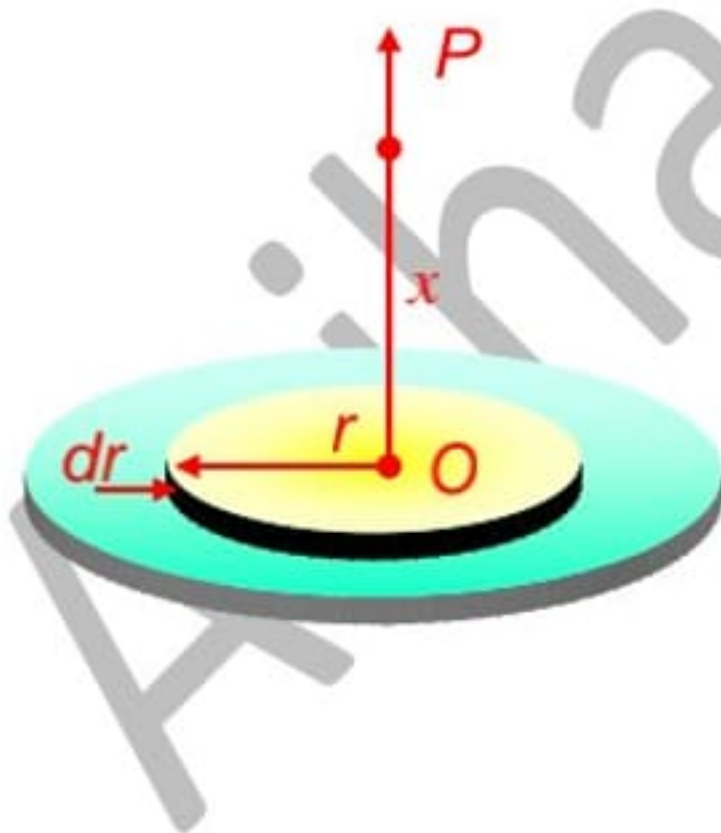
$$\begin{aligned} E &= \frac{1}{4\pi\epsilon_0} \frac{xQ}{(a^2 + x^2)^{3/2}} \\ \text{or } E &= \frac{1}{4\pi\epsilon_0} \frac{Qx}{(a^2 + x^2)^{3/2}} \quad \dots (9A) \end{aligned}$$

6.2 ELECTRIC FIELD DUE TO A UNIFORMLY CHARGED DISC AT A POINT ON THE AXIS OF THE DISC

Let us consider a flat, circular, non-conducting thin disc of radius R having a uniform surface charge density $\sigma \text{ C/m}^2$. We have to find the electric field intensity at an axial point at a distance x from the disc.

Let O be the centre of a uniformly charged disc of radius R and surface charge density σ . Let F be an axial point, distant x from O , at which electric field intensity is required.

From the circular symmetry of the disc, we imagine the disc to be made up of a large number of concentric circular rings and consider one such ring of radius r and an infinitesimally small width dr



The area of the elemental ring = circumference \times width = $(2\pi r dr)$

The charge dq on the elemental ring = $(2\pi r dr) \sigma$

Therefore, the electric field intensity at P due to the elementary ring is given by

$$dE = \frac{1}{4\pi\epsilon_0} \frac{(2\pi r dr) \sigma x}{(r^2 + x^2)^{3/2}} = \frac{\sigma x}{2\epsilon_0} \frac{r dr}{(r^2 + x^2)^{3/2}}$$

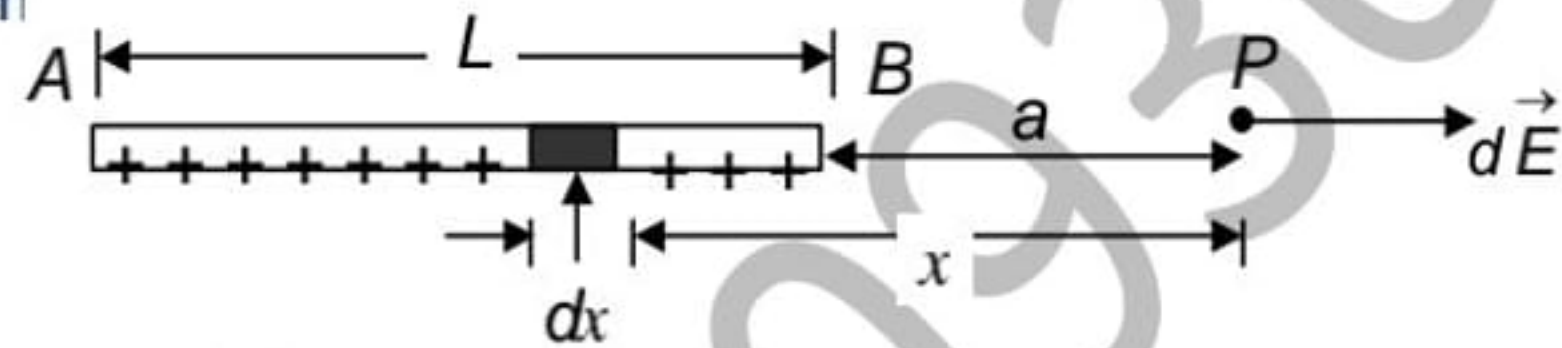
and is directed along the x -axis. Hence, the electric intensity E due to the whole disc is given by

$$\begin{aligned}
 E &= \frac{\sigma x}{2\epsilon_0} \int_0^R \frac{r dr}{(r^2 + x^2)^{3/2}} \\
 &= \frac{\sigma x}{2\epsilon_0} \left[-\frac{1}{(r^2 + x^2)^{1/2}} \right]_0^R = \frac{\sigma x}{2\epsilon_0} \left[-\frac{1}{(R^2 + x^2)^{1/2}} + \frac{1}{x} \right] \\
 &= \frac{\sigma}{2\epsilon_0} \left[1 - \frac{x}{(R^2 + x^2)^{1/2}} \right] \quad \dots (9B)
 \end{aligned}$$

Illustration 10

Question: A thin insulating rod of length L carries a uniformly distributed charge Q . Find the electric field strength at a point along its axis a distance ' a ' from one end. (In N/C)
(take $Q = 10^{-9}$ C, $a = 1$ m, $L = 2$ m)

Solution: Let us consider an infinitesimal element



The magnitude of the electric field at P due to this element is

$$dE = \frac{1}{4\pi\epsilon_0} \frac{dq}{x^2} = \frac{1}{4\pi\epsilon_0} \frac{(\lambda dx)}{x^2}$$

and its direction is to the right since λ is positive. The total electric field strength E is given by

$$\begin{aligned}
 E &= \frac{1}{4\pi\epsilon_0} \lambda \int_a^{a+L} \frac{dx}{x^2} \\
 &= \frac{\lambda}{4\pi\epsilon_0} \left[-\frac{1}{x} \right]_a^{a+L} \\
 &= \frac{\lambda}{4\pi\epsilon_0} \left[\frac{1}{a} - \frac{1}{a+L} \right] \\
 &= \frac{Q}{(4\pi\epsilon_0) a(a+L)} = 3
 \end{aligned}$$

7 MOTION OF A CHARGED PARTICLE IN AN UNIFORM ELECTRIC FIELD

A particle of mass m and charge q in an uniform electric field \vec{E} experiences a force

$$\vec{F} = q\vec{E}$$

From Newton's second law of motion,

$$\vec{F} = m\vec{a}$$

Hence, the acceleration of the charged particle in the uniform electric field is

$$\vec{a} = \frac{q\vec{E}}{m}$$

Since the field is uniform, the acceleration is constant in magnitude and direction. So we can use the equation of kinematics for constant acceleration. Now, there are two possibilities.

(a) **slf the particle is initially at rest**

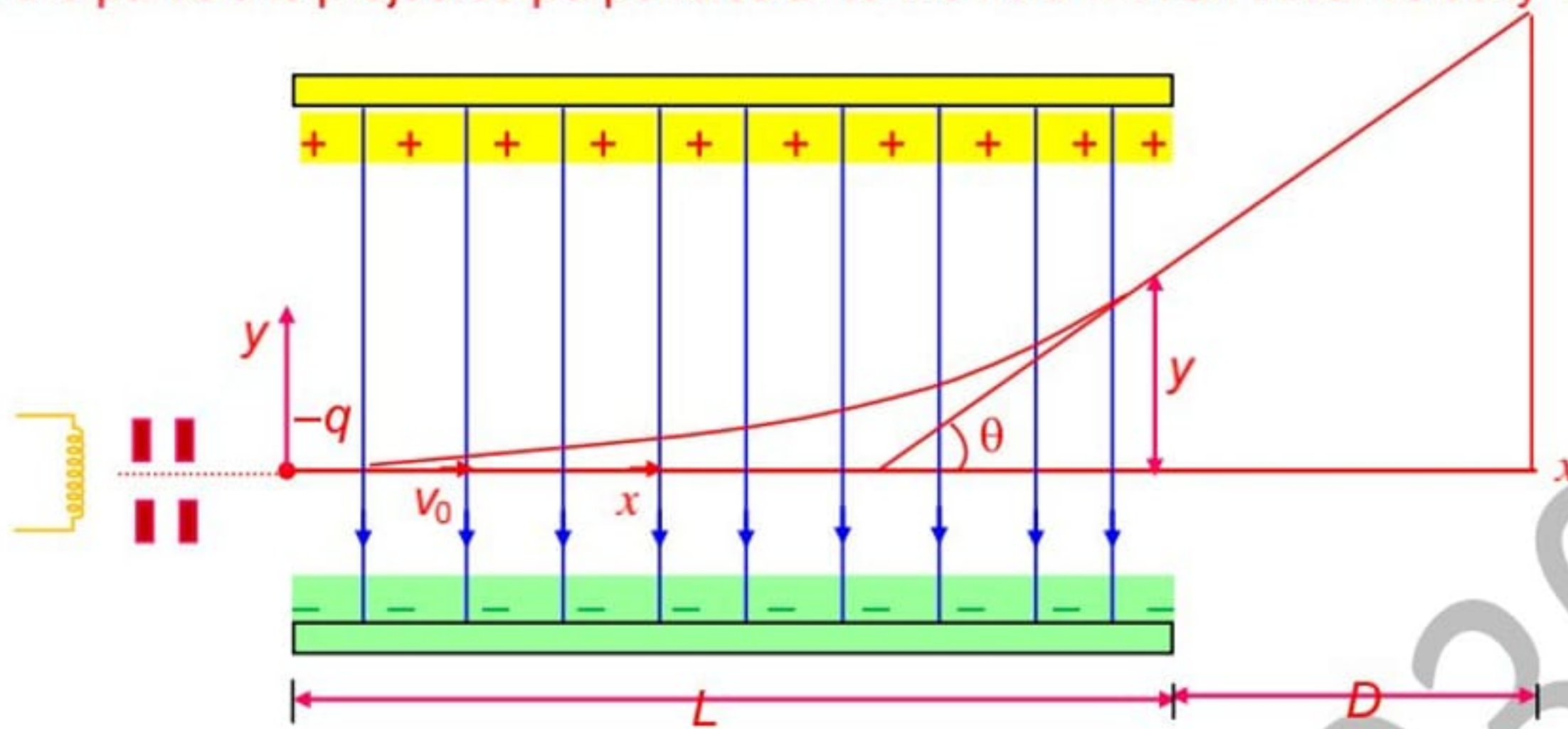
From equation $v = u + at$, we get

$$v = at = \frac{qE}{m} t \left[\because u = 0; a = \frac{qE}{m} \right]$$

From equation $S = ut + \frac{1}{2}at^2$, we have

$$S = \frac{1}{2}at^2 = \frac{qE}{2m}t^2$$

(b) (ii) If the particle is projected perpendicular to the field with an initial velocity v_0 .



For motion along x-axis, we have $v_x = v_0 = \text{constant}$ ($\because u = v_0$ and $a = 0$)

$$\therefore x = v_0 t \quad \dots (i)$$

for motion along y-axis, we have

$$y = \frac{1}{2} \left[\frac{qE}{m} \right] t^2 \quad \dots (ii)$$

$$\left[\because u = 0; a = \frac{qE}{m} \right]$$

Substituting the value of t from equation (i) in equation (ii), we get

$$y = \frac{qE}{2m} \left[\frac{x}{v_0} \right]^2$$

$$= \frac{qE}{2mv_0^2} x^2$$

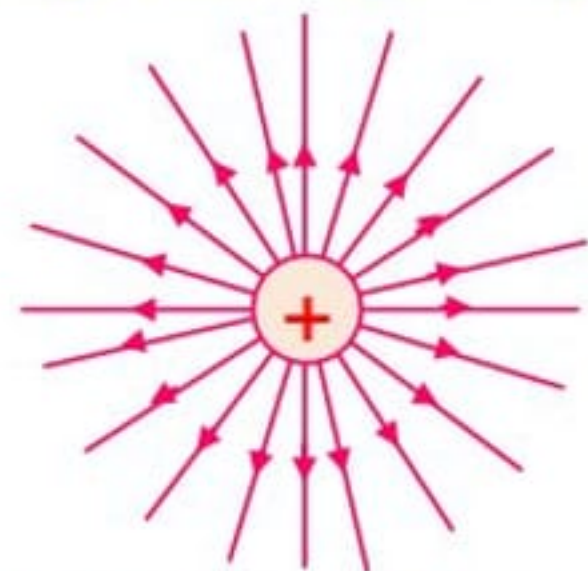
Which is the equation of the **parabola**.

8 ELECTRIC LINES OF FORCE

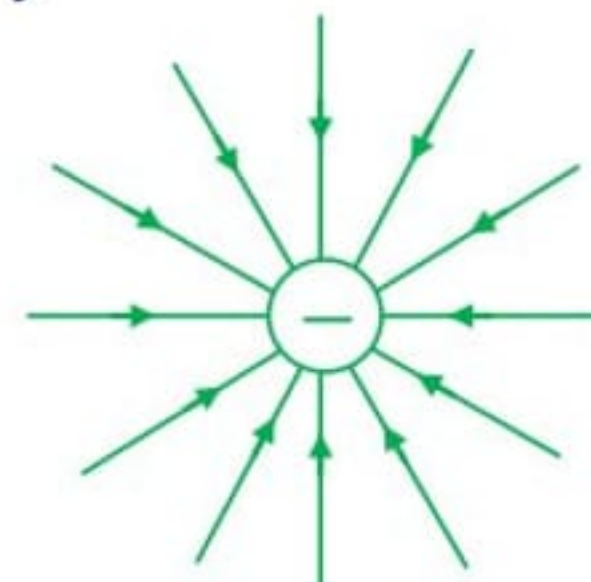
The idea of electric lines of force or the electric field lines introduced by Michel Faraday is a way to visualize electrostatic field geometrically.

The properties of electric lines of force are the following:

(i) The electric lines of force are continuous curves in an electric field starting from a positively charged body and ending on a negatively charged body.



Electric lines of force due to positive charge



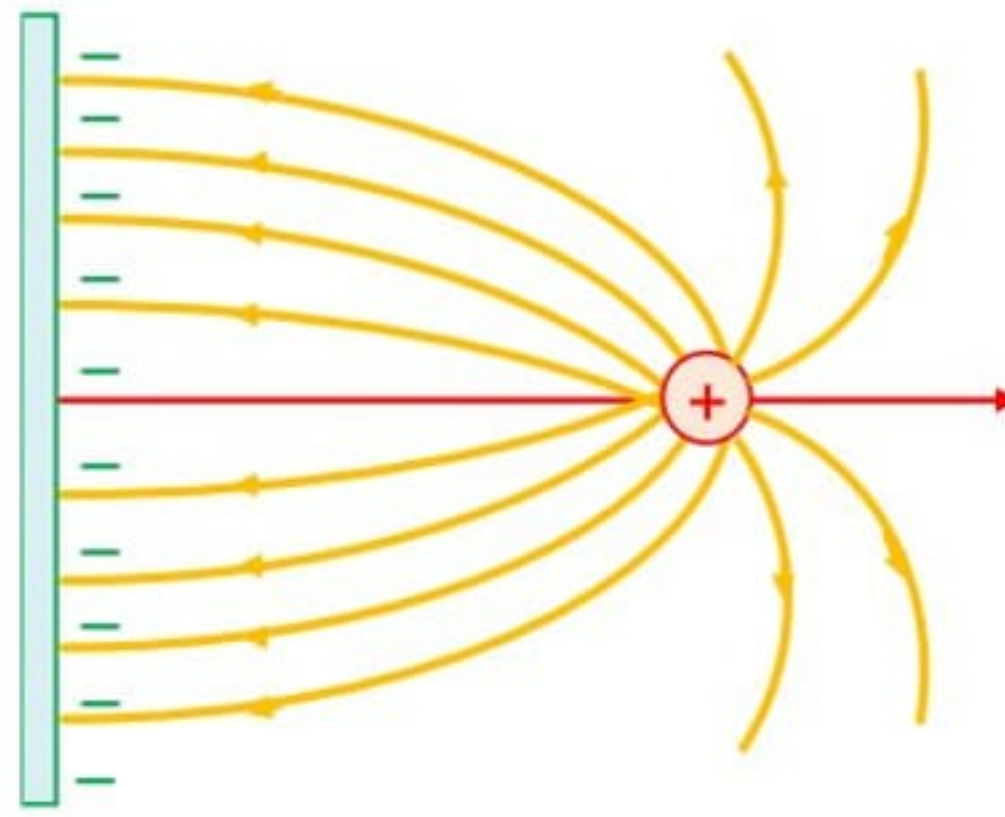
Electric lines of force due to negative charge

(ii) The tangent to the curve at any point gives the direction of the electric field intensity at that point.

(iii) Electric lines of force never intersect since if they cross at a point, electric field intensity at that point will have two directions, which is not possible

(iv) Electric lines of force do not pass but leave or end on a charged conductor normally. Suppose the lines of force are not perpendicular to the conductor surface. In this situation, the

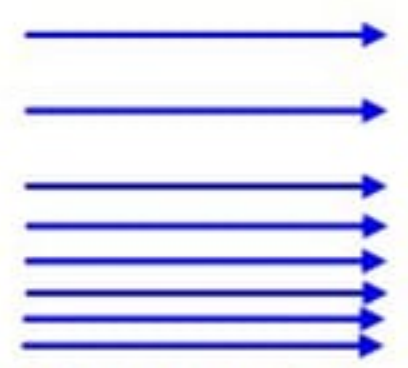
component of electric field parallel to the surface would cause the electrons to move and hence conductor will not remain equipotential which is absurd as in electrostatics conductor is an equipotential surface.



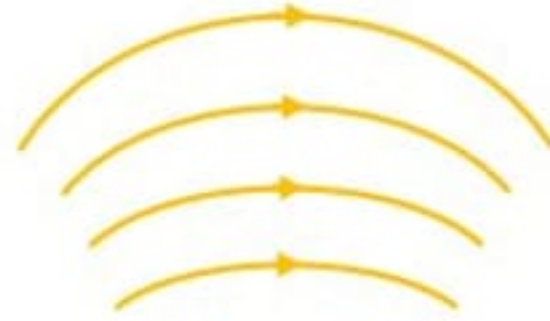
Fixed point charge near infinite metal plate

(v) The number of electric lines of force that originate from or terminate on a charge is proportional to the magnitude of the charge.

(vi) As number of lines of force per unit area normal to the area at point represents magnitude of intensity, crowded lines represent strong field while distant lines weak field. Further, if the lines of force are equidistant straight lines, the field is uniform.



Magnitude is not constant



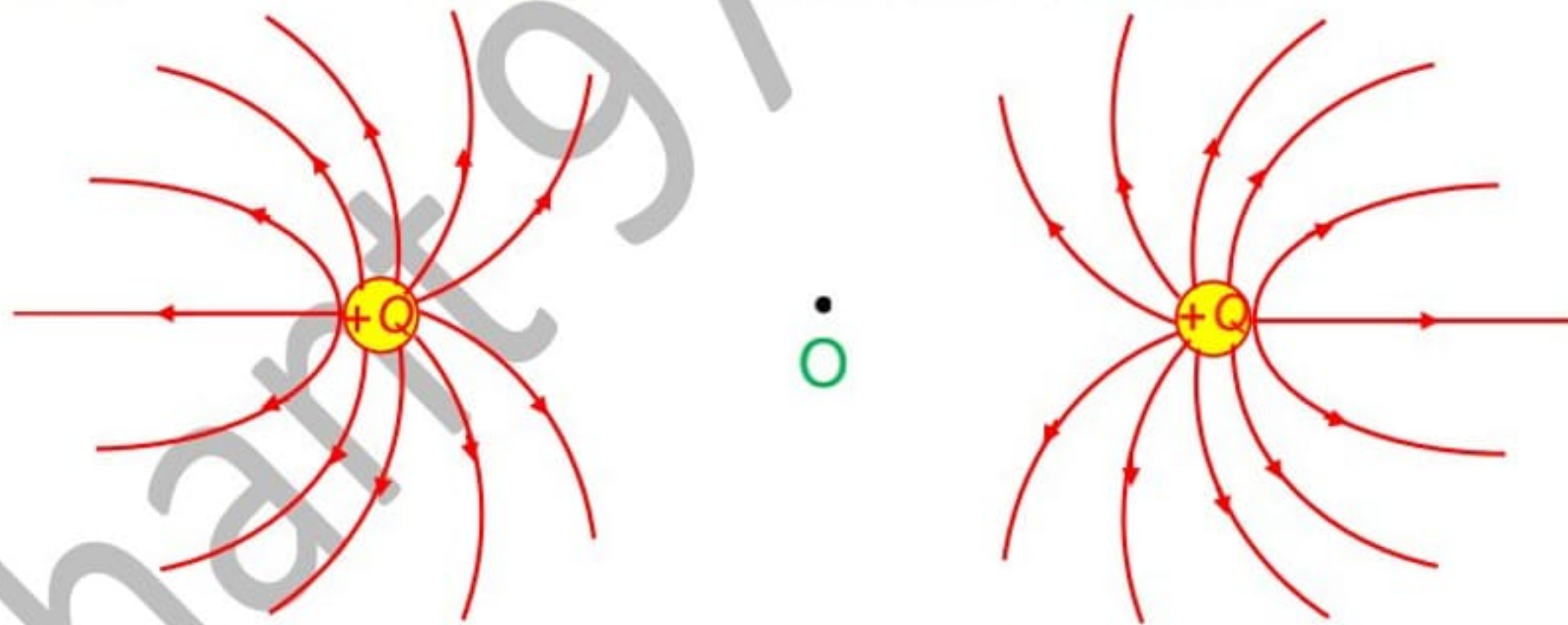
Direction is not constant



Both magnitude and direction not constant



Both magnitude and direction constant.

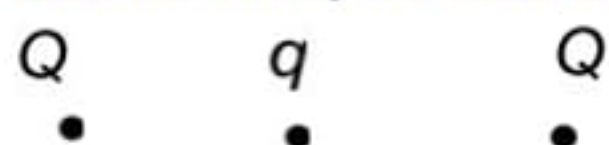


Electric lines of force due to two equal positive charges (field is zero at O). O is a null point.

PROFICIENCY TEST– I

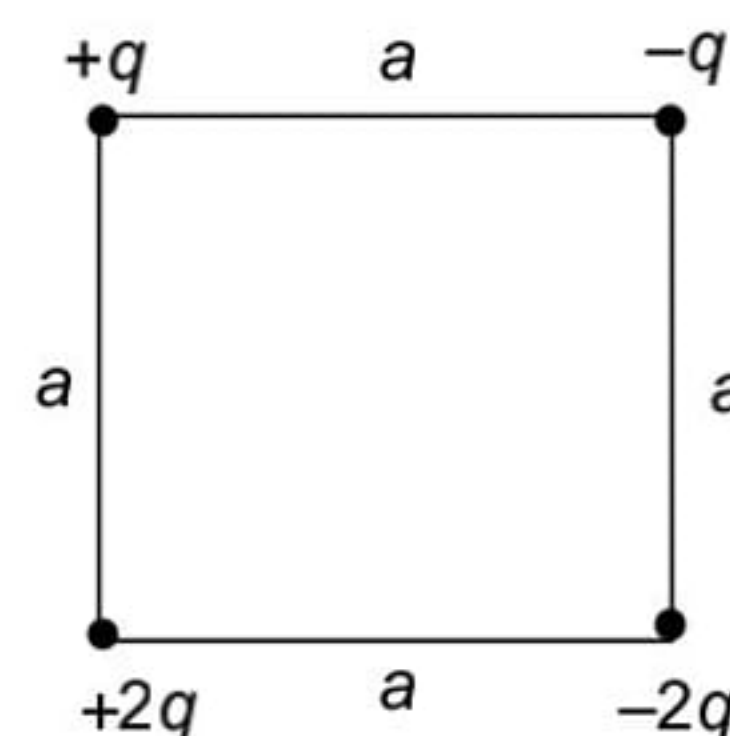
The following questions deal with the basic concepts of this section. Answer the following briefly. Go to the next section only if your score is at least 80%. Do not consult the Study Material while attempting these questions.

- A typical charge produced by rubbing is 1nC . Roughly no. of elementary charges (e) does this involve in n . If n is given as $x \times 10^7$. Find x
- A positively charged glass rod is brought close to a suspended metal needle. What can you say about the charge on the needle given that the needle is
(a) attracted; (b) repelled
- A point charge q is placed at the mid-point between two equal point charges of magnitude Q , as shown in the figure. Is q in equilibrium? If so is it stable or unstable equilibrium. Consider q to have (a) the same sign and (b) the opposite sign to Q .



- Two point charges of unknown magnitudes and signs are placed a distance d apart. If it is possible to have $E = 0$ at any point not between the charges but on the line joining them, what are the necessary conditions and where is the point located?
- A positive charge is brought very close to uncharged conductor which is grounded. Is the conductor charged positively, negatively, or not at all if
(a) the charge is taken away and then the ground connection is removed and
(b) the ground connection is removed and then the charge is taken away?
- Two identical small spheres are charged positively. Each sphere is repelled from the other with a force of $9 \times 10^{-3}\text{ N}$ when the spheres are 2 m apart. Calculate the charge (in μC) on each sphere.
- In the given figure, find (a) the horizontal component of electric force on the charge in the lower left corner of the square. Assume that the charges are at rest.

(take $kq^2 = \left(4 - \frac{1}{\sqrt{2}}\right)$ SI unit and $a = \frac{1}{\sqrt{2}}\text{ m}$)



- Electric field lines never cross. Why?
- A negatively charged particle of mass to charge ratio is 2 , is accelerated eastward at 8 m/s^2 by an electric field. Determine the magnitude and direction of the electric field.
- An alpha particle, the nucleus of a helium atom, has a mass of $6.4 \times 10^{-27}\text{ kg}$ and a charge of $+2e$. What are the magnitude and the direction of the electric field that will balance its weight?

ANSWERS TO PROFICIENCY TEST- I

1. 325
2. (a) negative charge or uncharged
(b) positive charge
3. (a) Yes, the charge q is in stable equilibrium.
(b) Yes, the charge q is in unstable equilibrium.
4. The charges must be of opposite signs and point should be near the charge of smaller magnitude.
5. (a) The conductor is not charged at all
(b) the conductor is negatively charged.
6. $2 \mu\text{C}$
7. 31N
8. Because electric field at a point has a unique direction
9. 16 N/C towards west
10. 200 nN/C upward

9 FLUX OF AN ELECTRIC FIELD OR ELECTRIC FLUX

Let us consider a plane surface of area S placed in an electric field \vec{E} .

Electric flux through an elementary area $d\vec{S}$ is defined as the scalar product of $d\vec{S}$ and \vec{E} i.e.

$d\phi_E = \vec{E} \cdot d\vec{S}$, where $d\vec{S}$ is the area vector, whose magnitude is the area ds of the element and whose direction is along the outward normal to the elementary area.

Hence, the electric flux through the entire surface is given by

$$\phi_E = \int \vec{E} \cdot d\vec{S} \quad \dots (10)$$

or, $\phi_E = \int EdS \cos \theta$

If the electric field is uniform, then $\phi_E = \int Eds \cos \theta = E \cos \theta \int ds$

When the electric flux through a closed surface is required, we use a small circular sign on the integration symbol;

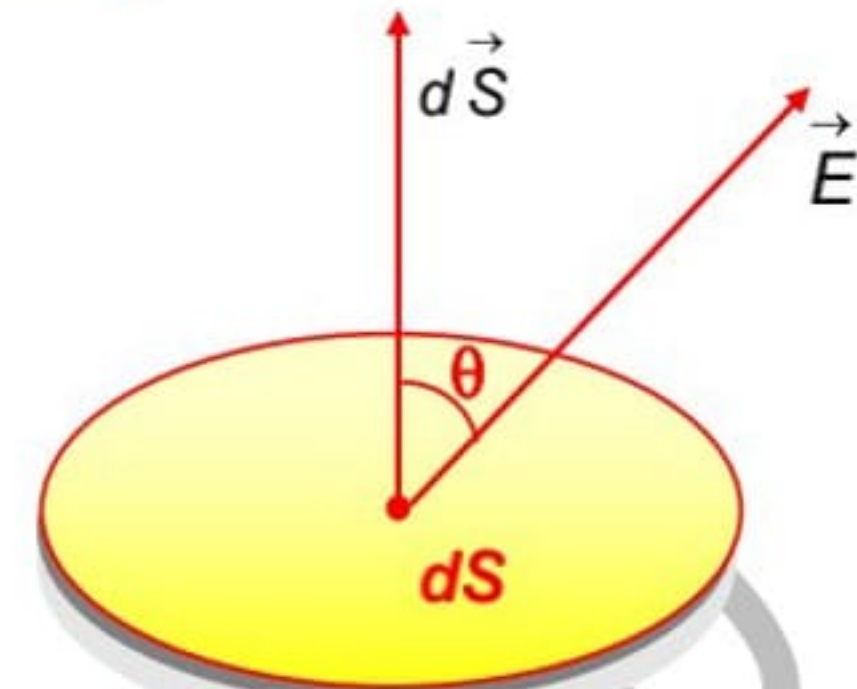
$$\phi_E = \oint \vec{E} \cdot d\vec{S} \quad \dots (11)$$

Important points regarding electric flux:

- (i) The number of lines of force passing normally to the given area gives the measure of flux of electric field over the given area.
- (ii) It is a real scalar physical quantity with units (volt \times m).
- (iii) It will be maximum when $\cos \theta = \text{max.} = 1$, i.e., $\theta = 0^\circ$, i.e., electric field is normal to the surface with $(d\phi_E)_{\text{max}} = EdS$

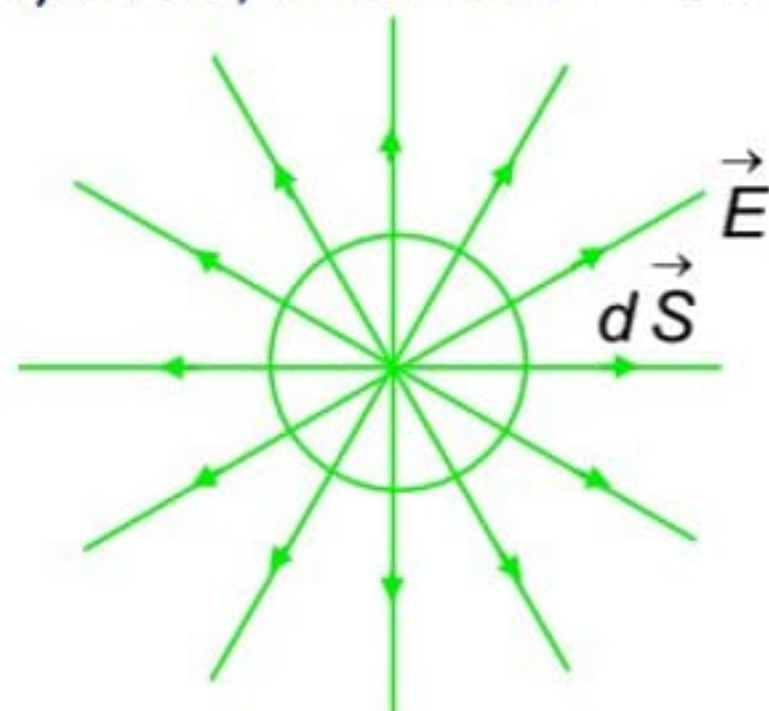
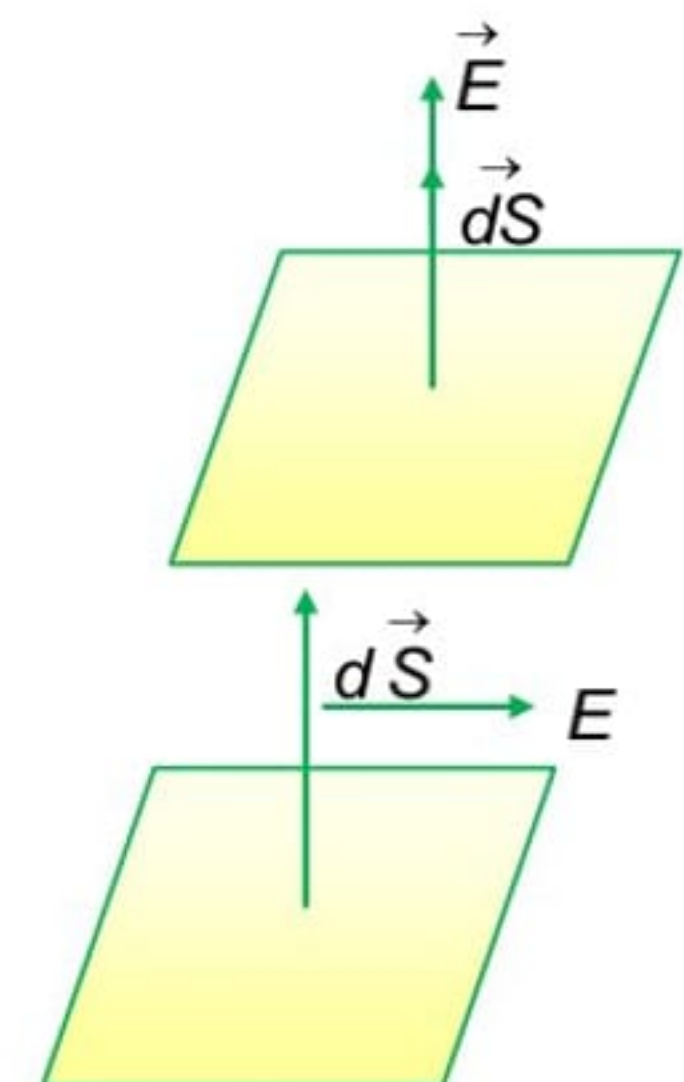
- (iv) It will be minimum when $|\cos \theta| = \text{min} = 0$, i.e., $\theta = 90^\circ$, i.e., field is parallel to the area with $(d\phi_E)_{\text{min}} = 0$

- (v) For a closed surface, ϕ_E is positive if the lines of force point outward everywhere (\vec{E} will be outward everywhere, $\theta < 90^\circ$ and $\vec{E} \cdot d\vec{S}$ will be positive) and negative if they point inward (\vec{E} is inward everywhere, $\theta > 90^\circ$ and $\vec{E} \cdot d\vec{S}$ will be negative)

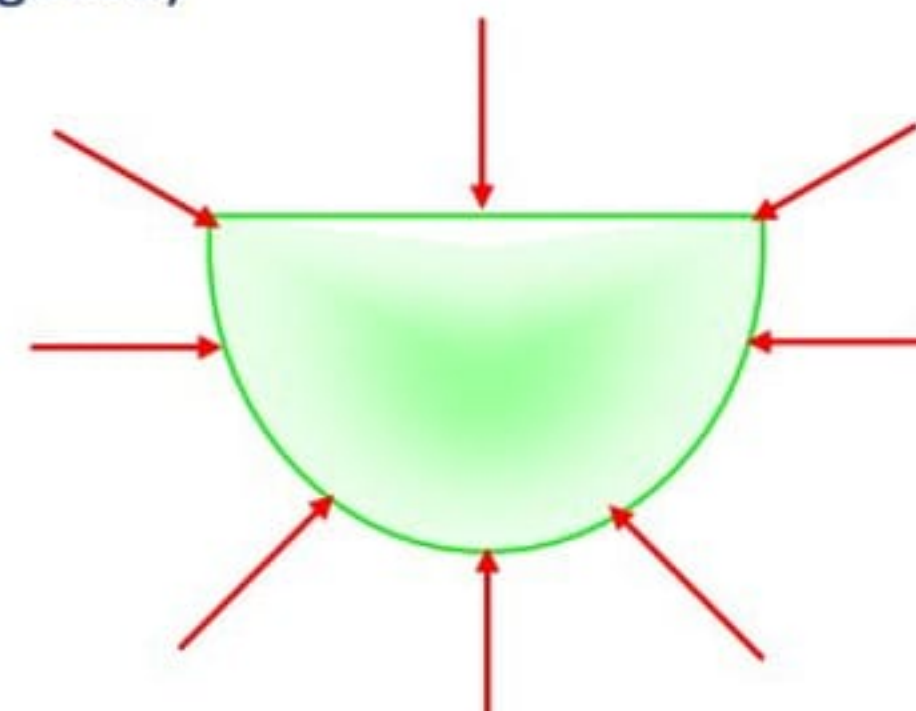


... (10)

... (11)



Positive flux



Negative flux

Illustration 11

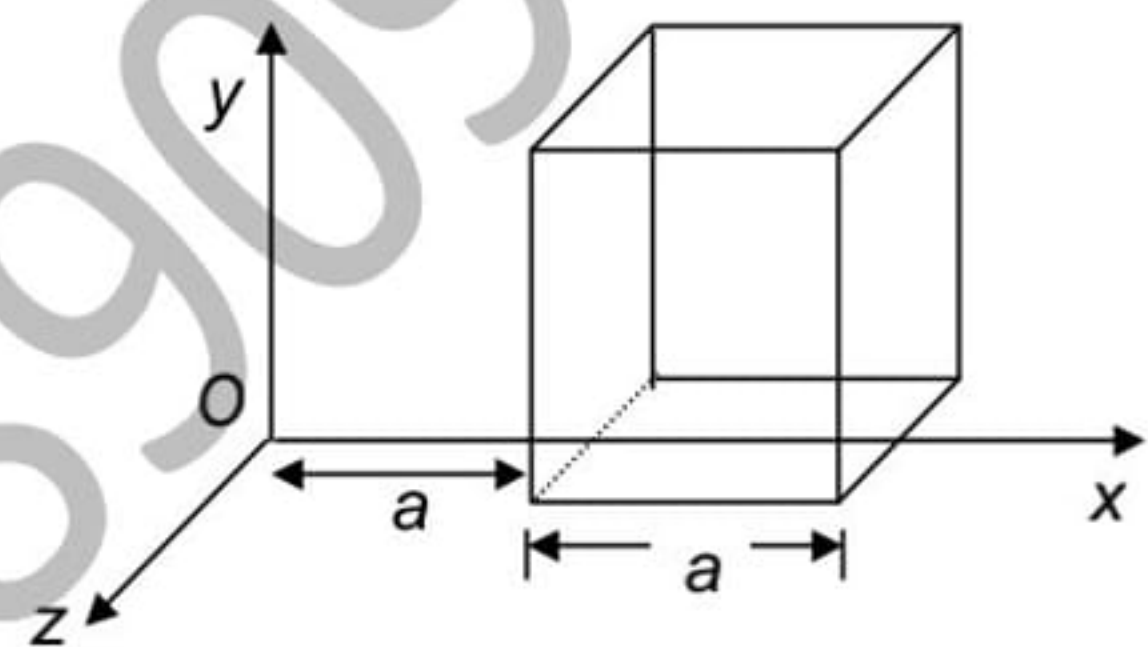
Question: In a region of space the electric field is given by $\vec{E} = 8\hat{i} + 4\hat{j} + 3\hat{k}$. Calculate the electric flux through a surface of area 100 units in x-y plane.

Solution: A surface of area 100 units in the xy plane is represented by an area vector $\vec{S} = 100\hat{k}$ (direction along the normal to the area). The electric flux through the surface is given by

$$\begin{aligned}\phi_E &= \vec{E} \cdot \vec{S} = (8\hat{i} + 4\hat{j} + 3\hat{k}) \cdot (100\hat{k}) \\ &= 300 \text{ units}\end{aligned}$$

Illustration 12

Question: Calculate the electric flux through a cube of side 'a' as shown, where $E_x = bx^{1/2}$, $E_y = E_z = 0$, $a = 10 \text{ cm}$ and $b = 800 \text{ N/C-m}^{1/2}$. (Nm^2/C)



Solution:

The electric field throughout the region is non-uniform and its x-component is given by

$$E_x = bx^{1/2}, \text{ where } b = 800 \text{ N/C}^{1/2}.$$

For the left face perpendicular to the x-axis, we have $x = a = 10 \text{ cm}$, while for the right face $x = 2a = 20 \text{ cm}$. Hence for the left face, the x-component of the field is

$$E_x = 800 \times (10 \times 10^{-2} \text{ m})^{1/2} = 253 \text{ N/C}$$

For the right face, we have

$$E_x' = 800 \times (20 \times 10^{-2})^{1/2} = 358 \text{ N/C}$$

The area of each face is $S = 100 \text{ cm}^2 = 10^{-2} \text{ m}^2$

Hence, the flux through the left face

$$= -E_x S = (253)(10^{-2}) = -2.53 \text{ N-m}^2/\text{C}$$

The flux through the right face

$$= E_x' S = (358)(10^{-2}) = 3.58 \text{ N-m}^2/\text{C}$$

The net flux through the other faces is zero, because $E_y = E_z = 0$

Hence, the net flux through the cube $\phi_E = 3.58 - 2.53 = 1$ (approx)

10 GAUSS'S LAW

This law gives a relation between the electric flux through any closed hypothetical surface (called a **Gaussian surface**) and the charge enclosed by the surface. It states, "The electric flux (ϕ_E) through any closed surface is equal to $\frac{1}{\epsilon_0}$ times the 'net' charge enclosed by the surface."

That is,

$$\phi_E = \vec{E} \cdot d\vec{S} = \frac{\sum q}{\epsilon_0}, \quad \dots (12)$$

where $\sum q$ denotes the algebraic sum of all the charges enclosed by the surface.

If there are several charges $+q_1, +q_2, +q_3, -q_4, -q_5 \dots$ etc inside the Gaussian surface, then

$$\sum q = q_1 + q_2 + q_3 - q_4 - q_5 \dots$$

It is clear from equation (11) that the electric flux linked with a closed body is independent of the shape and size of the body and position of charge inside it.

Applications of Gauss's Law

Gauss's law is useful when there is symmetry in the charge distribution, as in the case of uniformly charged sphere, long cylinders, and flat sheets. In such cases, it is possible to find a simple Gaussian surface over which the surface integral given by equation (10) can be easily evaluated.

These are steps to apply the Gauss's law

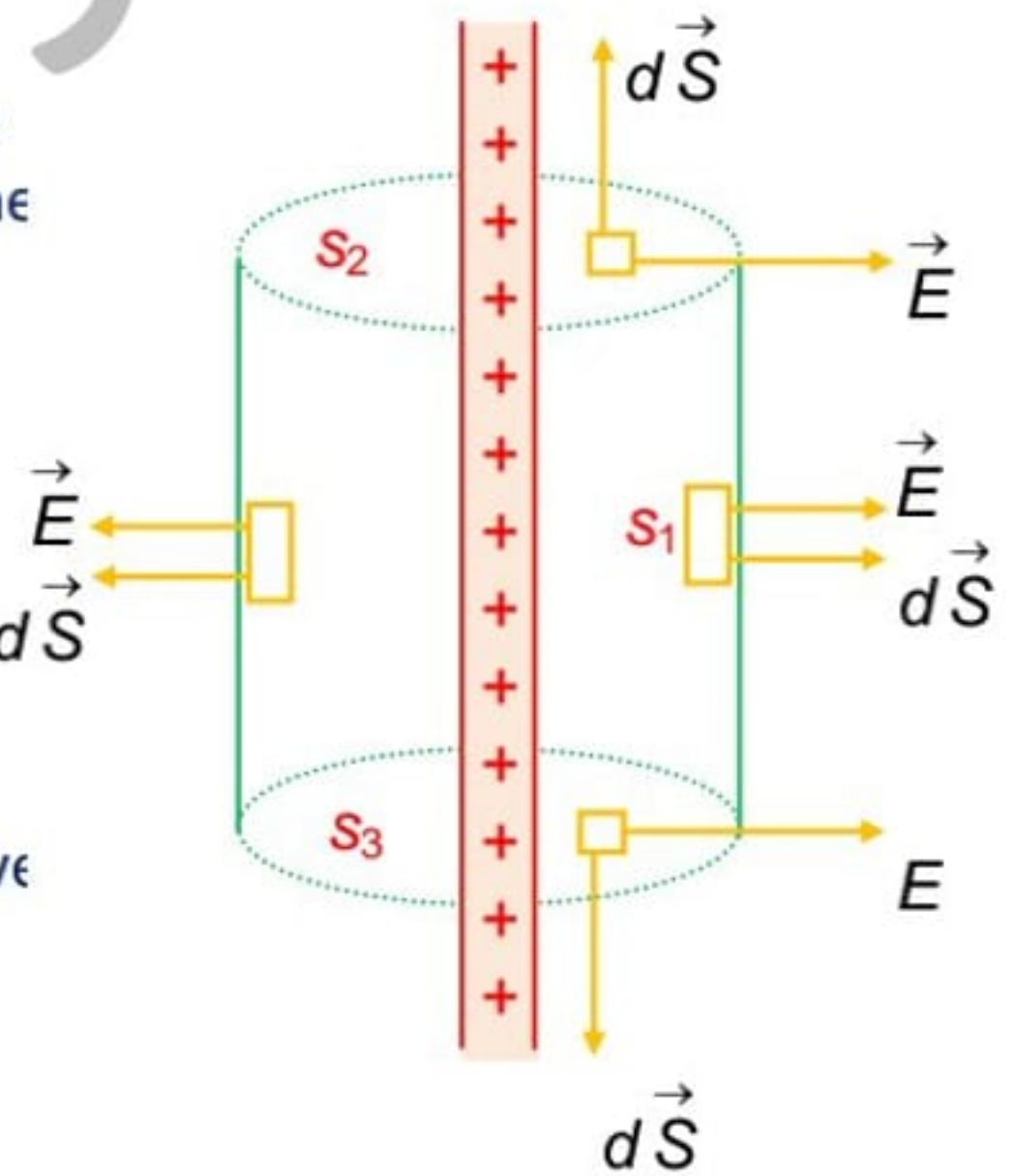
- (i) Use the symmetry of the charge distribution to determine the pattern of the lines
- (ii) Choose a Gaussian surface for which \vec{E} is either parallel to $d\vec{S}$ or perpendicular to $d\vec{S}$
- (iii) If \vec{E} is parallel to $d\vec{S}$, then the magnitude of \vec{E} should be constant over this part of the surface. The integral then reduces to a sum over area elements.

FIELD DUE TO AN INFINITE LINE OF CHARGE

Consider an infinite line of charge has a linear charge density λ . Using Gauss's law, let us find the electric field at a distance ' r ' from the line.

The cylindrical symmetry tells us that the field strength will be the same at all points at a fixed distance r from the line. Since the line is infinite and uniform, for every charge element on one side, the symmetrically located element on the other side. The component along the line of the fields due to all such elements cancel in pairs. Thus, the field lines are directed radially outward, perpendicular to the line of charge.

The appropriate choice of Gaussian surface is a cylinder of radius r and length L . On the flat end faces, S_2 and S_3 , \vec{E} perpendicular $d\vec{S}$, which means no flux crosses them. On the curved surface S_1 , \vec{E} is parallel $d\vec{S}$, so that $\vec{E} \cdot d\vec{S} = EdS$.

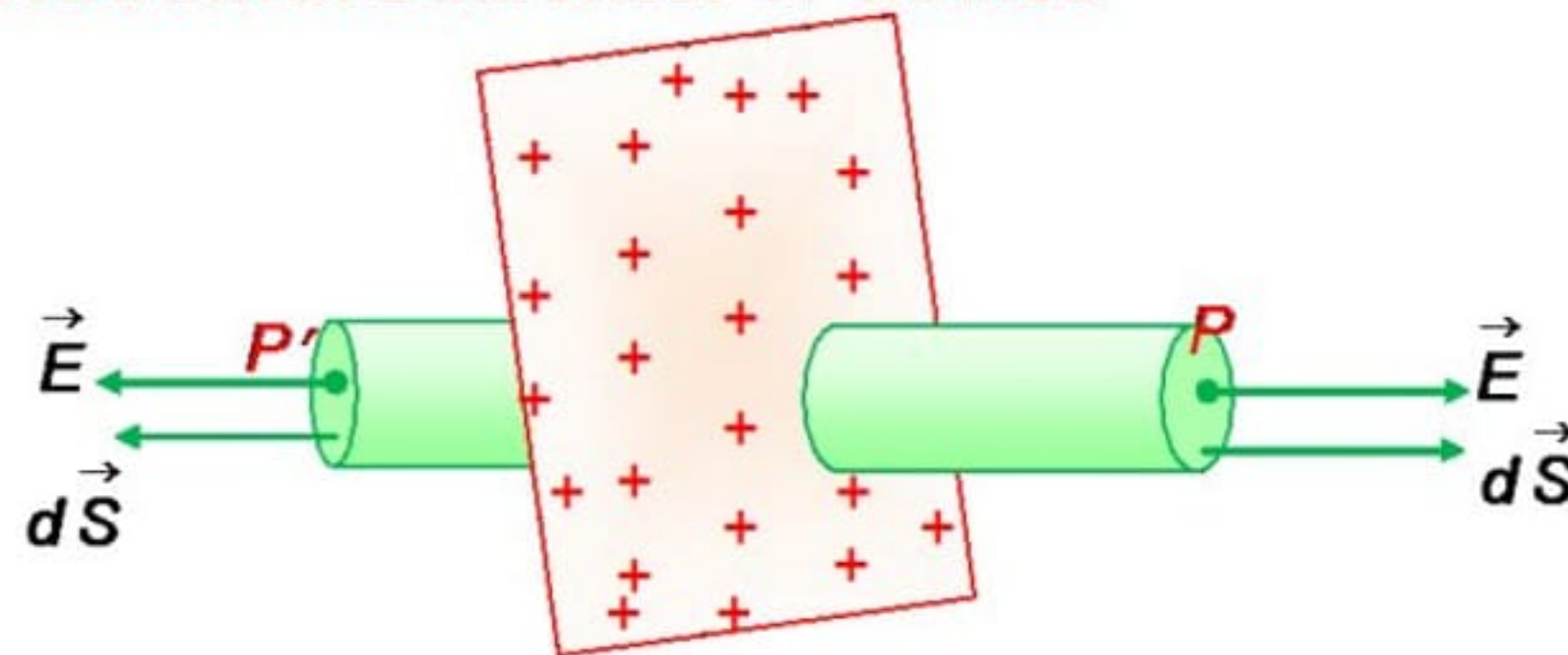


The charge enclosed by the cylinder is $Q = \lambda L$.

Applying Gauss's law to the curved surface, we have

$$E \cdot dS = E(2\pi rL) = \frac{\lambda L}{\epsilon_0} \quad \text{or, } E = \frac{\lambda}{2\pi\epsilon_0 r} \quad \dots (13A)$$

10.2 FIELD DUE TO AN INFINITE PLANE SHEET OF CHARGE



Let us consider a thin non-conducting plane sheet of charge, infinite in extent, and having a surface charge density (charge per unit area) σ C/m². Let P be a point, distant r from the sheet, at which the electric intensity is required.

Let us choose a point P' symmetrical with P , on the other side of the sheet. Let us now draw a Gaussian cylinder cutting through the sheet, with its plane ends parallel to the sheet and passing through P and P' . Let A be the area of each plane end.

By symmetry, the electric intensity at all points on either side near the sheet will be perpendicular to the sheet, directed outward (if the sheet is positively charged). Thus \vec{E} is perpendicular to the plane ends of the cylinder and parallel to the curved surface. Also its magnitude will be the same at P and P' . Therefore, the flux through the two plane ends is

$$\phi_E = \int \vec{E} \cdot d\vec{S} + \int \vec{E} \cdot d\vec{S} = \int EdS + \int EdS = EA + EA = 2EA$$

The flux through the curved surface of the Gaussian cylinder is zero because \vec{E} and $d\vec{S}$ are at right angles everywhere on the curved surfaces.

Hence, the total flux through the Gaussian cylinder is

$$\phi_E = 2EA$$

The charge enclosed by the Gaussian surface $q = \sigma A$

Applying **Gauss's law**, we have

$$2EA = \frac{\sigma A}{\epsilon_0}$$

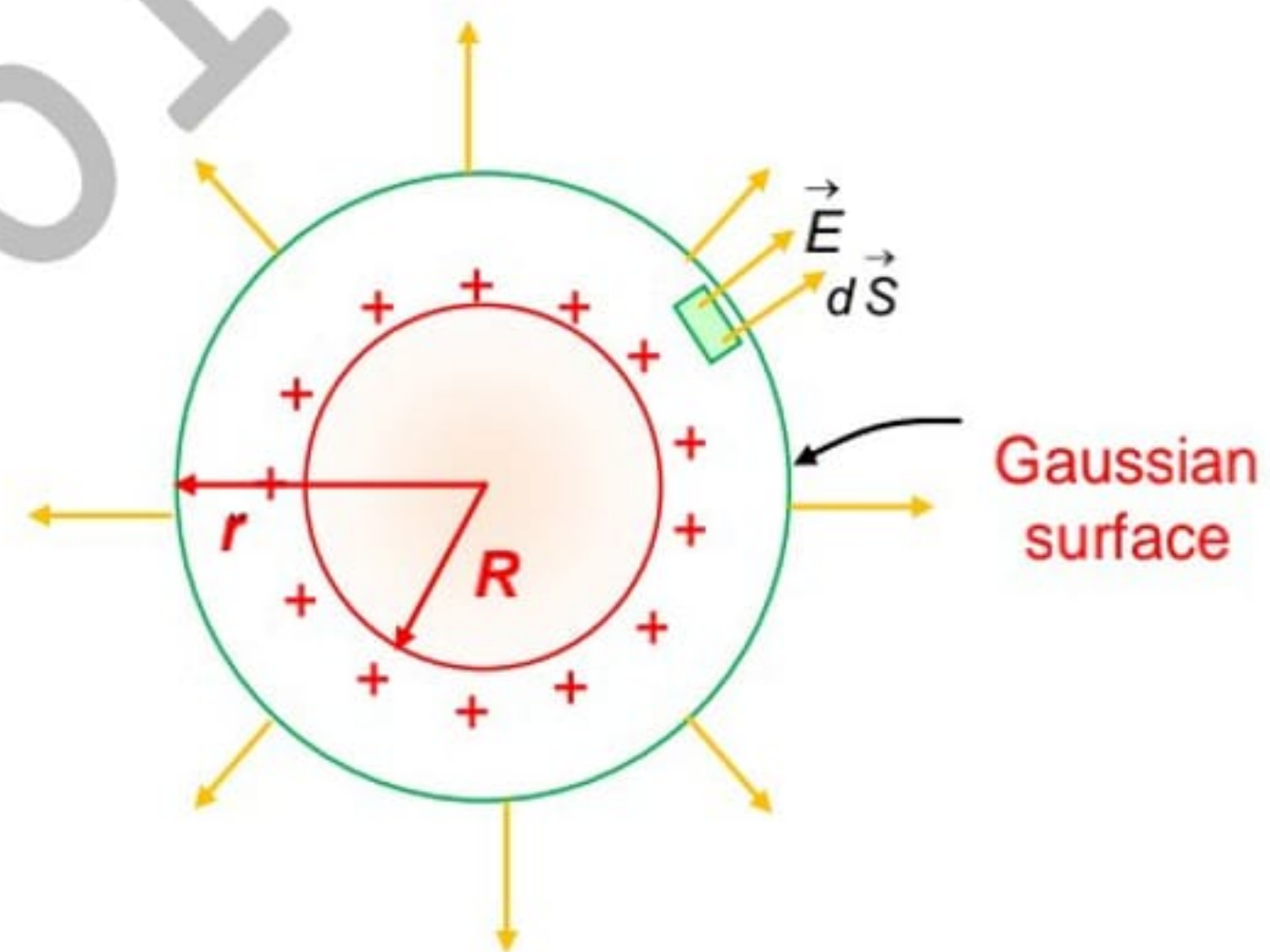
$$\Rightarrow E = \frac{\sigma}{2\epsilon_0} \quad \dots (13B)$$

10.3 ELECTRIC FIELD DUE TO A UNIFORMLY CHARGED SPHERICAL SHELL

Using Gauss's law, let us find the intensity of the electric field due to a uniformly charged spherical shell or a solid conducting sphere at

Case I: At an external point

At all points inside the charged spherical conductor or hollow spherical shell, electric field $\vec{E} = 0$, as there is no charge inside such sphere. In an isolated charged spherical conductor any excess charge on it is distributed uniformly over its outer surface same as that of charged spherical shell or hollow sphere. Since the charge lines must point radially outward. Also, the field strength will have the same value at all points on any imaginary spherical surface concentric with the charged conducting sphere or the shell. This symmetry leads us to choose the Gaussian surface to be a sphere of radius $r > R$.



Any arbitrary element of area $d\vec{S}$ is parallel to the local \vec{E} , so $\vec{E} \cdot d\vec{S} = EdS$ at all points on the surface.

According to Gauss's law, $dS = E(4\pi r) = \frac{Q}{\epsilon_0}$

Therefore, $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \quad \dots (13C)$

For points outside the charged conducting sphere or the charged spherical shell, the field is same as that of a point charge at the centre.

Case II: At an Internal Point ($r < R$)

The field still has the same symmetry and so we again pick a spherical Gaussian surface, but now with radius r less than R . Since the enclosed charge is zero, from Gauss's law we have

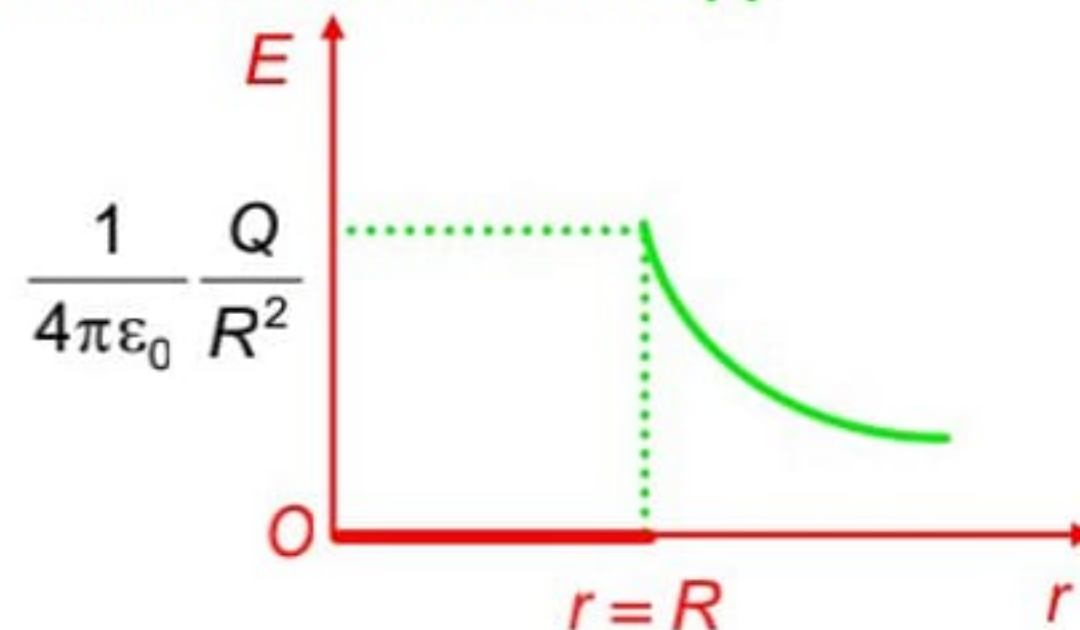
$$E(4\pi r^2) = 0$$

$$\therefore E = 0 \quad \dots (13D)$$

Thus, we conclude that $E = 0$ at all points inside a uniformly charged conducting sphere or the charged

spherical shell.

Variation of E with The Distance from the centre (r)

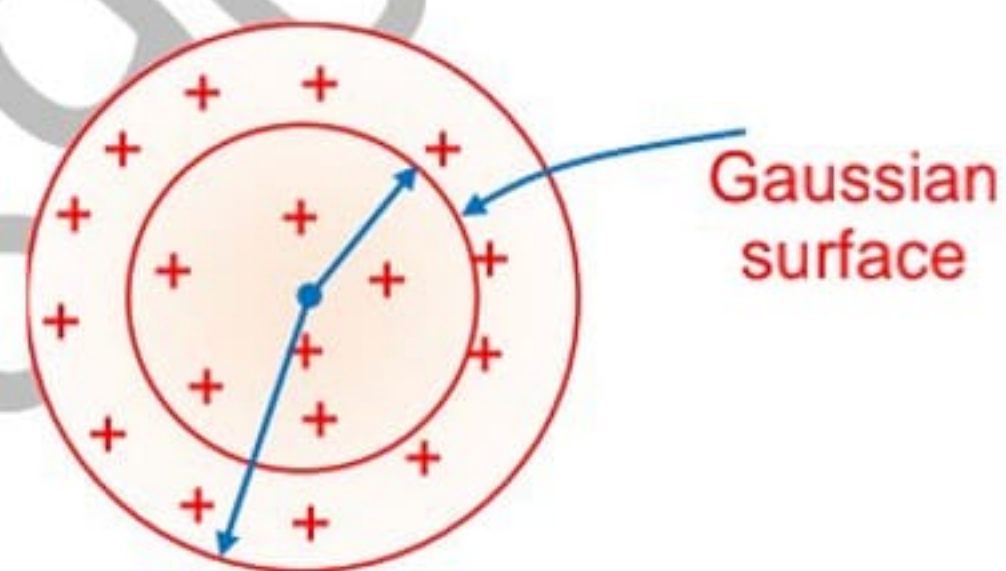


10.4 ELECTRIC FIELD DUE TO A UNIFORMLY CHARGED SPHERE

A non-conducting uniformly charged sphere of radius R has a total charge Q uniformly distributed throughout its volume. Using the Gauss's Law, Let us find the field

Case I: at an internal point ($r < R$)

Positive charge Q is uniformly distributed throughout the volume of sphere of radius R . For finding the electric field at a distance ($r < R$) from the centre, we choose a spherical Gaussian surface of radius r , concentric with the charge distribution. From symmetry the magnitude E of the electric field has the same value at every point on the Gaussian surface, and the direction of \vec{E} is radial at every point on the surface.



So, applying Gauss's law

$$= E (4\pi r^2) = \frac{Q}{\epsilon_0}$$

$$\text{Here, } Q = \left(\frac{4}{3}\pi r^3\right)\rho = \left(\frac{4}{3}\pi r^3\right) \times \frac{Q}{4\pi R^3} = \frac{Qr^3}{R^3}$$

where ρ is volume density of charge.

Therefore

$$E (4\pi r^2) = \frac{Qr^3}{R^3 \epsilon_0}$$

$$\text{or, } E = \frac{1}{4\pi \epsilon_0} \frac{Q}{R^3} r \quad \dots (13E)$$

The field increases linearly with distance from the centre

Case II: At an External point ($r > R$)

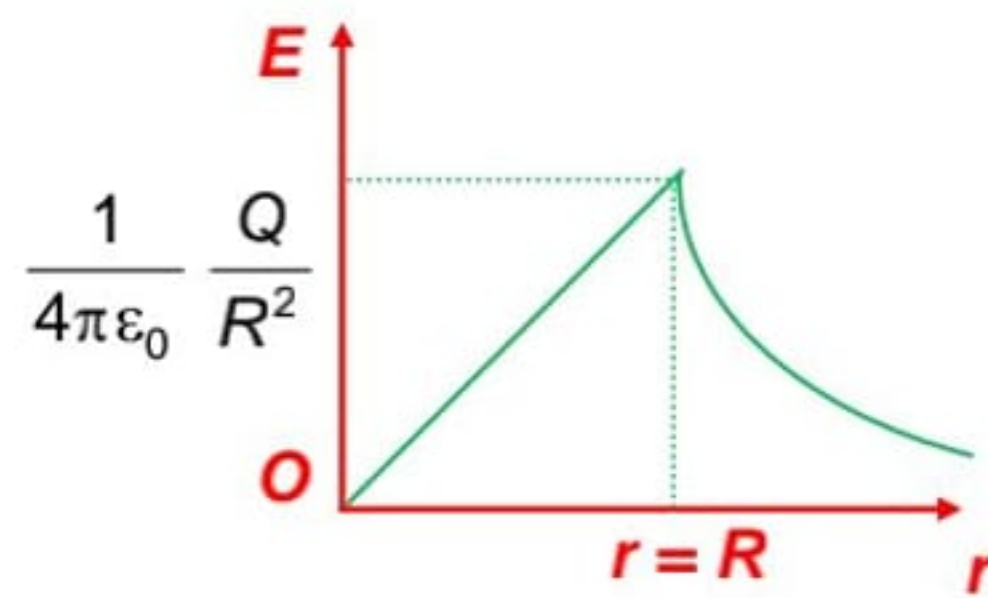
To find the electric field outside the charged sphere, we use a spherical Gaussian surface of radius $r (> R)$. This surface encloses the entire charged sphere. So, from Gauss's law, we have

$$E (4\pi r^2) = \frac{Q}{\epsilon_0}$$

$$\text{or, } E = \frac{1}{4\pi \epsilon_0} \frac{Q}{r^2} \quad \dots (13F)$$

The field at points outside the sphere is the same as that of a point charge at the centre.

Variation of E with the distance from the centre (r)

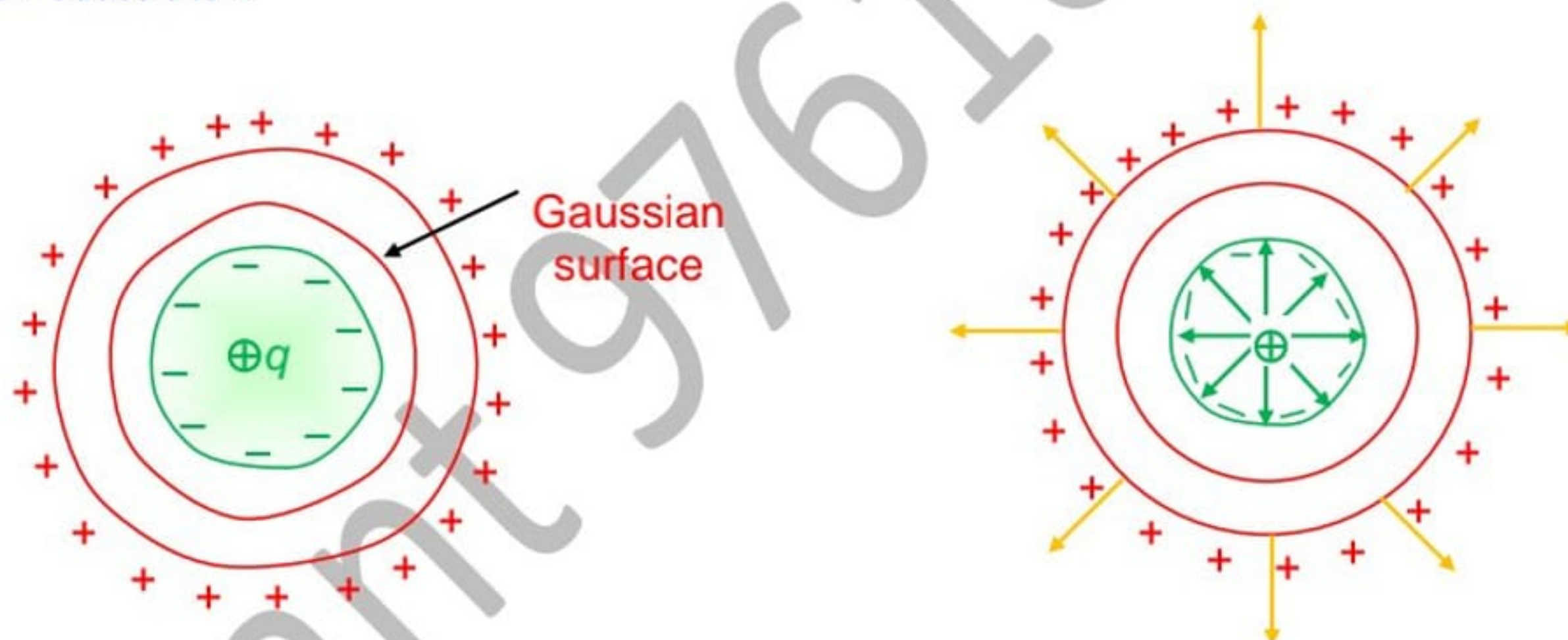


11 CONDUCTORS

A conductor contains “free” electrons, which can move freely in the material, but cannot leave it. Now, when an excess charge is given to an insulated conductor, it sets up electric field inside the conductor. The free electrons will redistribute themselves and within a fraction of a second (approx. 10^{-12} s) the internal field will vanish. Thus, in electrostatic equilibrium the value of \vec{E} at all points within a conductor is zero. This idea, together with the Gauss’s law can be used to prove interesting facts regarding a conductor.

11.1 CAVITY INSIDE A CONDUCTOR

Consider a charge $+q_0$ suspended in a cavity in a conductor. Consider a Gaussian surface just outside the cavity and inside the conductor. $\vec{E} = 0$ on this Gaussian surface as it is inside the conductor. Hence from Gauss’s law



$$\vec{E} \cdot d\vec{S} = \frac{\sum q}{\epsilon_0}, \text{ we have}$$

$$\sum q = 0$$

This concludes that a charge of $-q$ must reside on the metal surface of the cavity so that the sum of this induced charge $-q$ and the original charge $+q$ within the Gaussian surface is zero. In other words, a charge q suspended inside a cavity in a conductor induces an equal and opposite charge $-q$ on the surface of the cavity. Further as the conductor is electrically neutral, a charge $+q$ is induced on the outer surface of the conductor. As field inside the conductor is zero.

The field lines coming from q cannot penetrate into the conductor, as shown in the above figure.

The same line of approach can be used to show that the field inside the cavity of a conductor is zero when no charge is kept inside it.

11.2 ELECTROSTATIC SHIELDING

Suppose we have a very sensitive electronic instrument that we want to protect from external fields that might cause wrong measurements. We surround the instrument with a conducting box or we keep the instrument inside the cavity of a conductor. By doing this, the charge in the conductor is so distributed that the net electric field inside the cavity becomes zero and so instrument is protected from the external fields. This is

called electrostatic shielding.

12 FORCE ON THE SURFACE OF A CHARGED CONDUCTOR

In a charged conductor the charge resides entirely on the surface. This shows that every element of the surface of the conductor experiences a normal outward force, which holds its charge there. This force is produced as a result of repulsion of the charge on the element by the similar charge on the rest of the surface of the conductor. Let us calculate this force.

Let dS be a small element of the surface of a charged conductor. Let σ be the surface density of charge. Let us consider a point P just outside the surface. The magnitude of the electric intensity at P is given by

$$E = \frac{\sigma}{\epsilon_0}, \text{ and is directed along the outward drawn}$$

normal to the element.

The intensity E can be considered as made up of two parts: (i) an intensity E_1 due to the charge on the element dS , and (ii) an intensity E_2 due to the charge on the rest of the surface of the conductor. Since their directions are the same, we have

$$E = E_1 + E_2 = \frac{\sigma}{\epsilon_0} \quad \dots (i)$$

Let us now consider a point Q just inside the surface. The intensity at Q may again be considered as made up of two parts. The intensity due to the charge on the element dS is equal and opposite to that at P i.e., $-E_1$, since Q is very close to P but on the opposite side of the surface. The intensity due to the charge on the rest of the surface is same in magnitude and direction as at P i.e., E_2 (since Q is very close to P). But the resultant intensity at Q must be zero, since Q lies inside the conductor. Hence

$$-E_1 + E_2 = 0$$

$$\text{or } E_1 = E_2.$$

Substituting this in equation (i), we get

$$2E_2 = \frac{\sigma}{\epsilon_0}$$

$$\therefore E_2 = \frac{\sigma}{2\epsilon_0}$$

This gives the outward force experienced by a unit positive charge on the elements dS due to the charge on the rest of the surface. Since the charge on the element is σdS , the force on dS is

$$F = E_2(\sigma dS) = \frac{\sigma^2 dS}{2\epsilon_0}$$

Hence the force per unit area of the surface is

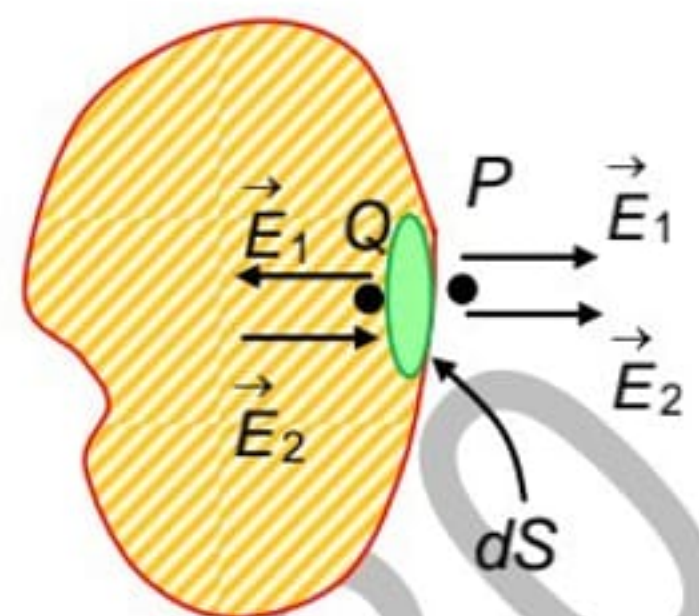
$$\frac{F}{dS} = \frac{\sigma^2}{2\epsilon_0} \quad \dots (14A)$$

Whatever the sign of σ , this force acts outward along the normal to the surface.

Now, from equation (i) $E = \frac{\sigma}{\epsilon_0}$, so that $\sigma = \epsilon_0 E$.

Substituting this value of σ in equation (14A), the outward force per unit area of the surface

$$\begin{aligned} &= \frac{(\epsilon_0 E)^2}{2\epsilon_0} \\ &= \frac{\epsilon_0 E^2}{2} \quad \dots (14B) \end{aligned}$$



Hence the force per unit area (or electrostatic pressure) experienced by a charged conductor is $\frac{\sigma^2}{2\epsilon_0}$ or $\frac{\epsilon_0 E^2}{2}$ newton/meter² directed along the outward drawn normal to the surface.

13 ENERGY DENSITY OF AN ELECTRIC FIELD

Let us consider an electrostatic field E around a charged conductor. The charged conductor experiences a force of $\frac{\epsilon_0 E^2}{2}$ Newton per meter² area, which is everywhere, directed along the outward drawn normal to the surface. If the conductor is placed in a medium of dielectric constant K , the normal force is $\frac{K\epsilon_0 E^2}{2}$ newton.

Suppose the surface is displaced through a small distance of dl meter everywhere along its outward normal. The work done per meter² area of the surface

$$= \frac{K\epsilon_0 E^2}{2} dl \text{ joule.}$$

The volume swept out by 1 meter² area is dl meter³. Thus the work done in producing dl meter³ of the field

$$\frac{K\epsilon_0 E^2}{2} dl \text{ joule.}$$

Hence the work done is producing unit volume of the field.

$$= \frac{K\epsilon_0 E^2}{2} \text{ joule}$$

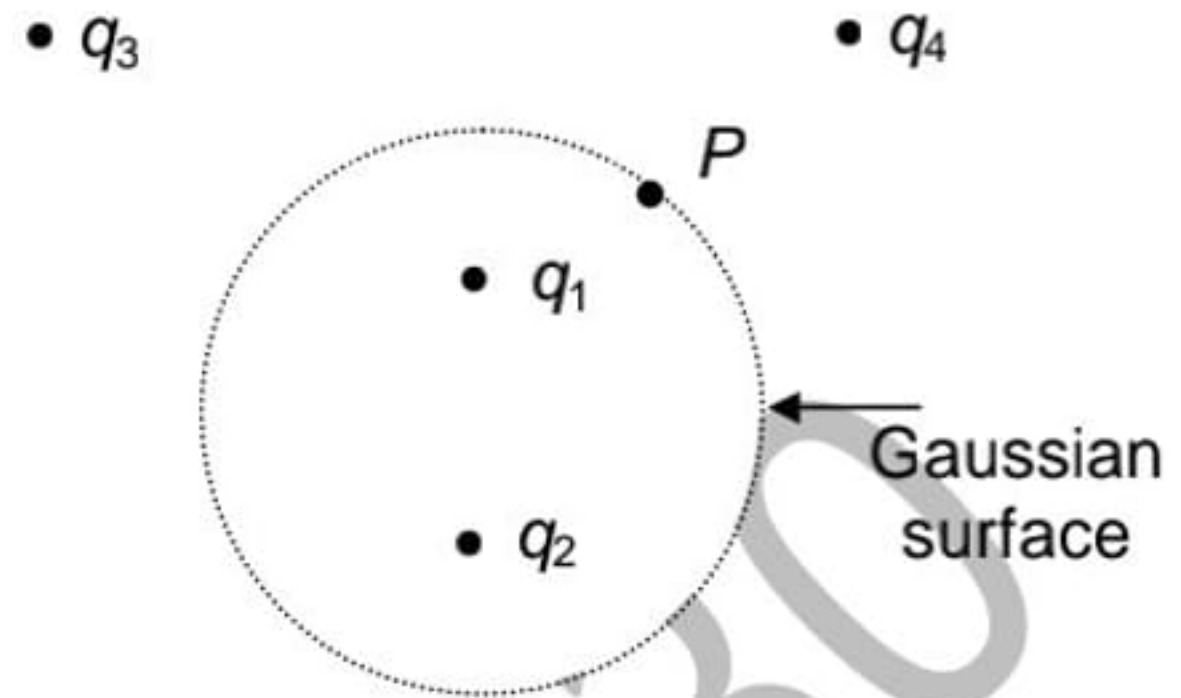
This work is stored as energy of strain in the field. Hence the energy per meter³, or the energy density u , of the field is

$$u = \frac{1}{2} K\epsilon_0 E^2 \quad \dots (15)$$

PROFICIENCY TEST– II

The following questions deal with the basic concepts of this section. Answer the following briefly. Go to the next section only if your score is at least 80%. Do not consult the Study Material while attempting these questions.

1. Consider the Gaussian surface that surrounds part of the charge distribution shown above.



- (a) Which of the charges contribute to the electric field at point P ?
- (b) Would the value obtained for the flux through the surface, calculated using only the field due to q_1 and q_2 , be greater than, equal to, or less than that obtained using the total field?

2. A point charge is placed at the centre of a spherical Gaussian surface. Is ϕ_E changed?

- (a) if the surface is replaced by a cube of the same volume?
- (b) if the sphere is replaced by a cube of one-tenth the volume?

3. In the proceeding question, is ϕ_E changed

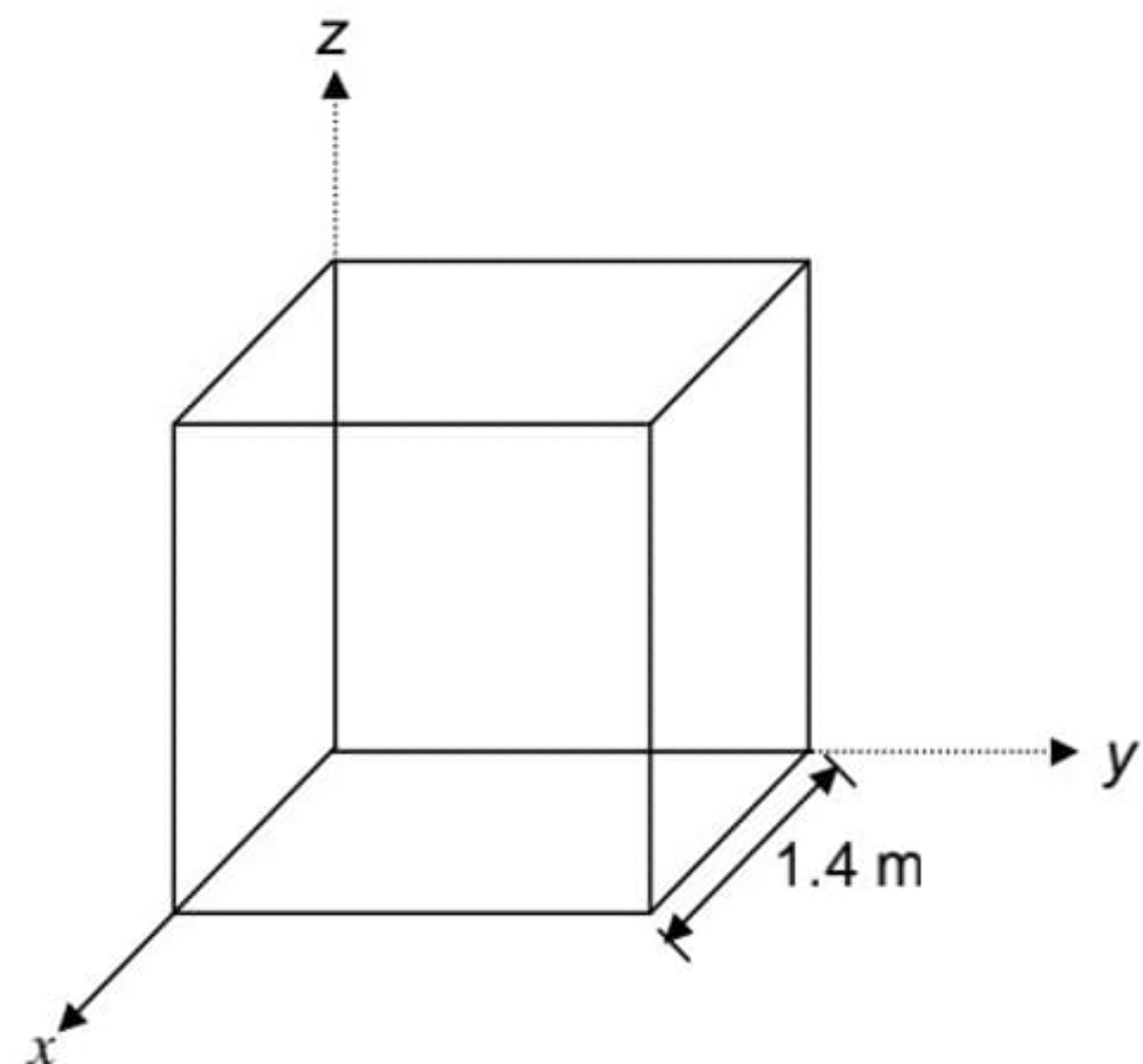
- (a) if the charge is moved off-centre in the original sphere, still remaining inside?
- (b) if the charge moved just outside the original sphere?

4. In question (2), will ϕ_E change

- (a) if a second charge is placed near, and outside, the original sphere?
- (b) if a second charge is placed inside the Gaussian surface

5. A cube with edge 2 m is oriented as shown above, in a region of uniform electric field. Find the electric flux through the right face if the electric field is given by

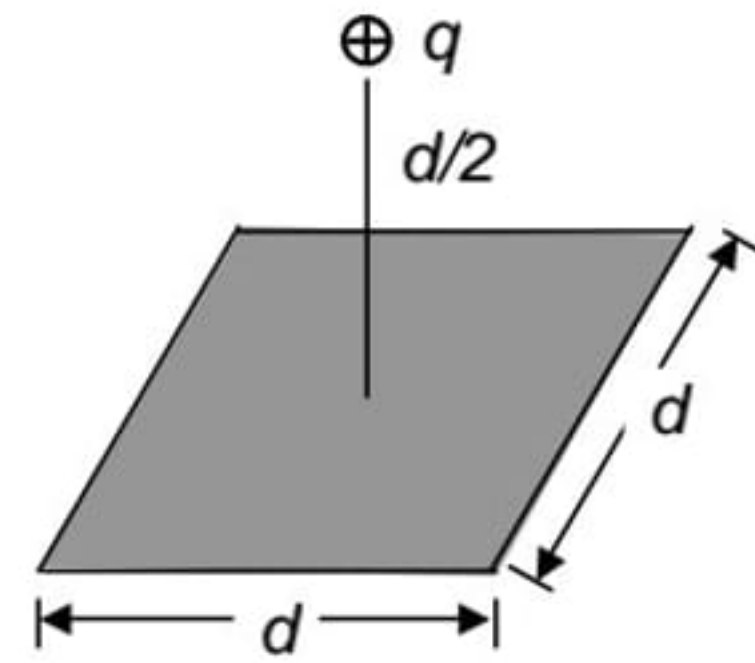
- (a) $\left(6 \frac{N}{C}\right) \hat{i}$;
- (b) $(-2N/C) \hat{j}$, and
- (c) $(-3N/C) \hat{i} + (4 N/C) \hat{k}$,
- (d) calculate the total flux through the cube for each of these fields.



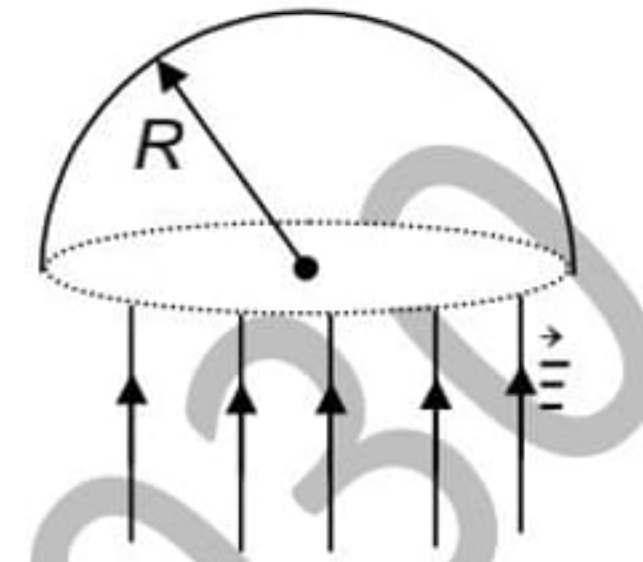
6. A point charge $q = 24\epsilon_0$ is placed at the centre of a cube of edge a . What is the flux through each of the cube faces?

7. A point charge $q = 48 \epsilon_0$ is placed at one corner of a cube of edge a . What is the flux through each of the cube faces?

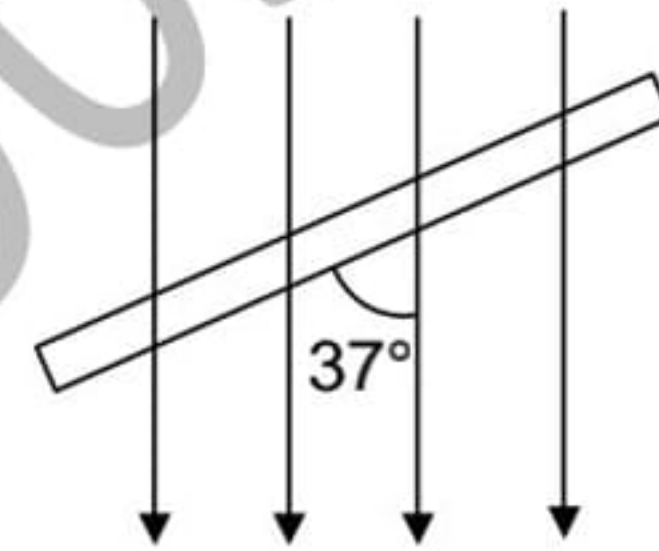
8. A point charge $+q = 6\epsilon_0$ is a distance $d/2$ from a square surface of side d and is directly above the centre of the square, as shown above. Find the electric flux through the square.



9. A hemisphere of radius $R = \frac{1}{\sqrt{\pi}}$ is placed in a uniform electric field $|\vec{E}| = 1 \text{ N/C}$ with its axis perpendicular to the electric field \vec{E} . What is the electric flux through the curved surface?



10. A flat plate with dimensions $50 \text{ cm} \times 60 \text{ cm}$ is set with its plane at 37° to a uniform electric field $\vec{E} = -500 \hat{j} \text{ N/C}$, as shown below. What is the flux through the plate?



ANSWERS TO PROFICIENCY TEST- II

1. (a) q_1, q_2, q_3 and q_4
(b) equal
2. (a) No
(b) No
3. (a) No
(b) Yes
4. (a) No
(b) Yes
5. (a) zero
(b) $-8 \text{ Nm}^2\text{C}^{-1}$
(c) zero
(d) zero in each case
6. 4
7. 2
8. 1
9. $1 \text{ Nm}^2/\text{C}$
10. $90 \text{ N-m}^2/\text{C}$

14 ELECTRIC POTENTIAL

The electric potential at a point in an electric field is the external work needed to bring a unit positive charge, with constant, from infinity (point of zero potential) to the given point. Thus,

$$V = \frac{W_{\text{ext}}}{q_0} \quad \dots (16)$$

Where W_{ext} is work done in moving a charge q_0 from infinity to that point.

Important points regarding electric potential

(i) As electric field is conservative, $W_{\text{ext}} = U$.

So,

$$V = \frac{U}{q_0}$$

or, $U = q_0 V$

Thus, the electric potential at a point is numerically equal to the potential energy per unit charge at that point.

(ii) It is a scalar having SI unit (J/C) called volt (V).

$$1V = \frac{1J}{1C}$$

(iii) If V_A and V_B are the electric potentials of two points A and B, the potential difference between A and B is equal to $V_B - V_A$.

Thus the potential difference between two points, A and B, is defined as

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

where $W_{A \rightarrow B}$ is the work done by an external agent in moving a positive test charge q_0 from A to B

(iv) We know that

$$\Delta V = \frac{W_{\text{ext}}}{q_0}$$

$$\text{Now, } W_{\text{ext}} = \int \vec{F}_{\text{ext}} \cdot d\vec{l}$$

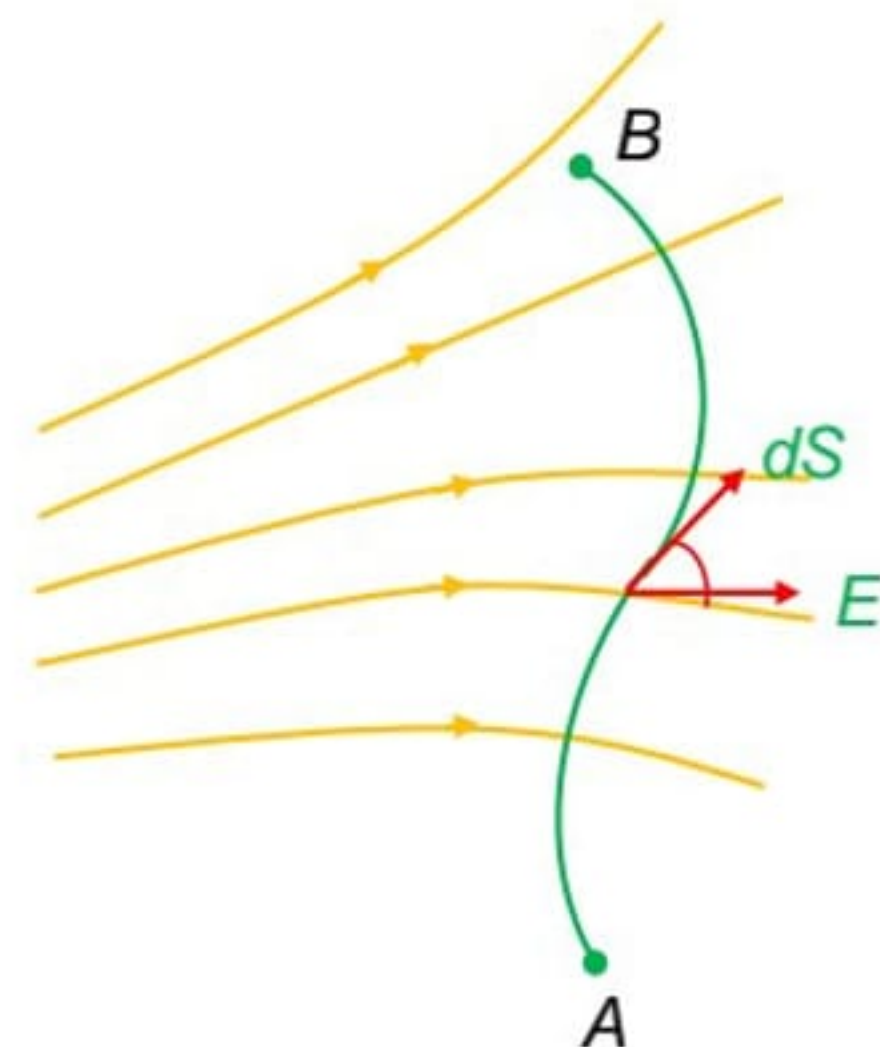
Since the external force is equal and opposite of the electrostatic force, we have

$$\vec{F}_{\text{ext}} = -q\vec{E}$$

$$\text{or } W_{\text{ext}} = \int q\vec{E} \cdot d\vec{l}$$

The figure shows a curved path in a non-uniform field. The potential difference between the points A and B is given by

$$V_B - V_A = - \int_A^B \vec{E} \cdot d\vec{l} \quad \dots (17)$$



Since the electrostatic field is conservative, the value of this line integral depends only on the end points A and B and not on the path taken. So the electric potential at a point can be interpreted as the negative of the work done by the field in displacing a unit positive charge from some reference point (usually taken at infinity) to the given point.

Illustration 13

Question: The electric potential at point A is 200 V and at B is -400 V. Find the work done by an external force and electrostatics force in moving charge of 2×10^{-8} C slowly from B to A. (in μ J)

Solution: Here,
 $q_0 = 2 \times 10^{-8}$ C; $V_A = 200$ V;
 $V_B = -400$ V
 work done by the external force = $W_{B \rightarrow A}$
 $= q_0 (V_A - V_B)$
 $= (2 \times 10^{-8}) [(200 - (-400))]$
 Work done by the electric force = $-(W_{B \rightarrow A})_{\text{external}}$
 $= 12$

Illustration 14

Question: Find the work done by some external force in moving a charge $q = 2 \mu\text{C}$ from infinity to a point where electric potential is 10^6 V. (in J)

Solution: $(E_{\infty \rightarrow A})_{\text{external}} = (2 \times 10^{-6}) (10^4)$
 $= 2$

14.1 ELECTRIC POTENTIAL AT A POINT DUE TO A POINT CHARGE

As $\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^3} \vec{r}$ and $V = -\int_{\infty}^r \vec{E} \cdot d\vec{r}$

$\therefore V = -\int_{\infty}^r \frac{1}{4\pi\epsilon_0} \frac{q}{r^3} \vec{r} \cdot d\vec{r} = -\frac{1}{4\pi\epsilon_0} \int_{\infty}^r \frac{q}{r^2} dr$

or $V = \frac{1}{4\pi\epsilon_0} \frac{q}{r}$, ... (18)

where r is the distance of A from the point charge q .

The electric potential at A (V_A) is positive if the point charge q is positive. V_A will be negative if the point charge q is negative.

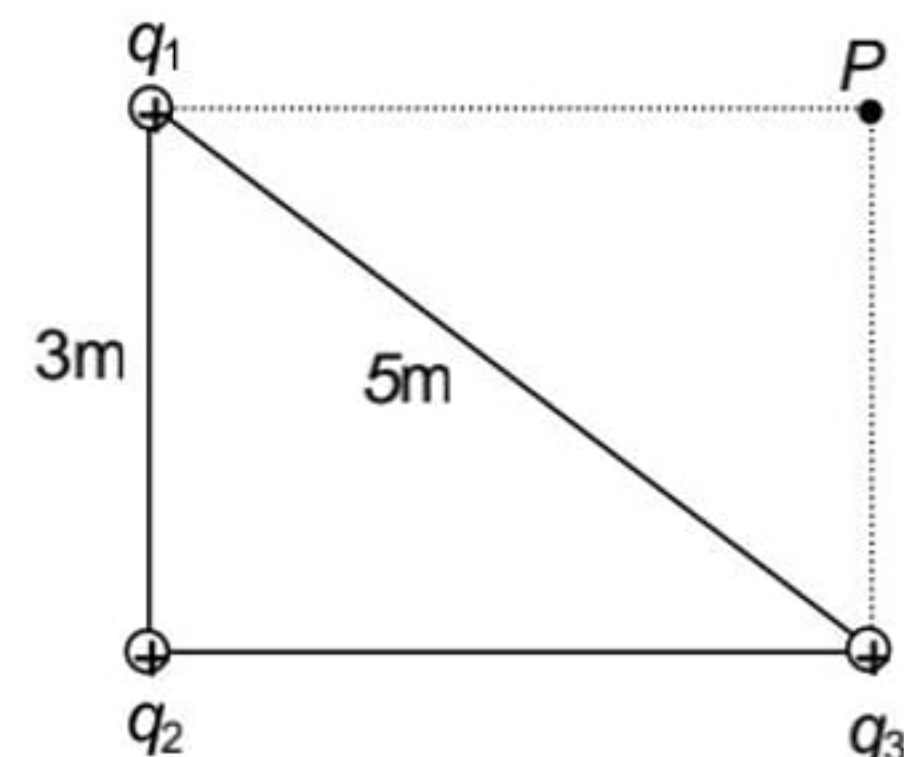
14.2 ELECTRIC POTENTIAL DUE TO A GROUP OF POINT CHARGES

The potential at any point due to a group of point charges is the algebraic sum of the potentials contributed at the same point by all the individual point charges.

$V = V_1 + V_2 + V_3 + \dots$... (19)

Illustration 15

Question: Three point charges $q_1 = 1 \mu\text{C}$; $q_2 = 2 \mu\text{C}$; and $q_3 = 3 \mu\text{C}$ are fixed at a position shown. How much work would be needed to bring a charge $q_4 = 25 \mu\text{C}$ from infinity and to place it at P? (in mJ)



Solution: The external work is $W_{\text{ext}} = q[V_f - V_i]$
 In this case, $V_i = 0$.
 So, $W_{\text{ext}} = q_4 V_P = (2.5 \times 10^{-6} \text{ C}) (7.65 \times 10^3 \text{ V}) = 19$

14.3 ELECTRIC POTENTIAL DUE TO A CONTINUOUS CHARGE DISTRIBUTION

The electric potential due to a continuous charge distribution is the sum of potentials of all the infinitesimal charge elements in which the distribution may be divided.

$V = \int dV$

$$V = \int \frac{dq}{4\pi\epsilon_0 r}$$

14.3.1 Electric Potential due to a charged ring

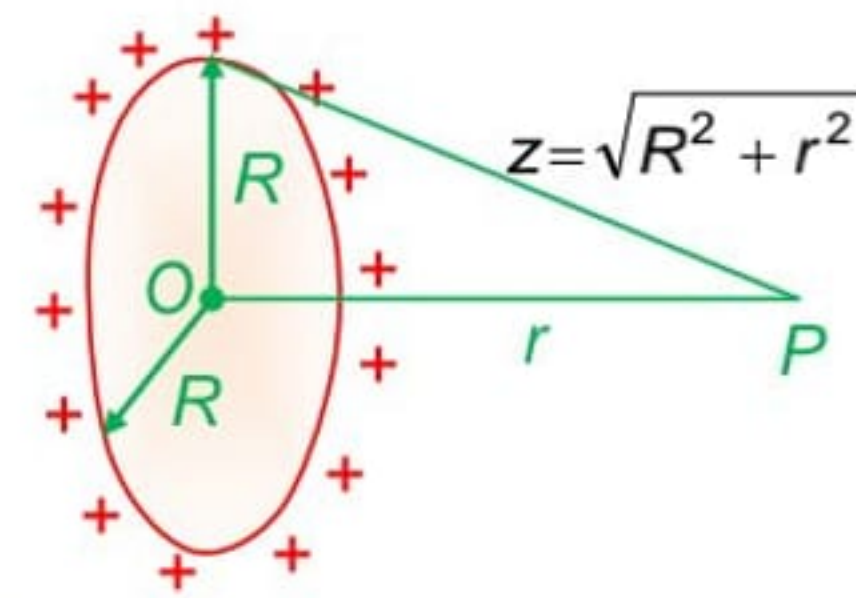
A charge Q is uniformly distributed over the circumference of a ring. Let us calculate the electric potential at an axial point at a distance r from the centre of the ring.

The electric potential at P due to the charge element dq of the ring is given by

$$dV = \frac{1}{4\pi\epsilon_0} \frac{dq}{Z} = \frac{1}{4\pi\epsilon_0} \frac{dq}{(R^2 + r^2)^{1/2}}$$

Hence, the electric potential at P due to the uniformly charged ring is given by

$$\begin{aligned} V &= \int \frac{1}{4\pi\epsilon_0} \frac{dq}{(R^2 + r^2)^{1/2}} = \frac{1}{4\pi\epsilon_0} \frac{1}{(R^2 + r^2)^{1/2}} \int dq \\ &= \frac{1}{4\pi\epsilon_0} \frac{Q}{\sqrt{(R^2 + r^2)}} \end{aligned} \quad \dots (19A)$$

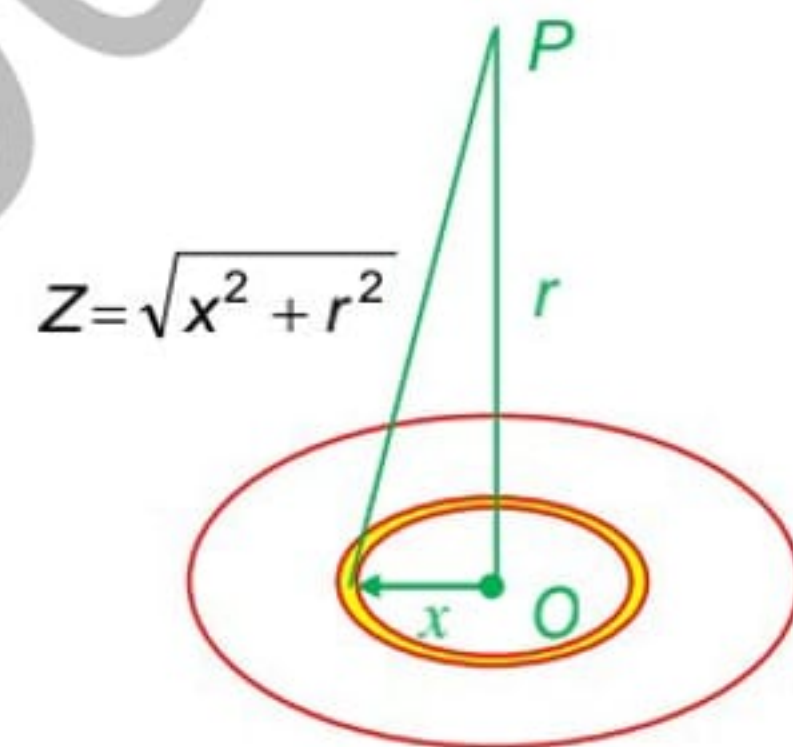


14.3.2 Electric potential due to a charged disc at a point on the axis

A non-conducting disc of radius ' R ' has a uniform surface charge density σ C/m². Let us calculate the potential at a point on the axis of the disc at a distance ' r ' from its centre

The symmetry of the disc tells us that the appropriate choice of element is a ring of radius x and thickness dx . All points on this ring are at the same distance $Z = \sqrt{x^2 + r^2}$, from the point P . The charge on the ring is $dq = \sigma dA = \sigma (2\pi x dx)$ and so the potential due to the ring is

$$dV = \frac{1}{4\pi\epsilon_0} \frac{dq}{Z} = \frac{1}{4\pi\epsilon_0} \frac{\sigma(2\pi x dx)}{\sqrt{x^2 + r^2}}$$



Since potential is scalar, there are no components to worry about.

The potential due to the whole disc is given by

$$\begin{aligned} V &= \frac{\sigma}{2\epsilon_0} \int_0^R \frac{x dx}{\sqrt{x^2 + r^2}} = \frac{\sigma}{2\epsilon_0} \left[(x^2 + r^2)^{1/2} \right]_0^R \\ &= \frac{\sigma}{2\epsilon_0} \left[(R^2 + r^2)^{1/2} - r \right] \end{aligned} \quad \dots (19B)$$

Let us see how this expression behaves at large distances, when $r \gg R$. We use binomial theorem $(1+x)^n \approx 1+nx$ for small x to expand the first term

$$\begin{aligned} (R^2 + r^2)^{1/2} &= r \left[1 + \frac{R^2}{r^2} \right]^{1/2} \\ &\approx r \left[1 + \frac{R^2}{2r^2} + \dots \right] \end{aligned}$$

Substituting this into the expression for V , we find

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}, \text{ where } Q = \pi R^2 \sigma \text{ is the total charge on the disc.}$$

Thus, we conclude that at large distances, the potential due to the disc is the same as that of a point charge Q .

14.3.3 Electric Potential due to a closed disc at a point on the edge.

Let us calculate the potential at the edge of a thin disc of radius ' R ' carrying a uniformly distributed charge with surface density σ

Let AB be a diameter and A be a point where the potential is to be calculated. From A as centre, we draw two arcs of radii r and $r + dr$ as shown. The infinitesimal region between these two arcs is an element whose area is $dA = (2r\theta) dr$, where 2θ is the angle subtended by this element PQ at the point A . Potential at A due to the element PQ is

$$dV = \frac{\sigma dA}{4\pi\epsilon_0 r} = \frac{2\sigma r\theta dr}{4\pi\epsilon_0 r} = \frac{2\sigma\theta dr}{4\pi\epsilon_0}$$

From $\triangle APB$, we have

$$r = 2R \cos\theta$$

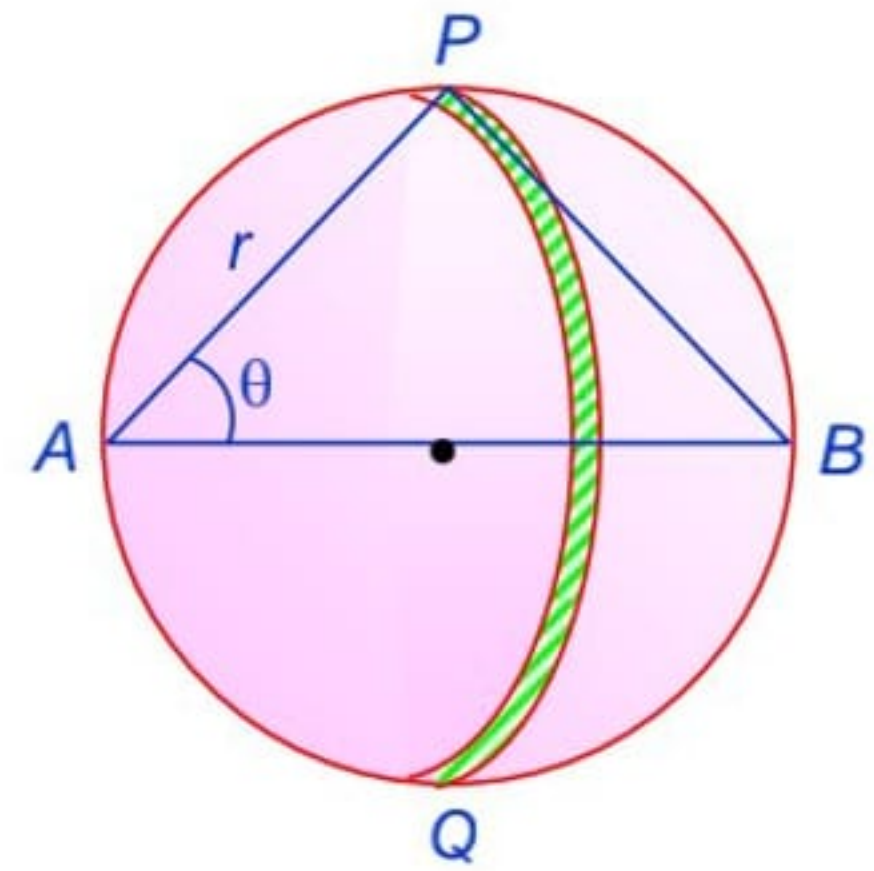
$$\text{or, } dr = -2R \sin\theta d\theta$$

Hence

$$dV = \frac{-4\sigma\theta R \sin\theta d\theta}{4\pi\epsilon_0}$$

$$V = - \int_{\pi/2}^0 \frac{\sigma R \theta \sin\theta d\theta}{\pi\epsilon_0}$$

$$V = - \frac{\sigma R}{\pi\epsilon_0} \left[-\theta \cos\theta + \sin\theta \right]_{\pi/2}^0 \quad V = \frac{\sigma R}{\pi\epsilon_0} \quad \dots (19C)$$



14.3.4 Electric Potential due to a shell

A shell of radius R has a charge Q uniformly distributed over its surface. Let us calculate the potential at a point

(a) outside the shell; ($r > R$)

(b) inside the shell ($r < R$).

(a) At points outside a uniform spherical distribution, the electric field is $\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \hat{r}$

since \vec{E} is radial, $\vec{E} \cdot d\vec{r} = E dr$
since $V(\infty) = 0$, we have

$$V(r) - V(\infty) = \int_{\infty}^r \frac{Q}{4\pi\epsilon_0 r^2} dr = \frac{Q}{4\pi\epsilon_0} \left[-\frac{1}{r} \right]_{\infty}^r$$

$$\Rightarrow V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r} \quad (r > R) \quad \dots (19D)$$

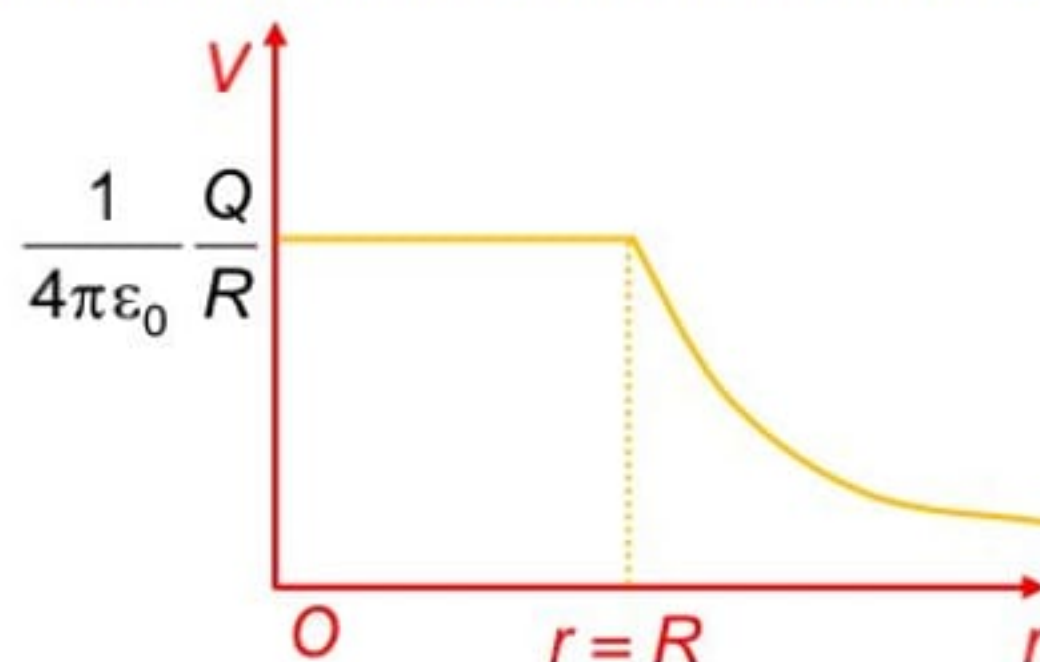
We see that the potential due to a uniformly charged shell is the same as that due to a point charge Q at the centre of the shell.

(b) At an Internal Point

At points inside the shell, $E = 0$. So, the work done in bringing a unit positive charge from a point on the surface to any point inside the shell is zero. Thus, the potential has a fixed value at all points within the spherical shell and is equal to the potential at the surface.

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{R} \quad \dots (19E)$$

Variation of electric potential with the distance from the centre (r)



☞ All the above results hold for a "conducting sphere" also whose charge lies entirely on the outer surface.

14.3.5 Electric Potential due to a non-conducting charged sphere

A charge Q is uniformly distributed throughout a non-conducting spherical volume of radius R . Let us find expressions for the potential at an (a) external point ($r > R$); (b) internal point ($r < R$); where r is the distance of the point from the centre of the sphere.

(a) At an external point

Let O be the centre of a non-conducting sphere of radius R , having a charge Q distributed uniformly over its entire volume.

Let P be a point distant r ($>R$) from O at which potential is required. Let ρ be the charge density

Let us divide the sphere into a large number of thin concentric shells carrying charges $q_1, q_2, q_3 \dots$ etc. The potential at the point P due to the shell of charge q_1

$$\text{is } \frac{1}{4\pi\epsilon_0} \frac{q_1}{r}$$

Now, potential is a scalar quantity. Therefore the potentials V due to the whole sphere is equal to the sum of the potentials due to all the shells.

$$\begin{aligned} \therefore V &= \frac{1}{4\pi\epsilon_0} \frac{q_1}{r} + \frac{1}{4\pi\epsilon_0} \frac{q_2}{r} + \dots \\ &= \frac{1}{4\pi\epsilon_0 r} [q_1 + q_2 + q_3 + \dots] \end{aligned}$$

But $q_1 + q_2 + q_3 + \dots = Q$, the charge on the sphere.

$$\therefore V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r} \quad \dots (19F)$$

(b) Potential at an internal point

Suppose the point P lies inside the sphere at a distance r from the centre O , If we draw a concentric sphere through the point P , the point P will be external for the solid sphere of radius r , and internal for the outer spherical shell of internal radius r and external radius R .

The charge on the inner solid sphere is $\frac{4}{3}\pi r^3\rho$. Therefore, the potential V_1 at P due to this sphere is given by

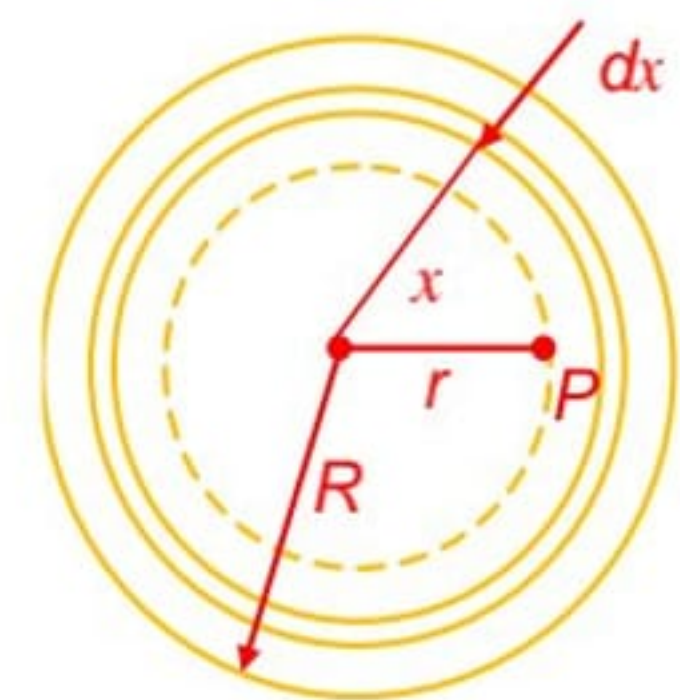
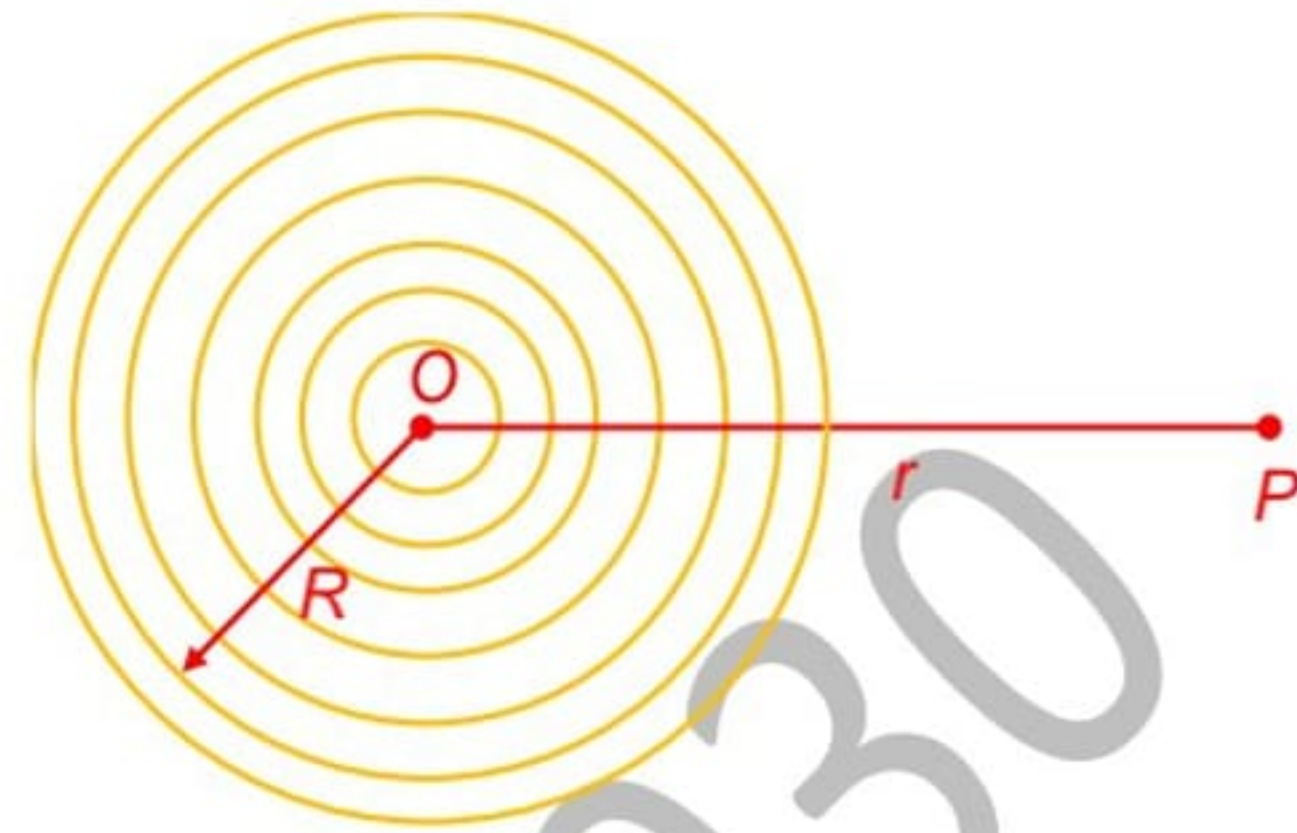
$$V_1 = \frac{1}{4\pi\epsilon_0} \frac{4/3 \pi r^3 \rho}{r} = \frac{r^2 \rho}{3\epsilon_0}$$

Let us now find the potential at P due to the outer spherical shell. Let us divide this shell into a number of thin concentric shells and consider one such shell of radius x and infinitesimally small thickness dx . The volume of this shell = surface area \times thickness = $4\pi x^2 dx$. The charge on this shell, $dq = 4\pi x^2 dx \rho$. The potential at P due to this shell

$$\begin{aligned} dV_2 &= \frac{1}{4\pi\epsilon_0} \frac{dq}{x} = \frac{1}{4\pi\epsilon_0} \frac{4\pi x^2 (dx)\rho}{x} \\ &= \frac{\rho x dx}{\epsilon_0} \end{aligned}$$

The potential V_2 at P due to the whole shell of internal radius r and external radius R is given by

$$V_2 = \int_r^R \frac{\rho x dx}{\epsilon_0} = \frac{\rho}{\epsilon_0} \left[\frac{x^2}{2} \right]_r^R$$



$$= \frac{\rho(R^2 - r^2)}{2\epsilon_0}$$

Since the potential is a scalar quantity, the total potential V at P is given by

$$\begin{aligned} V &= V_1 + V_2 \\ &= \frac{r^2\rho}{3\epsilon_0} + \frac{\rho(R^2 - r^2)}{2\epsilon_0} \\ &= \frac{\rho(3R^2 - r^2)}{6\epsilon_0} \end{aligned}$$

But $\rho = \frac{Q}{\frac{4}{3}\pi R^3}$

$$\therefore V = \frac{1}{4\pi\epsilon_0} \frac{Q}{2R^3} [3R^2 - r^2] \quad \dots (19G)$$

15 CALCULATION OF ELECTRIC FIELD FROM ELECTRIC POTENTIAL

In rectangular components, the electric field is

$$\vec{E} = E_x \hat{i} + E_y \hat{j} + E_z \hat{k};$$

and an infinitesimal displacement is $d\vec{S} = dx\hat{i} + dy\hat{j} + dz\hat{k}$

Thus,

$$\begin{aligned} dV &= -\vec{E} \cdot d\vec{S} \\ &= -[E_x dx + E_y dy + E_z dz] \end{aligned} \quad \dots (20)$$

for a displacement in the x -direction,

$dy = dz = 0$ and so

$dV = -E_x dx$. Therefore,

$$E_x = -\left(\frac{dV}{dx}\right)_{y,z \text{ constant}}$$

A derivative in which all variables except one are held constant is called partial derivative and is written with ∂ instead of d . The electric field is, therefore,

$$\vec{E} = -\frac{\partial V}{\partial x} \hat{i} - \frac{\partial V}{\partial y} \hat{j} - \frac{\partial V}{\partial z} \hat{k} \quad \dots (21)$$

Illustration 16

Question: The electrical potential due to a point charge is given by $V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$. Find

the x -component of the electric field. (take $r = 2\text{m}$, $x = 1\text{m}$, $Q = \frac{8}{9} \times 10^{-9} \text{C}$) (in N/C)

Solution: (a) The radial component is given by

$$E_r = -\frac{dV}{dr} = +\frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

(b) In terms of rectangular components, the radial distance is $r = (x^2 + y^2 + z^2)^{1/2}$; therefore, the potential function

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r} = \frac{1}{4\pi\epsilon_0} \frac{Q}{(x^2 + y^2 + z^2)^{1/2}}$$

To find the x -component of the electric field, we treat y and z constants. Thus

$$E_x = -\frac{\partial V}{\partial x}$$

$$\text{or } E_x = +\frac{1}{4\pi\epsilon_0} \frac{Qx}{(x^2 + y^2 + z^2)^{3/2}}$$

$$= \frac{\begin{matrix} \uparrow & \downarrow & \uparrow & \downarrow & \uparrow & \downarrow & \uparrow & \downarrow \\ \uparrow & \downarrow & \uparrow & \downarrow & \uparrow & \downarrow & \uparrow & \downarrow \end{matrix}}{\begin{matrix} \uparrow & \downarrow & \uparrow & \downarrow & \uparrow & \downarrow & \uparrow & \downarrow \\ \uparrow & \downarrow & \uparrow & \downarrow & \uparrow & \downarrow & \uparrow & \downarrow \end{matrix}} = 1$$

16 EQUIPOTENTIAL SURFACES

If we join the points in an electric field, which are at same potential, the surface (or curve) obtained is known as equipotential surface (curve).

Important Points Regarding Equipotential surfaces

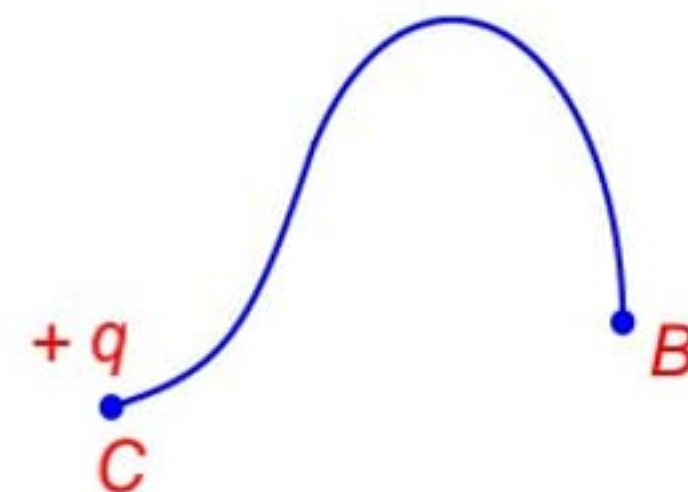
- (i) The lines of forces are always normal to equipotential surfaces
- (ii) The net work done in taking a charge from A to B is zero if A and B are on same equipotential surface.

Examples

- (i) In the field of a point charge, the equipotential surfaces are spheres centered on the point charge.
- (ii) In a uniform electric field, the equipotential surfaces are planes which are perpendicular to the field lines.
- (iii) In the field of an infinite line charge, the equipotential surfaces are co-axial cylinders having their axes at the line charge.
- (iv) The surface of a conductor is an equipotential surface and the inside of conductor is equipotential space. Hence there is no electric field (and charge) inside the conductor's surface. The lines of forces are always normal to the surface of a conductor.

17 ELECTRIC POTENTIAL ENERGY

If a charge is moved between two points in an electric field, work is usually done against the field or by the field. In the figure, if a charge $+q$ is moved from B to C in the electric field of charge $+Q$, the work will have to be done by some outside agency in pushing the charge $+q$ against the force of field of $+Q$.



This situation is very similar to that of a mass moved in gravitational field of earth away from it. Work done against the gravitational pull of earth is stored in Gravitational potential energy and can be recovered back. Similarly in electric field, work done against an electric field is stored in the form of electric potential energy & can be recovered back. If the charge $+q$ is taken back from C to B, the electric force will try to accelerate the charge and hence to recover the potential stored in the form of kinetic energy.

As the work done against an electric field can be recovered back, electrostatic forces and fields fall under the category of conservative forces and fields. Another property of these fields is that the work done is independent of path taken from one point to the another.

17.1 POTENTIAL ENERGY OF A SYSTEM OF TWO POINT CHARGES

The potential energy possessed by a system of two-point charges q_1 and q_2 separated by a distance r is the work done required to bring them to this arrangements from infinity. This electrostatic potential energy is given by

$$U = \frac{q_1 q_2}{4\pi\epsilon_0 r} \quad \dots (22)$$

17.2 ELECTRIC POTENTIAL ENERGY OF A SYSTEM OF POINT CHARGES

The electric potential energy of such a system is the work done in assembling this system starting from infinite separation between any two-point charges.

For a system of point charges q_1, q_2, \dots, q_n , the potential energy is

$$U = \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \frac{q_i q_j}{4\pi\epsilon_0 r_{ij}} \quad (i \neq j) \quad \dots (23)$$

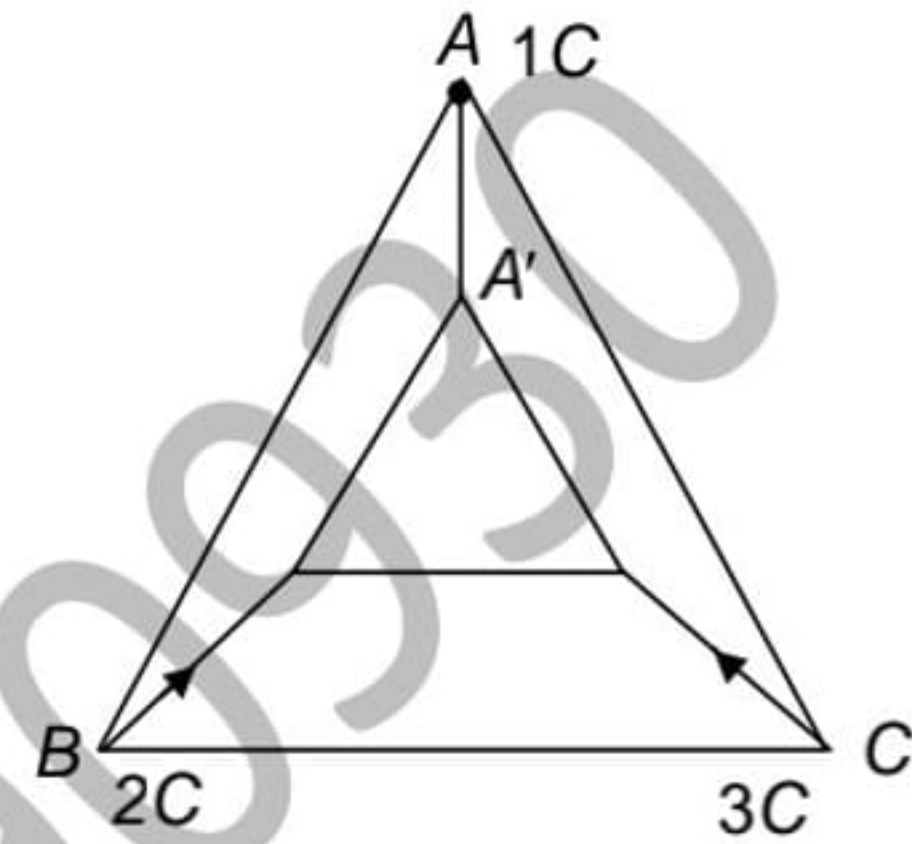
If simply means that we have to consider all the pairs that are possible.

Important points regarding Electrostatic potential energy

- (i) Work done required by an external agency to move a charge q from A to B in an electric field with constant speed
 $W_{A \rightarrow B} = q [V_B - V_A]$
- (ii) When a charge q is let free in an electric field, it loses potential energy and gains kinetic energy, if it goes from A to B , then loss in potential energy = gain in kinetic energy
- or, $q (V_B - V_A) = \frac{1}{2} m V_B^2 - \frac{1}{2} m V_A^2$

Illustration 17

Question: Three point charges $1\mu\text{C}$, $2\mu\text{C}$ and $3\mu\text{C}$ are placed at the corner of an equilateral triangle of side 1m . Calculate the work required to move these charges to the corners of a smaller equilateral triangle of side 0.5m as shown. (in mJ)



Solution: As the potential energy of two point charges separated by a distance ' r ' is given by $[U = \frac{q_1 q_2}{4\pi\epsilon_0 r}]$, the initial and the final potential energy of the system will be

$$U_i = \frac{10^{-12}}{4\pi\epsilon_0} \left[\frac{1 \times 2}{1} + \frac{2 \times 3}{1} + \frac{3 \times 1}{1} \right]$$

$$= 9 \times 10^9 \times 11 = 9.9 \times 10^{-2} \text{ J}$$

$$U_f = \frac{10^{-12}}{4\pi\epsilon_0} \left[\frac{1 \times 2}{0.5} + \frac{2 \times 3}{0.5} + \frac{3 \times 1}{0.5} \right] = 9 \times 10^9 \times 22 \times 10^{-12}$$

$$= 19.8 \times 10^{-2} \text{ J}$$

So, the work done in changing the configuration of the system
 $W = U_f - U_i = (19.8 - 9.9) \times 10^{-2} \times 10^{-12}$

$$= 99 \text{ mJ}$$

18 ELECTRIC DIPOLE

Two equal and opposite point charges placed at a short distance apart constitute an electric dipole.

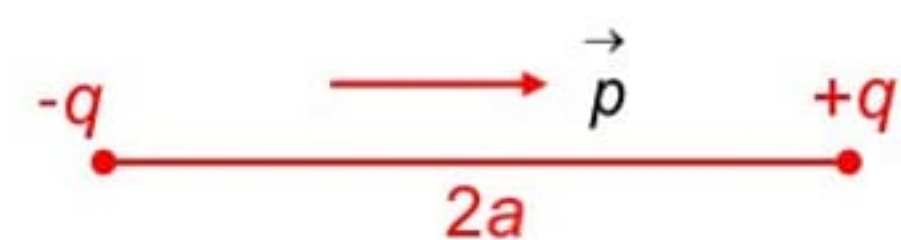
18.1 ELECTRIC DIPOLE MOMENT

Electric dipole moment is a vector \vec{p} directed along the axis of the dipole, from the negative to the positive charge.

The magnitude of dipole moment is

$$p = (2a) q$$

where $2a$ is the distance between the two charges.



$$\dots (24)$$

18.2 ELECTRIC POTENTIAL DUE TO AN ELECTRIC DIPOLE

Suppose, the negative charge $-q$ is placed at a point A and a positive charge q is placed at a point B . The separation $AB = 2a$

The middle point of AB is O . The potential is to be evaluated at

a point P where $OP = r$ and $\angle POB = \theta$. Let AA' be the perpendicular from A to PO and BB' be the perpendicular from B to PO . As $2a$ is very small compared to r ,

$$AP \approx A'P = OP + OA' = r + a \cos \theta$$

Similarly, $BP \approx B'P = OP - OB' = r - a \cos \theta$

The potential at P due to the charge $-q$ is

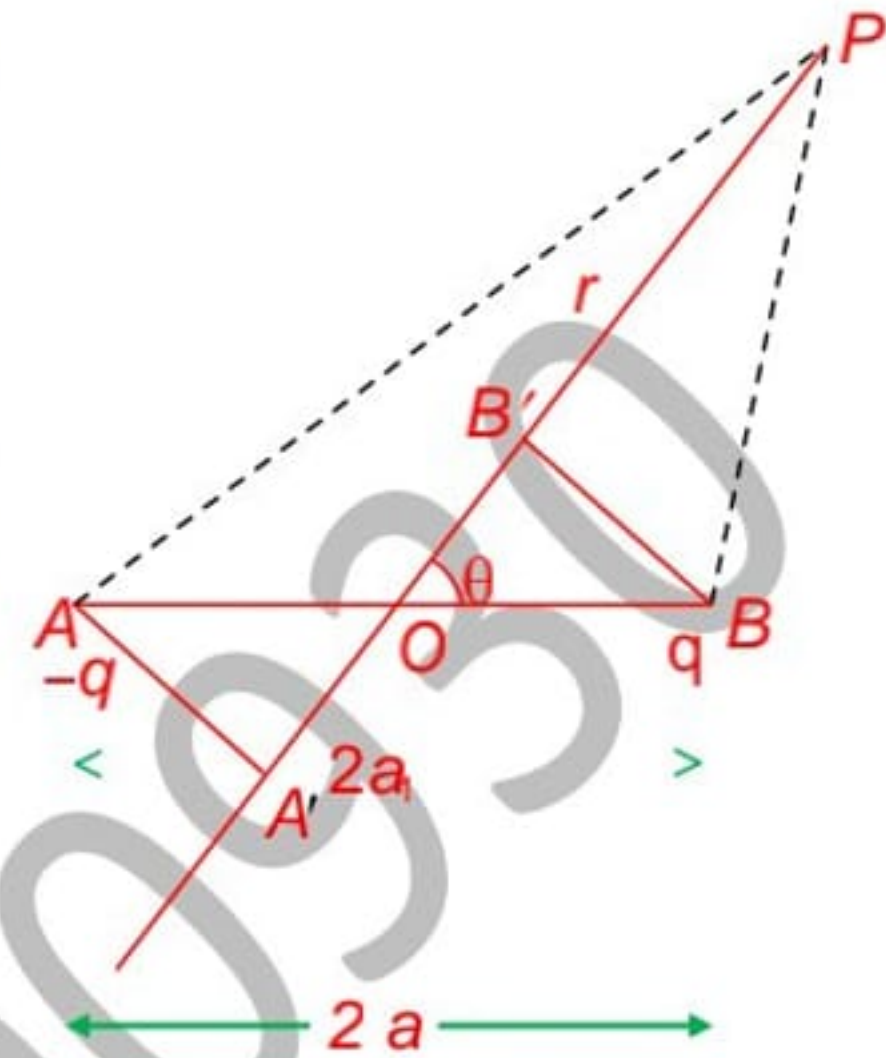
$$V_1 = -\frac{1}{4\pi\epsilon_0} \frac{q}{AP} \approx -\frac{1}{4\pi\epsilon_0} \frac{q}{r + a \cos \theta} \text{ and that due to the charge } +q \text{ is}$$

$$V_2 = \frac{1}{4\pi\epsilon_0} \frac{q}{BP} \approx \frac{1}{4\pi\epsilon_0} \frac{q}{r - a \cos \theta}$$

The net potential at P due to the dipole is

$$\begin{aligned} V &= V_1 + V_2 \\ &= \frac{1}{4\pi\epsilon_0} \left[\frac{q}{r - a \cos \theta} - \frac{q}{r + a \cos \theta} \right] \\ &= \frac{1}{4\pi\epsilon_0} \frac{2qa \cos \theta}{(r^2 - a^2 \cos^2 \theta)} \approx \frac{p \cos \theta}{4\pi\epsilon_0 r^2} \end{aligned}$$

... (25)



18.3 ELECTRIC FIELD DUE TO AN ELECTRIC DIPOLE

Consider a point P at a distance r from O making an angle θ with AB . PP_1 is a small displacement in the direction of OP and PP_2 is a small displacement perpendicular to OP . Thus PP_1 is in radial direction and PP_2 is in transverse direction. In going from P to P_1 , the angle θ does not change and the distance OP changes from r to $r + dr$. Thus $PP_1 = dr$. In going from P to P_2 , the angle θ changes from θ to $\theta + d\theta$ while the distance r remains almost constant so $PP_2 = r d\theta$.

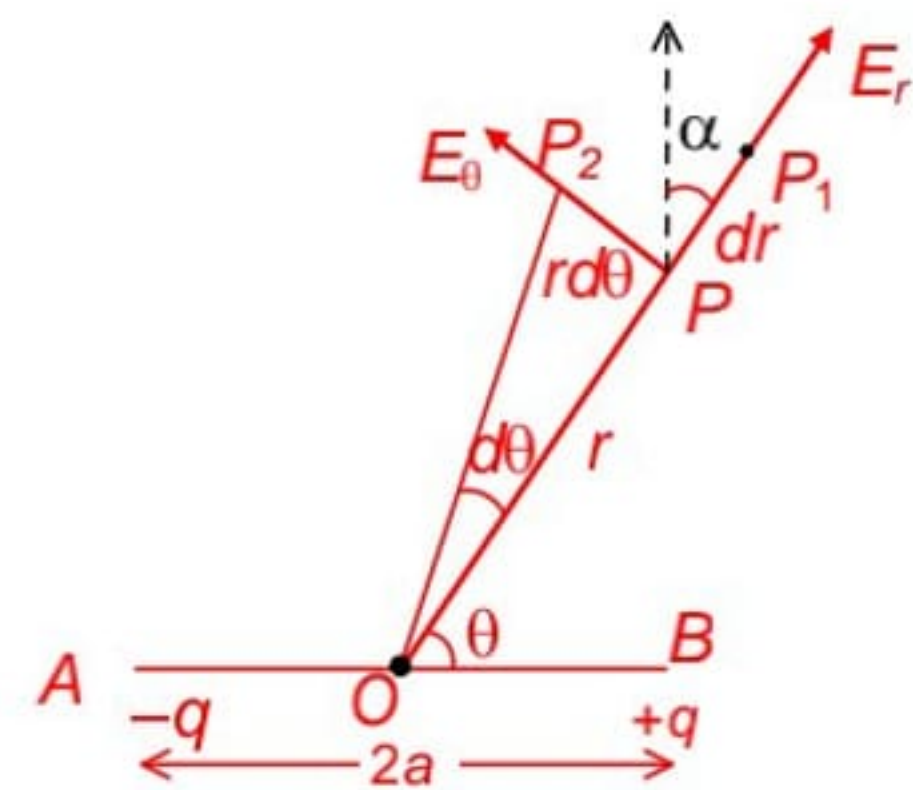
The component of the electric field at P in the radial direction PP_1 is

$$E_r = -\frac{dV}{dr} = -\frac{\partial V}{\partial r} = -\frac{1}{4\pi\epsilon_0} \frac{\partial}{\partial r} \left(\frac{p \cos \theta}{r^2} \right) = \frac{2p \cos \theta}{4\pi\epsilon_0 r^3}$$

The component of the electric field at P in the transverse direction PP_2 is

$$E_\theta = -\frac{dV}{PP_2} = -\frac{dV}{r d\theta} = -\frac{1}{r} \frac{\partial V}{\partial \theta} = -\frac{1}{r} \frac{\partial}{\partial \theta} \left(\frac{p \cos \theta}{4\pi\epsilon_0 r^2} \right) = \frac{p \sin \theta}{4\pi\epsilon_0 r^3}$$

The resultant electric field at P , $E = \sqrt{E_r^2 + E_\theta^2}$



$$\begin{aligned}
 &= \frac{1}{4\pi\epsilon_0} \sqrt{\left(\frac{2p\cos\theta}{r^3}\right)^2 + \left(\frac{p\sin\theta}{r^3}\right)^2} \\
 &= \frac{1}{4\pi\epsilon_0} \frac{p}{r^3} \sqrt{3\cos^2\theta + 1} \quad \dots (26)
 \end{aligned}$$

If the resultant field makes an angle α with the radial direction OP , we have

$$\tan \alpha = \frac{E_\theta}{E_r} = \frac{\frac{p\sin\theta}{r^3}}{\frac{2p\cos\theta}{r^3}} = \frac{\tan\theta}{2}$$

$$\text{or } \alpha = \tan^{-1}\left(\frac{\tan\theta}{2}\right) \quad \dots (27)$$

Now consider some special cases

Case I: $\theta = 0$. In this case, the point P is on the axis of the dipole

$$V = \frac{p}{4\pi\epsilon_0 r^2} \quad \dots (28A)$$

$$E = \frac{2p}{4\pi\epsilon_0 r^3} \quad \dots (28B)$$

Such a position of the point is called an end-on position.

Case II: $\theta = 90^\circ$. In this case, the point P is on the perpendicular bisector of the dipole

$$V = 0, \quad \dots (28C)$$

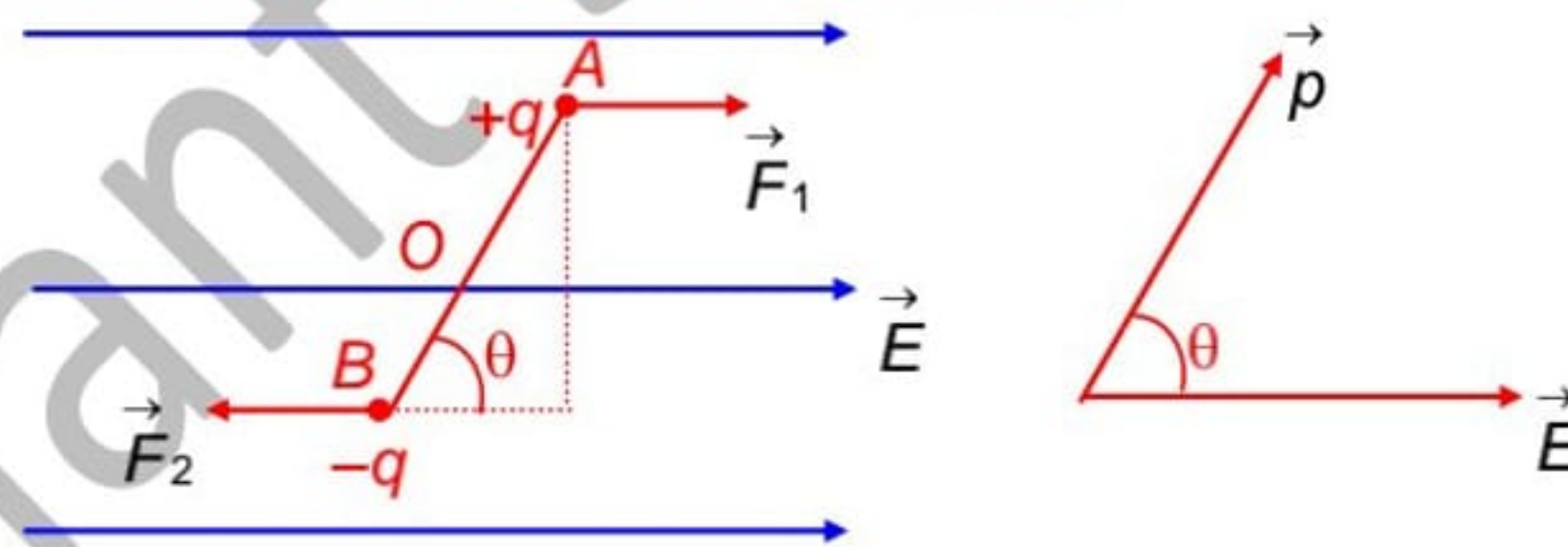
$$E = \frac{p}{4\pi\epsilon_0 r^3} \quad \dots (28D)$$

$$\tan \alpha = \frac{\tan\theta}{2} = \infty$$

$$\alpha = 90^\circ$$

The field is anti-parallel to the dipole axis. Such a position of the point P is called a broad side on position.

18.4 DIPOLE IN AN EXTERNAL UNIFORM ELECTRIC FIELD



Suppose an electric dipole of dipole moment $|\vec{p}| = 2aq$ is placed in a uniform electric field \vec{E} at an angle θ . A force $\vec{F}_1 = q\vec{E}$ will act on positive charge and $\vec{F}_2 = -q\vec{E}$ on the negative charge. Since \vec{F}_1 and \vec{F}_2 are equal in magnitude but opposite in direction, we have

$$\vec{F}_1 + \vec{F}_2 = 0$$

Thus, the net force on a dipole in a uniform electric field is zero.

The torque of \vec{F}_1 about O ,

$$\vec{\tau}_1 = \vec{OA} \times \vec{F}_1 = q(\vec{OA} \times \vec{E})$$

The torque of \vec{F}_2 about O ,

$$\vec{\tau}_2 = \vec{OB} \times \vec{F}_2 = -q(\vec{OB} \times \vec{E})$$

$$= (\vec{BO} \times \vec{E})$$

The net torque acting on the dipole is

$$\begin{aligned} \vec{\tau} &= \vec{\tau}_1 + \vec{\tau}_2 = q (\vec{OA} \times \vec{E}) + q (\vec{BO} \times \vec{E}) \\ &= q(\vec{OA} + \vec{BO}) \times \vec{E} \\ &= q(\vec{BA} \times \vec{E}) \end{aligned}$$

$$\text{or, } \vec{\tau} = \vec{p} \times \vec{E} \quad \dots (29)$$

Thus, the magnitude of the torque is $\tau = pE \sin\theta$. The direction of torque is perpendicular to the plane of paper and inwards. Further this torque is zero at $\theta = 0^\circ$ or $\theta = 180^\circ$, i.e., when the dipole is parallel or antiparallel to \vec{E} and maximum at $\theta = 90^\circ$.

18.5 POTENTIAL ENERGY OF DIPOLE

When an electric dipole is placed in an electric field \vec{E} , a torque $\vec{\tau} = \vec{p} \times \vec{E}$ acts on it. If we rotate the dipole through a small angle $d\theta$, the work done by the torque is

$$dW = \tau d\theta$$

$$\text{or, } dW = -pE \sin\theta d\theta$$

The work is negative as the rotation $d\theta$ is opposite to the torque. The change in electric potential energy of the dipole is therefore

$$dU = -dW = pE \sin\theta d\theta$$

Now at angle $\theta = 90^\circ$, the electric potential energy of the dipole may be assumed to be zero as net work done by the electric forces in bringing the dipole from infinity to this position will be zero.

$dU = pE \sin\theta d\theta$ from 90° to θ , we have

$$\int_{90^\circ}^{\theta} dU = \int_{90^\circ}^{\theta} pE \sin\theta d\theta$$

$$\text{or, } U(\theta) - U(90^\circ) = pE [-\cos\theta]_{90^\circ}^{\theta}$$

$$\text{or } U(\theta) = -pE \cos\theta = -\vec{p} \cdot \vec{E} \quad \dots (30)$$

If the dipole is rotated from an angle θ_1 to θ_2 , then

work done by external forces = $U(\theta_2) - U(\theta_1)$

$$\text{or, } W_{\text{ext}} = -pE \cos\theta_2 - (-pE \cos\theta_1)$$

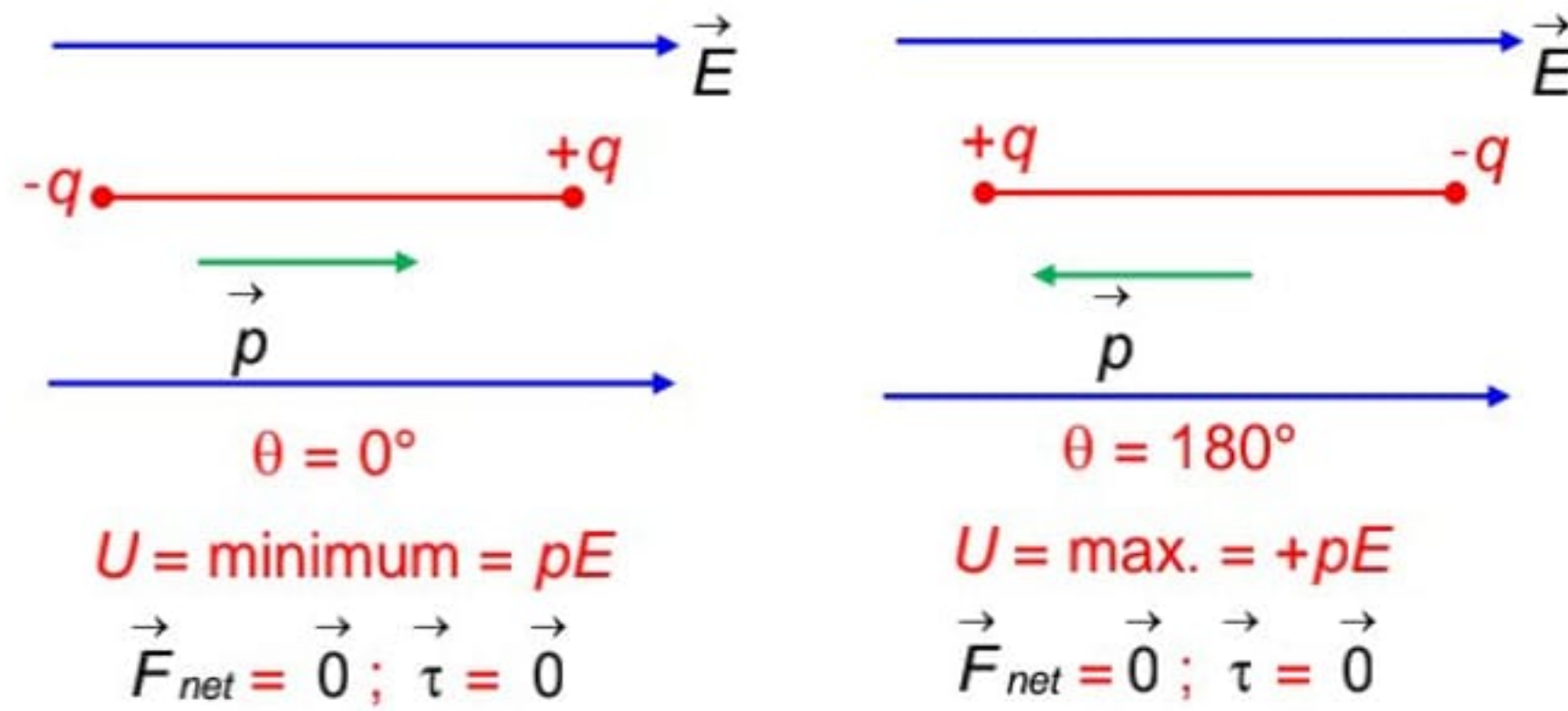
$$\text{or, } W_{\text{ext}} = pE (\cos\theta_1 - \cos\theta_2) \quad \dots (31)$$

Work done by electric force

$$W_{\text{electric force}} = -W_{\text{ext}} = pE [\cos\theta_2 - \cos\theta_1] \quad \dots (32)$$

18.6 EQUILIBRIUM OF DIPOLE

When an electric dipole is placed in a uniform electric field, the net force on it is zero for any position of the dipole in the electric field. But torque acting on it is zero only at $\theta = 0^\circ$ and 180° . Thus, we can say that at these two positions of the dipole, net force or torque on it is zero or the dipole is in equilibrium. Of this $\theta = 0^\circ$ is the 'stable equilibrium' position of the dipole because potential energy in this position is minimum ($U = -pE \cos\theta = -pE$) and when displaced from this position, a torque starts acting on it which is restoring in nature and which has a tendency to bring the dipole back in its equilibrium position. On the other hand, at $\theta = 180^\circ$, the potential energy of the dipole is maximum ($U = -pE \cos 180^\circ = +pE$) and when it is displaced from this position, the torque has a tendency to rotate it in other direction. This torque is not restoring in nature. So this equilibrium is known as 'unstable equilibrium position'.



18.7 ANGULAR SHM OF DIPOLE

When a dipole is suspended in a uniform electric field, it will align itself parallel to the field. Now if it is given a small angular displacement θ about its equilibrium, the (restoring) couple will be

$$C = -pE \sin\theta$$

or, $C = -pE\theta$ [as $\sin\theta \approx \theta$, for small θ]

or, $I \frac{d^2\theta}{dt^2} = -pE\theta$

or, $\frac{d^2\theta}{dt^2} = -\frac{pE}{I} \theta$

or, $\frac{d^2\theta}{dt^2} = -\omega^2 \theta$

where $\omega^2 = \frac{pE}{I}$

This is standard equation of angular simple harmonic motion with time-period $T \left(= \frac{2\pi}{\omega} \right)$. So the dipole will execute angular SHM with time-period

$$T = 2\pi \sqrt{\frac{I}{pE}} \quad \dots (33)$$

18.8 FORCE ACTING ON A DIPOLE IN AN EXTERNAL NON-UNIFORM FIELD

When dipole lies in a non-uniform electric field the charges of the dipole experience unequal forces. Therefore, the net force on the dipole is not equal to zero. The magnitude of the force is given by the negative derivative of the potential energy with respect to distance along the axis of the dipole

$$\vec{F} = -\frac{dU}{dl} = \vec{p} \cdot \frac{d\vec{E}}{dl}$$

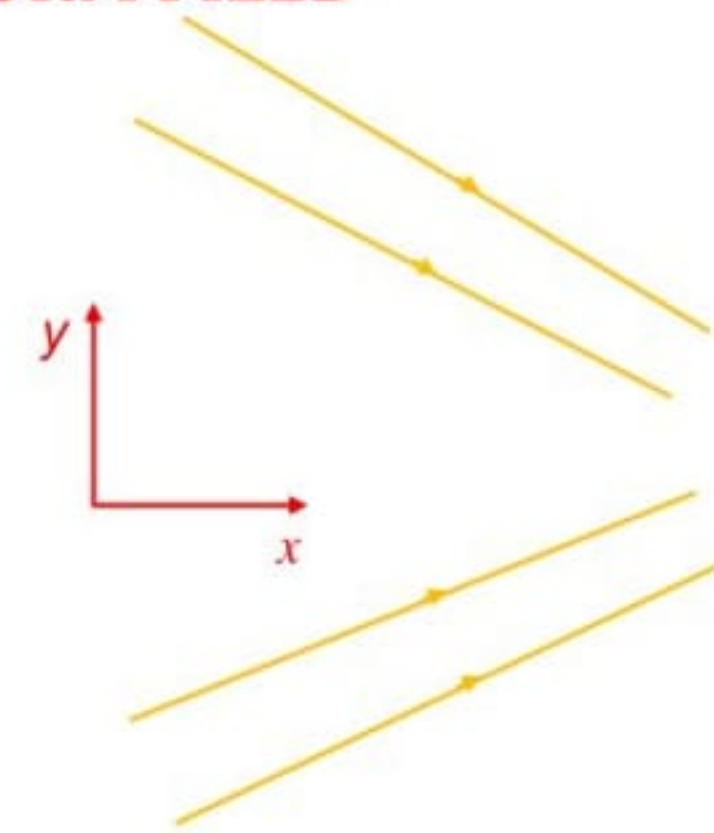


Illustration 18

Question: A dipole whose dipole moment is p lies along the x -axis ($\vec{p} = p\hat{i}$) in a non-uniform field $\vec{E} = \frac{C}{x} \hat{i}$.

What is the magnitude of the force on the dipole? (take, $P = 2$ SI unit, $C = 1$ SI unit, $x = 1$ SI unit) (in SI unit)

Solution: We have $U = -\vec{p} \cdot \vec{E} = -p\hat{i} \cdot \frac{C}{x} \hat{i} = -\frac{pC}{x}$

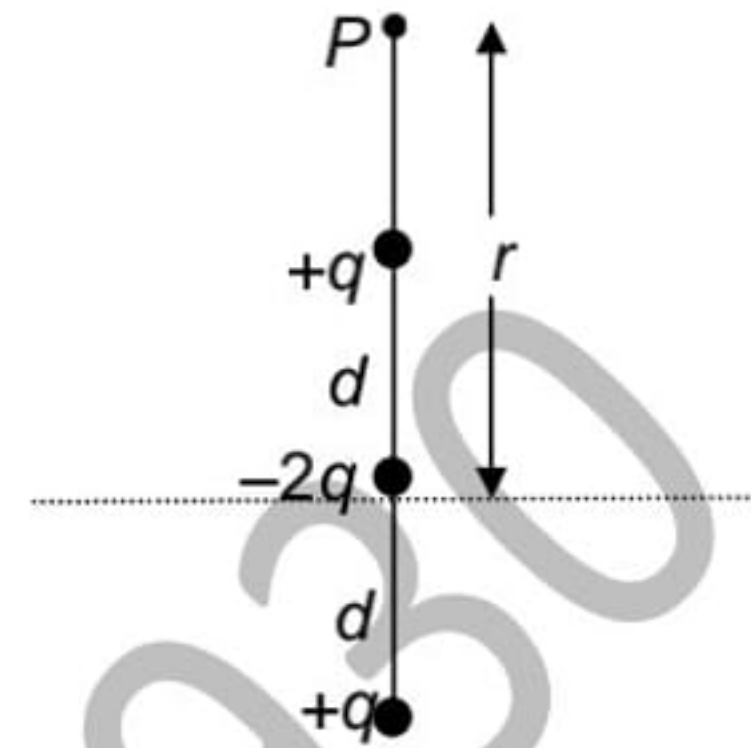
$$\text{Now } F = -\frac{dU}{dx} = -\frac{d}{dx} \left(-\frac{pC}{x} \right) = -\frac{pC}{x^2}$$

$$\Rightarrow \vec{F} = -\frac{pC}{x^2} \hat{i} = 2$$

Illustration 19

stion: An Electric quadrupole consists of two equal and opposite dipoles arranged that their electric effects do not quite cancel each other at distant pts. In the figure given, Calculate electric potential V for the point P on the axis of this quadrupole.

(take $q = \frac{8}{9} \times 10^{-9} \text{ C}$, $d = 1$, $r = 2$)



Solution:

The electric potential at P is given by

$$V = \frac{1}{4\pi\epsilon_0} \left[\frac{q}{r-d} + \frac{-2q}{r} + \frac{q}{r+d} \right]$$

$$= \frac{1}{4\pi\epsilon_0} \frac{2qd^2}{r(r^2-d^2)} = \frac{1}{4\pi\epsilon_0} \frac{2qd^2}{r^3 \left[1 - \frac{d^2}{r^2} \right]}$$

Because $d \ll r$, we can neglect $\frac{d^2}{r^2}$ compared to 1, in which case the potential becomes


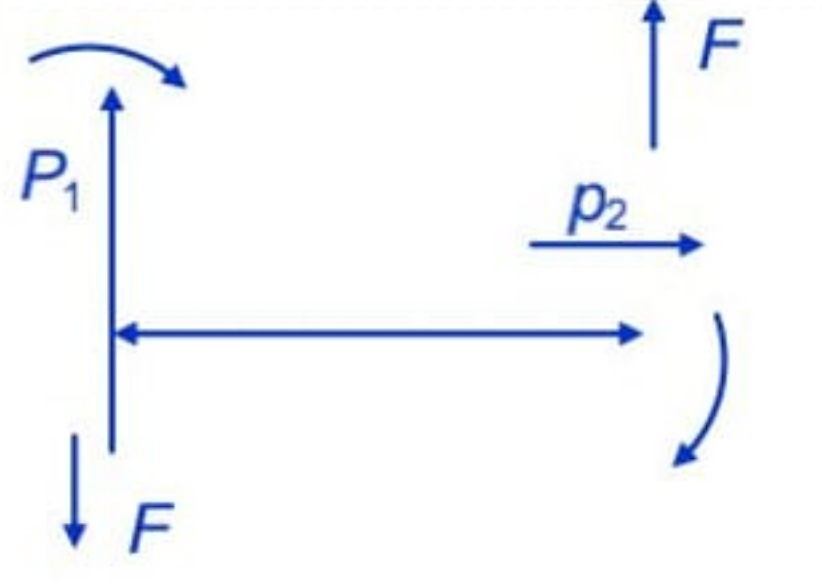
$$V = \frac{1}{4\pi\epsilon_0} \frac{2qd^2}{r^3}$$

$$= 2$$

18.8 INTERACTION BETWEEN DIPOLES

In this situation, one dipole is in the field of other dipole. Depending on the positions of dipoles relative to each other, force, couple and potential energy are different.

S. No.	Relative Position of Dipole	Potential energy (U)	Force (F)	Couple (C)
1.		$-\frac{1}{4\pi\epsilon_0} \frac{2p_1 p_2}{r^3}$	$-\frac{1}{4\pi\epsilon_0} \frac{6p_1 p_2}{r^4}$ (along r)	0
2.		$\frac{1}{4\pi\epsilon_0} \frac{p_1 p_2}{r^3}$	$+\frac{1}{4\pi\epsilon_0} \frac{3p_1 p_2}{r^4}$ (along r)	0

				
3.		0	$\pm \frac{1}{4\pi\epsilon_0} \frac{3p_1p_2}{r^4}$ (perpendicular + or)	on $p_1 = \frac{1}{4\pi\epsilon_0} \frac{2p_1p_2}{r^3}$ (CW) on $p_2 = \frac{1}{4\pi\epsilon_0} \frac{p_1p_2}{r^3}$ (CW)

19 EARTHING A CONDUCTOR

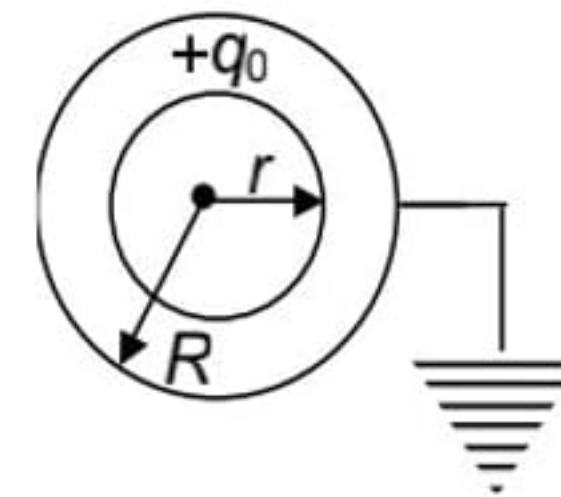
Potential of earth is often taken to be zero. If a conductor is connected to the earth, the potential of the conductor becomes equal to that of the earth, i.e., zero. If the conductor was at some other potential, charges will flow from it to the earth or from the earth to it to bring its potential to zero. The figure given below shows the symbol for earthing.



Illustration 20

Question: Given two concentric conducting spheres of radii r and R ($r < R$). The inner surface carries a charge q_0 and the outer sphere is earthed taking $q_0 = -1C$.

Find the charge on the outer sphere. (in C)



Solution: (a) Let q be a final charge on the outer sphere.
The potential of the outer sphere is given by

$$V_2 = \frac{-Kq_0}{R} + \frac{Kq}{R} \quad \left\{ k = \frac{1}{4\pi\epsilon_0} \right\}$$

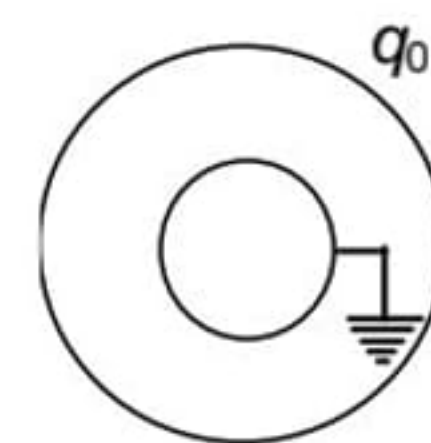
Since it has been earthed, $V_2 = 0$

$$\text{Thus, } \frac{-Kq_0}{R} + \frac{Kq}{R} = 0$$

$$\Rightarrow q = 1$$

Illustration 21

Question: In the previous example, if the outer sphere carries a charge q_0 and the inner sphere is earthed, then find the charge on the inner sphere. (Take $q_0 = 2C$, $r = 1m$, $R = 2m$) (in C)



Solution: Let q be the charge on the inner sphere.
The potential of the inner sphere is given by

$$V_1 = \frac{kq}{r} - \frac{kq_0}{R} \quad \left\{ k = \frac{1}{4\pi\epsilon_0} \right\}$$

Since it is connected to earth, $V_1 = 0$

$$\therefore \frac{Kq}{r} + \frac{Kq_0}{R} = 0$$

$$\Rightarrow q = -q_0 \frac{r}{R} = -1$$

PROFICIENCY TEST- III

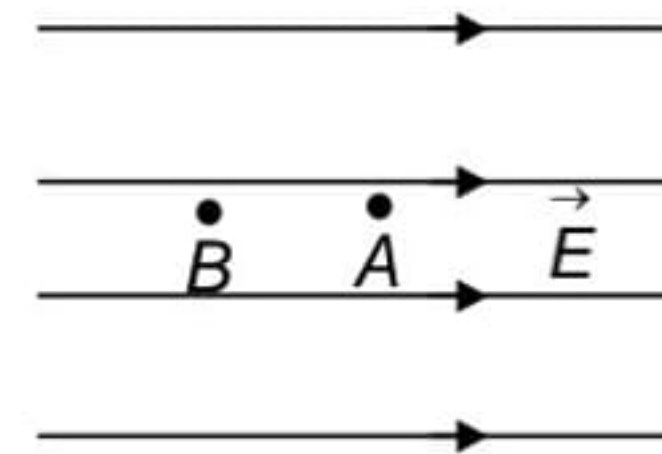
The following questions deal with the basic concepts of this section. Answer the following briefly. Go to the next section only if your score is at least 80%. Do not consult the Study Material while attempting these questions.

1. An electric field is given $\vec{E} = 2x\hat{i} - 3y^2\hat{j}$ N/C. Find the change in potential from the position $\vec{r}_A = (\hat{i} - 2\hat{j})$ m to $\vec{r}_B = (2\hat{i} + \hat{j} + 3\hat{k})$ m.

2. Find the potential function $V(x)$ corresponding to the electric field, at $x = 1$ m, where $A = 2$
 $\vec{E} = (Ax)\hat{i}$; Take $V = 0$ at $x = 0$

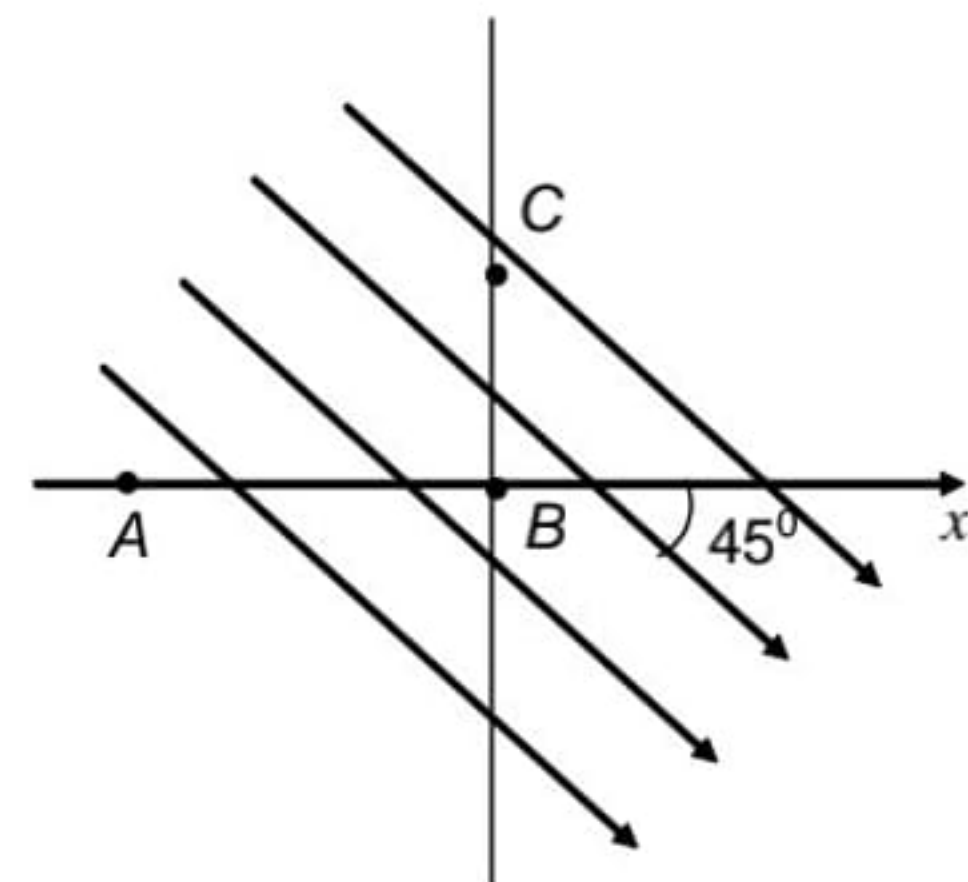
3. External work equal to (4×10^{-7}) J is needed to move a -5 nC charge at constant speed to a point at which the potential is -20 V. What is the potential at the initial point?

4. In the above figure, points A and B are 4 cm apart along the lines of a uniform field $\vec{E} = 600\hat{i}$ V/m. What is the change in potential energy ($U_B - U_A$) as the point charge $q = 3\mu\text{C}$ is moved from A to B in μJ



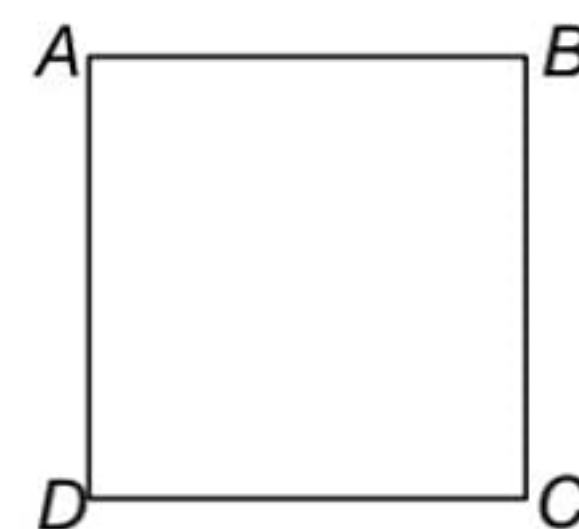
5. A uniform electric field of $400\sqrt{2}$ V/m is directed at 45° below the x-axis, as shown. Find the changes in potential (take $AB = BC = 3$ cm)

- (a) $V_B - V_A$
 (b) $V_B - V_C$



6. Charges $+q, -q, +q, -q$ are placed at the corners ABCD of a square of side a . A charge $+q$ is placed at the centre of square. Find the interaction energy of the system.

(take $\frac{q^2}{4\pi\epsilon_0} = (4 - 2\sqrt{2})\text{mJ}\cdot\text{m}, a = 1\text{m}$)



7. It requires 1 mJ of work to move two identical positive charges $+q$ from infinity so that they are separated by a distance a . How much work is required to move three identical positive

charges $+q$ from infinity so that they are arranged at the vertices of an equilateral triangle with edge length a in mJ.

8. An electric dipole, consisting of charges of magnitude $1 \mu\text{C}$ separated by $1 \mu\text{m}$, is in an electric field of strength 1000 N/C .
 - (a) What is magnitude of the electric dipole moment (in pico-C-m)
 - (b) What is difference in potential energy corresponding to dipole orientations parallel and antiparallel to the field in nJ.
9. An electric dipole consists of charges $+2e$ and $-2e$ separated by 0.78 nm . It is in an electric field of strength $3.4 \times 10^6 \text{ N/C}$. Calculate the magnitude of the torque on the dipole when the dipole moment is (a) parallel, and (b) opposite the electric field.
10. A charge $q = 3.16 \mu\text{C}$ is $1 \mu\text{m}$ from a small dipole along its perpendicular bisector. The force on the charge equals 9 N . Find the dipole moment of the dipole in nCm.

ANSWERS TO PROFICIENCY TEST- III

1. 6 V
2. $-\frac{1}{2}Ax^2 = -1$
3. 60 V
4. 72 μ J
5. (a) - 12 V,
(b) -12 V
6. 12 J
7. 3 mJ
8. (a) 1 pico- C-m
(b) 2 nJ
9. (a) 0
(b) 0
10. 1

20 CAPACITY OF AN ISOLATED CONDUCTOR

When charge is given to an isolated body, its potential increases i.e.,

$$Q \propto V$$

or, $Q = CV$... (34)

where C is a constant called capacity of the body.

if $V = 1$ then $C = Q$,

So Capacity of a body is numerically equal to the charge required to raise its potential by unity.

In SI system, the unit of capacity is (Coulomb/volt) and is called farad (F).

$$1F = \frac{1C}{1V} = \frac{3 \times 10^9 \text{ esu of charge}}{\left(\frac{3}{300}\right) \text{ esu of potential}} = 9 \times 10^{11} \text{ esu of capacity.}$$

The capacity of a body is independent of the charge given to it and depends on its shape and size only.

21 CAPACITOR

Capacitor is an arrangement of two conductors carrying charges of equal magnitude and opposite sign and separated by an insulating medium. The following points may be carefully noted

(i) The net charge on the capacitor as a whole is zero. When we say that a capacitor has a charge Q , we mean that positively charged conductor has a charge $+Q$ and the negatively charged conductor has a charge $-Q$.

(ii) The positively charged conductor is at a higher potential than negatively charged conductor. The potential difference V between the conductors is proportional to the magnitude of charge Q and the ratio Q/V is known as capacitance C of the capacitor.

$$C = \frac{Q}{V}$$

Unit of capacitance is farad (F). The capacitance is usually measured in microfarad μF .

$$1\mu F = 10^{-6} F$$

(iii) In a circuit, a capacitor is represented by the symbol:—



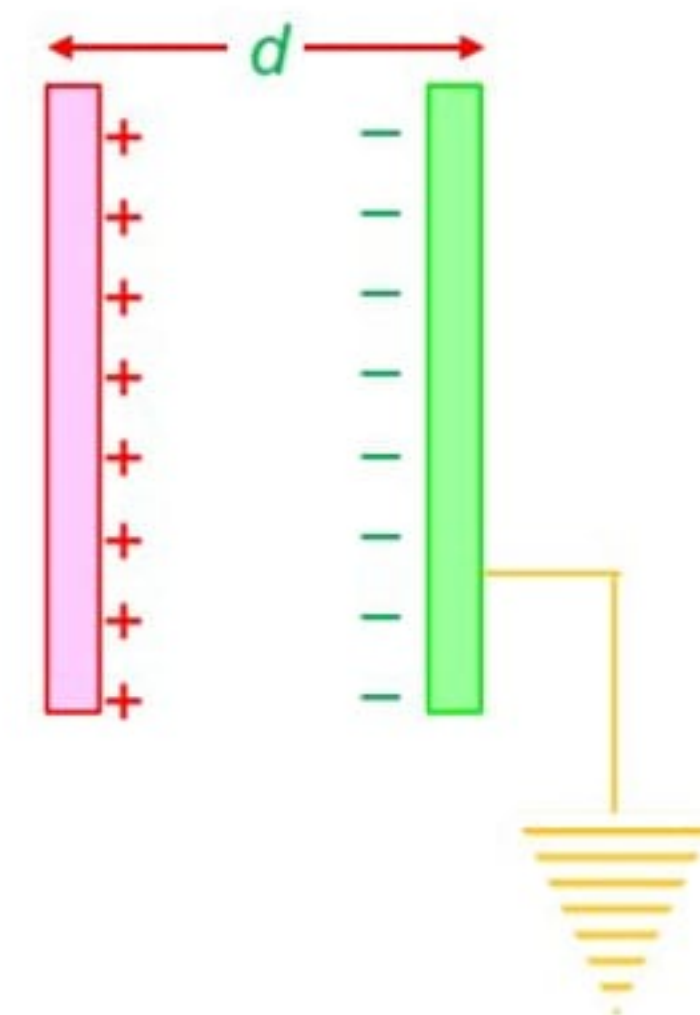
21.1 PARALLEL PLATE CAPACITOR

A parallel plate capacitor consists of two metal plates placed parallel to each other and separated by a distance d that is very small as compared to the dimensions of the plates. The area of each plate is A . The electric field between the plates is given by

$$E = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} = \frac{\sigma}{\epsilon_0}$$

Where σ is surface charge density on either plate.

the potential difference (V) between plates is given by $V = Ed$.



or, $V = \frac{\sigma}{\epsilon_0} d = \frac{Q}{A\epsilon_0} d$

Hence, $C = \frac{Q}{V} = \frac{\epsilon_0 A}{d}$... (35)

21.2 CYLINDRICAL CAPACITOR

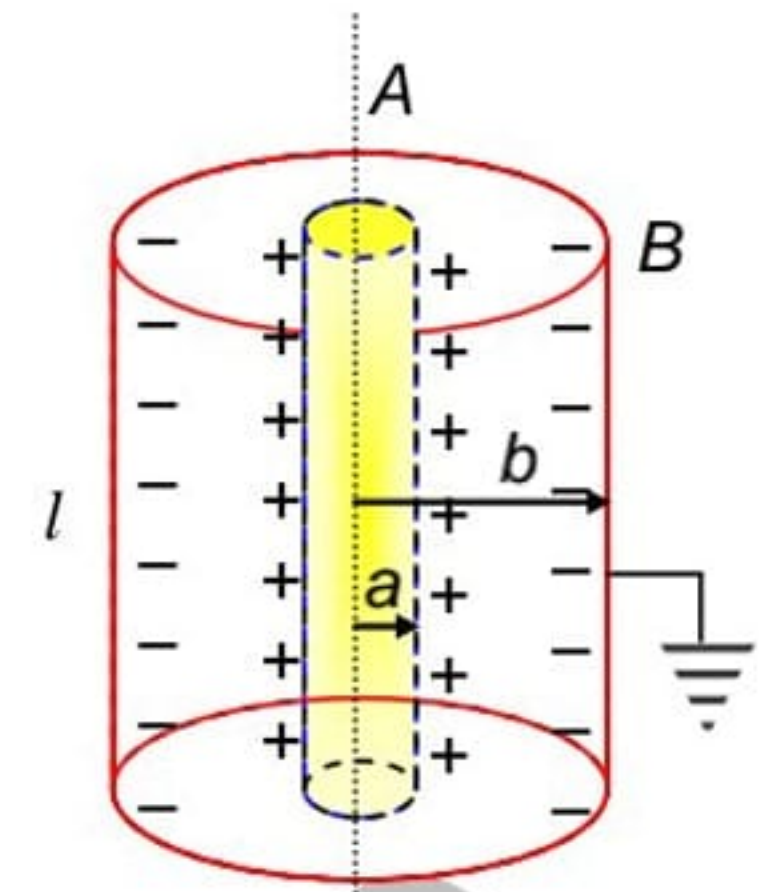
Cylindrical capacitor consists of two co-axial cylinders of radii a and b and length l . If a charge q is given to the inner cylinder, induced charge $-q$ will reach to the inner surface of the outer cylinder. By symmetry, the electric field in region between the cylinders is radially outward.

By Gauss's theorem, the electric field at a distance r from the axis of the cylinders is given by

$$E = \frac{1}{2\pi\epsilon_0 l} \frac{q}{r}$$

The potential difference between the cylinders is given by

$$\begin{aligned} V &= -\int_b^a \vec{E} \cdot d\vec{r} = -\frac{1}{2\pi\epsilon_0 l} q \int_b^a \frac{dr}{r} \\ &= \frac{-q}{2\pi\epsilon_0 l} \left(\ln \frac{a}{b} \right) \\ \text{or, } V &= \frac{q}{V} = \frac{2\pi\epsilon_0 l}{\ln \left(\frac{b}{a} \right)} \end{aligned}$$



... (36)

21.3 SPHERICAL CAPACITOR

A spherical capacitor consists of two concentric spheres of radii a and b as shown. The inner sphere is positively charged to potential V and outer sphere is at zero potential.

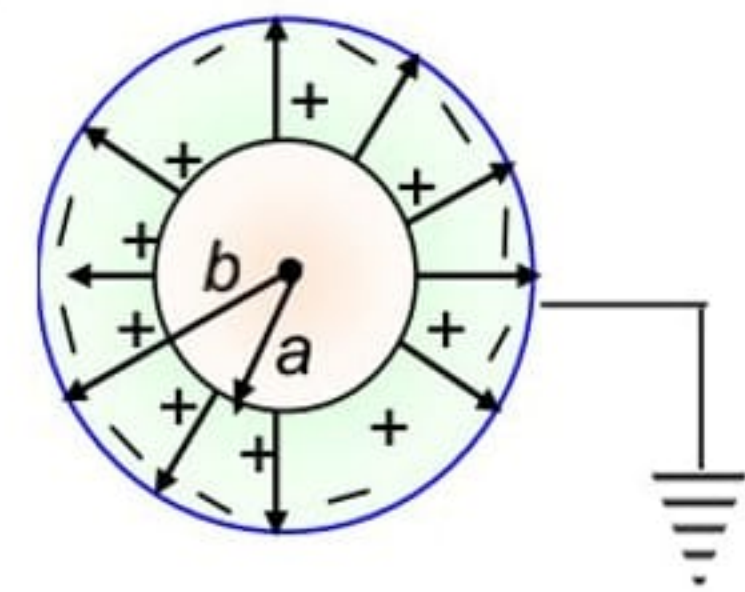
The inner surface of the outer sphere has an equal negative charge.

The potential difference between the spheres is

$$V = \frac{Q}{4\pi\epsilon_0 a} - \frac{Q}{4\pi\epsilon_0 b}$$

Hence, capacitance

$$C = \frac{Q}{V} = \frac{4\pi\epsilon_0 ab}{b-a}$$



... (37)

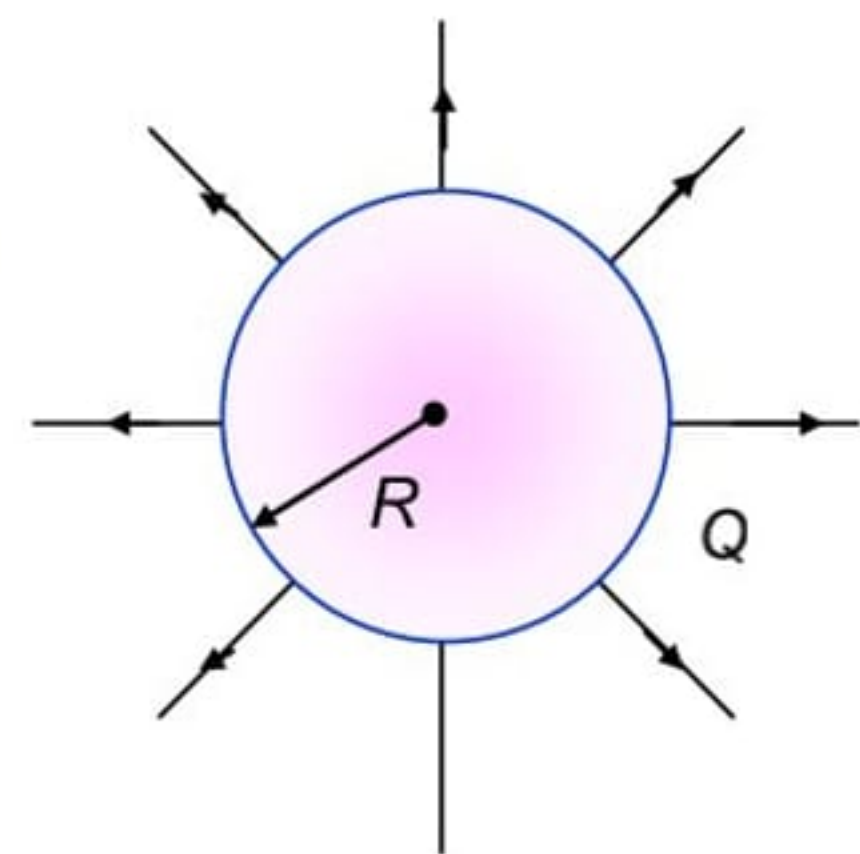
21.4 ISOLATED SPHERE AS A CAPACITOR

A conducting sphere of radius R carrying a charge Q can be treated as a capacitor with high potential conductor as the sphere itself and the low potential conductor as a sphere of infinite radius. The potential difference between these two spheres is

$$V = \frac{Q}{4\pi\epsilon_0 R} - 0$$

Hence, capacitance $C = \frac{Q}{V} = 4\pi\epsilon_0 R$

(38)



22 ENERGY STORED IN CHARGED CAPACITOR

If dq charge is given to a capacitor at potential V

$$dW = dq (V)$$

or,
$$E = \int_0^q \left(\frac{q}{C} \right) dq \quad [\because q = CV]$$

or,
$$W = \frac{q^2}{2C} = \frac{1}{2} CV^2 = \frac{1}{2} qV$$

This work is stored as electrical potential energy i.e., a capacitor stores electrical energy

$$U = \frac{1}{2} CV^2 = \frac{q^2}{2C} = \frac{1}{2} qV \quad \dots (39)$$

22.1 ENERGY DENSITY OF A CHARGED CAPACITOR

This energy is not localized on the charges or the plates but is distributed in the field. Since in case of a parallel plate capacitor, the electric field is only between the plates, i.e., in a volume ($A \times d$), the energy density

$$U_E = \frac{U}{\text{volume}} = \frac{\frac{1}{2} CV^2}{A \times d} = \frac{1}{2} \left[\frac{\epsilon_0 A}{d} \right] \frac{V^2}{Ad}$$

or,
$$U_E = \frac{1}{2} \epsilon_0 \left(\frac{V}{d} \right)^2 = \frac{1}{2} \epsilon_0 E^2 \quad [\because \frac{V}{d} = E] \quad \dots (40)$$

22.2 FORCE BETWEEN THE PLATES OF A CAPACITOR

In a capacitor as plates carry equal and opposite charges, there is a force of attraction between the plates. To calculate this force, we use the fact that the electric field is conservative

and in a conservative field $F = -\frac{dU}{dx}$. In case of parallel plate capacitor

$$U = \frac{q^2}{2C} = \frac{1}{2} \frac{q^2 x}{\epsilon_0 A} \quad \left[\text{as } C = \frac{\epsilon_0 A}{x} \right]$$

SO,
$$F = -\frac{d}{dx} \left[\frac{q^2}{2\epsilon_0 A} x \right] = \frac{-1}{2} \frac{q^2}{\epsilon_0 A} \quad \dots (41)$$

The negative sign implies that the force is attractive.

Illustration 22

Question: The plates of a parallel plate capacitor are 5 mm apart and 2m^2 in area. The plates are in vacuum. A potential difference of 10,000 V is applied across a capacitor. Calculate:-

- (a) the capacitance: (in fm)
(b) the charge on each plate ; (in nC)

Solution: (a)
$$C = \frac{\epsilon_0 A}{d} = \frac{8.85 \times 10^{-12} \times 2}{5 \times 10^{-3}} = 3540$$

(b)
$$Q = CV = (0.00354 \times 10^{-6}) \times (10,000) = 3540$$

The plate at higher potential has a positive charge of $+3.54 \mu\text{C}$ and the plate at lower potential has a negative charge of $-3.54 \mu\text{C}$.

23 EFFECT OF DIELECTRIC

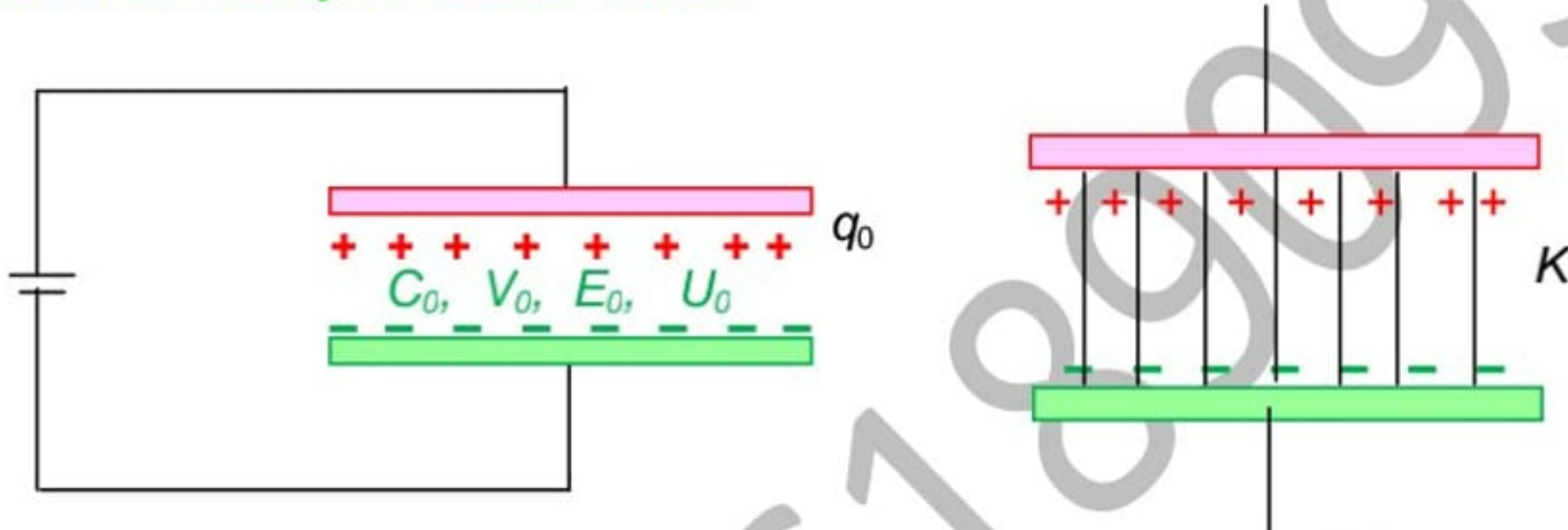
When certain non-conducting materials such as glass, paper or plastic are introduced between the plates of a capacitor, its capacity increases. These materials are called 'dielectrics' and the ratio of capacity of a capacitor when completely filled with dielectric C to that without dielectric C_0 is called 'dielectric constant K , or relative permittivity ϵ_r or specific inductive capacity (S. I. C) i.e.,

$$K = \frac{C}{C_0} \quad \dots (42)$$

The effect of dielectric on other physical quantities such as charges, potential difference, field and energy associated with a capacitor depends on the fact that whether the charge capacitor is isolated (i.e., charge held constant) or battery attached (i.e., potential is held constant).

23.1 INTRODUCTION OF A DIELECTRIC SLAB OF DIELECTRIC CONSTANT K BETWEEN THE PLATES

(a) When the battery is disconnected



Let q_0, C_0, V_0, E_0 and U_0 represents the charge, capacity, potential difference electric field and energy associated with charged air capacitor respectively. With the introduction of a dielectric slab of dielectric constant K between the plates and the battery disconnected.

- (i) Charge remains constant, i.e., $q = q_0$, as in an isolated system charge is conserved.
- (ii) Capacity increases, i.e., $C = KC_0$, as by the presence of a dielectric capacity becomes K times.
- (iii) potential difference between the plates decreases, i.e., $V = \left(\frac{V_0}{K}\right)$, as

$$V = \frac{q}{C} = \frac{q_0}{KC_0} = \frac{V_0}{K} \quad [\because q = q_0 \text{ and } C = KC_0]$$

- (iv) Field between the plates decreases, i.e., $E = \frac{E_0}{K}$, as

$$E = \frac{V}{d} = \frac{V_0}{Kd} = \frac{E_0}{K} \quad [\text{as } V = \frac{V_0}{K}]$$

and $E_0 = \frac{V_0}{d}$

- (v) Energy stored in the capacitor decreases i.e.,

$$U = \left(\frac{U_0}{K}\right), \text{ as}$$

$$U = \frac{q^2}{2C} = \frac{q_0^2}{2KC_0} = \frac{U_0}{K} \quad (\text{as } q = q_0 \text{ and } C = KC_0)$$

(b) When the battery remains connected (potential is held constant)

- (i) Potential difference remains constant, i.e., $V = V_0$, as battery is a source of constant potential difference.

- (ii) Capacity increases, i.e., $C = KC_0$, as by presence of a dielectric capacity becomes K times.
- (iii) Charge on capacitor increases, i.e., $q = Kq_0$, as
 $q = CV = (KC_0)V = Kq_0$ [$\because q_0 = C_0V$]
- (iv) Electric field remains unchanged, i.e., $E = E_0$, as
 $E = \frac{V}{d} = \frac{V_0}{d} = E_0$ [as $V = V_0$ and $\frac{V_0}{d} = E_0$]
- (v) Energy stored in the capacitor increases,
 i.e., $U = KU_0$, as $U = \frac{1}{2}CV^2 = \frac{1}{2}(KC_0)(V_0)^2 = \frac{1}{2}KU_0$
 [as $C = KC_0$ and $U_0 = \frac{1}{2}C_0V_0^2$]

Illustration 23

Question: A parallel plate capacitor has plates of area 4 m^2 separated by a distance of 0.5 mm . The capacitor is connected across a cell of emf 100 V . Find the energy store in the capacitor (in mJ) if a dielectric slab of dielectric strength 3 thickness 0.5 mm is inserted inside this capacitor after it has been disconnected from the cell.

Solution:

$$C = \frac{K\epsilon_0 A}{d} = KC_0 = 0.2124 \mu\text{F}$$

$$V = \frac{Q}{C} = \frac{Q_0}{KC_0} = \frac{V_0}{K} = \frac{100}{3} \text{ V}$$

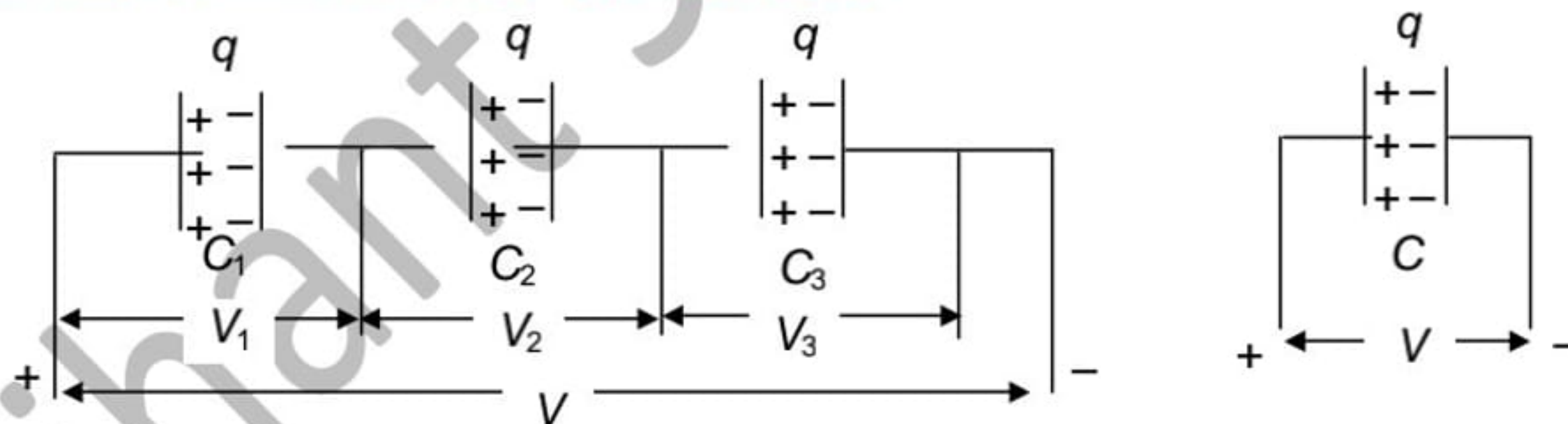
$$U = \frac{Q_0^2}{2C} = \frac{Q_0^2}{2KC_0} = \frac{U_0}{K}$$

$$= 118$$

24 GROUPING OF CAPACITORS

Replacing a combination of capacitors by a single equivalent capacitor is called 'grouping of capacitors'. It simplifies the problem and is divided into two types

24.1 SERIES COMBINATION OF CAPACITORS.



Capacitors are said to be in series if charge on each individual capacitor is same.

In this situation,

$$V = V_1 + V_2 + V_3$$

We know, $V = \left(\frac{q}{C}\right)$, so

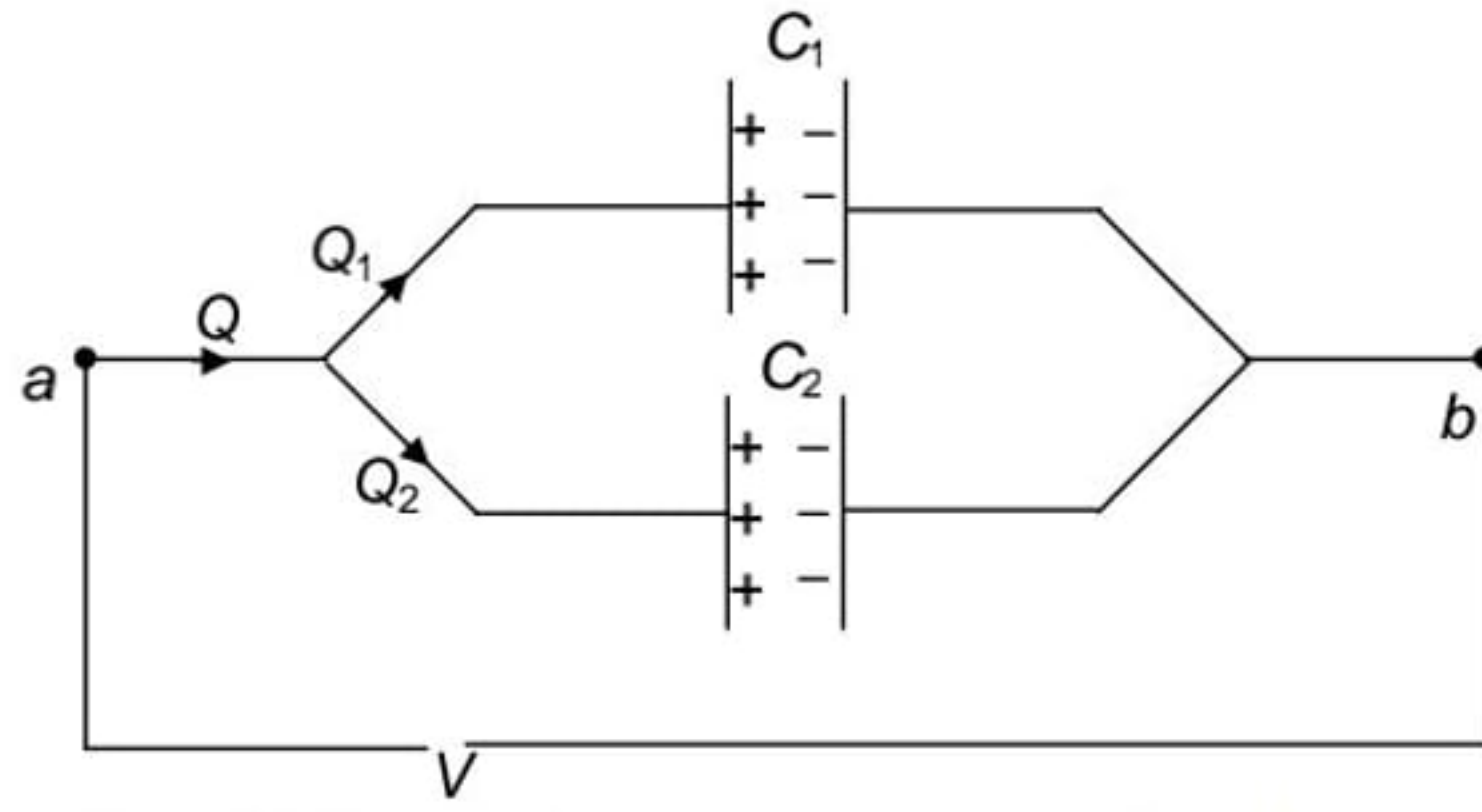
$$\frac{q}{C} = \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3}$$

$$\text{or, } \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \quad \dots (43)$$

In case the two capacitors connected in series, we have

$$V_1 = \left(\frac{C_2}{C_1 + C_2}\right)V; \quad V_2 = \left(\frac{C_1}{C_1 + C_2}\right)V$$

24.2 PARALLEL COMBINATION OF CAPACITORS



When capacitors are connected in parallel, the potential difference V across each is same and the charge on C_1 , C_2 is different, i.e., Q_1 and Q_2 ,

The total charge Q is given as

$$Q = Q_1 + Q_2$$

$$Q = C_1 V + C_2 V \text{ or } \frac{Q}{V} = C_1 + C_2$$

Hence, the equivalent capacitance between a and b is

$$C = C_1 + C_2$$

The charges on capacitors is given as

$$Q_1 = \left(\frac{C_1}{C_1 + C_2} \right) Q$$

$$Q_2 = \left(\frac{C_2}{C_1 + C_2} \right) Q$$

In case of more than two capacitors.

$$C = C_1 + C_2 + C_3 + \dots \quad \dots (44)$$

Illustration 24

Question: Two capacitors of capacitances $C_1 = 6 \mu\text{F}$ and $C_2 = 3 \mu\text{F}$ are connected in series across a cell of emf 18 V . Calculate :-

- (i) The equivalent capacitance (in μF)
- (ii) the potential difference across each capacitor (in V)

Solution:

$$(i) \quad \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\Rightarrow C = \frac{C_1 C_2}{C_1 + C_2} = \frac{6 \times 3}{6 + 3} = 2 \mu\text{F}$$

$$(ii) \quad V_1 = \left(\frac{C_2}{C_1 + C_2} \right) V = \left(\frac{3}{6 + 3} \right) \times 18 = 6 \text{ V}$$

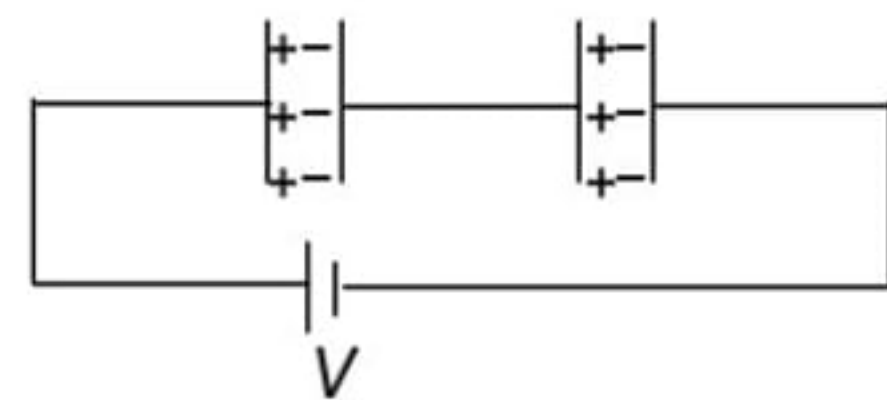
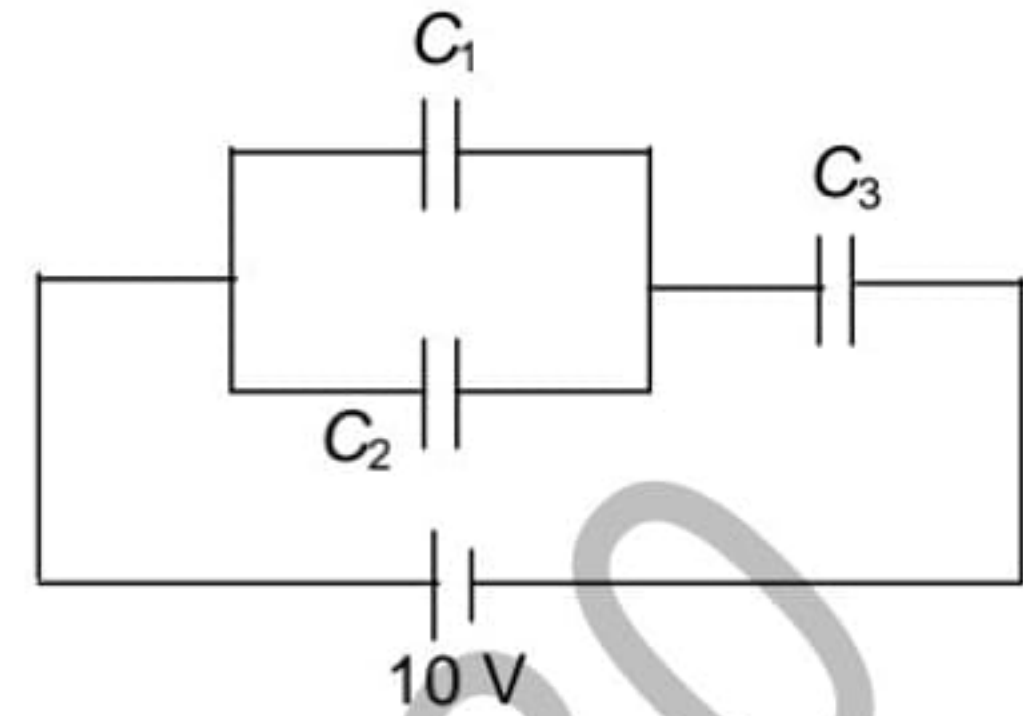
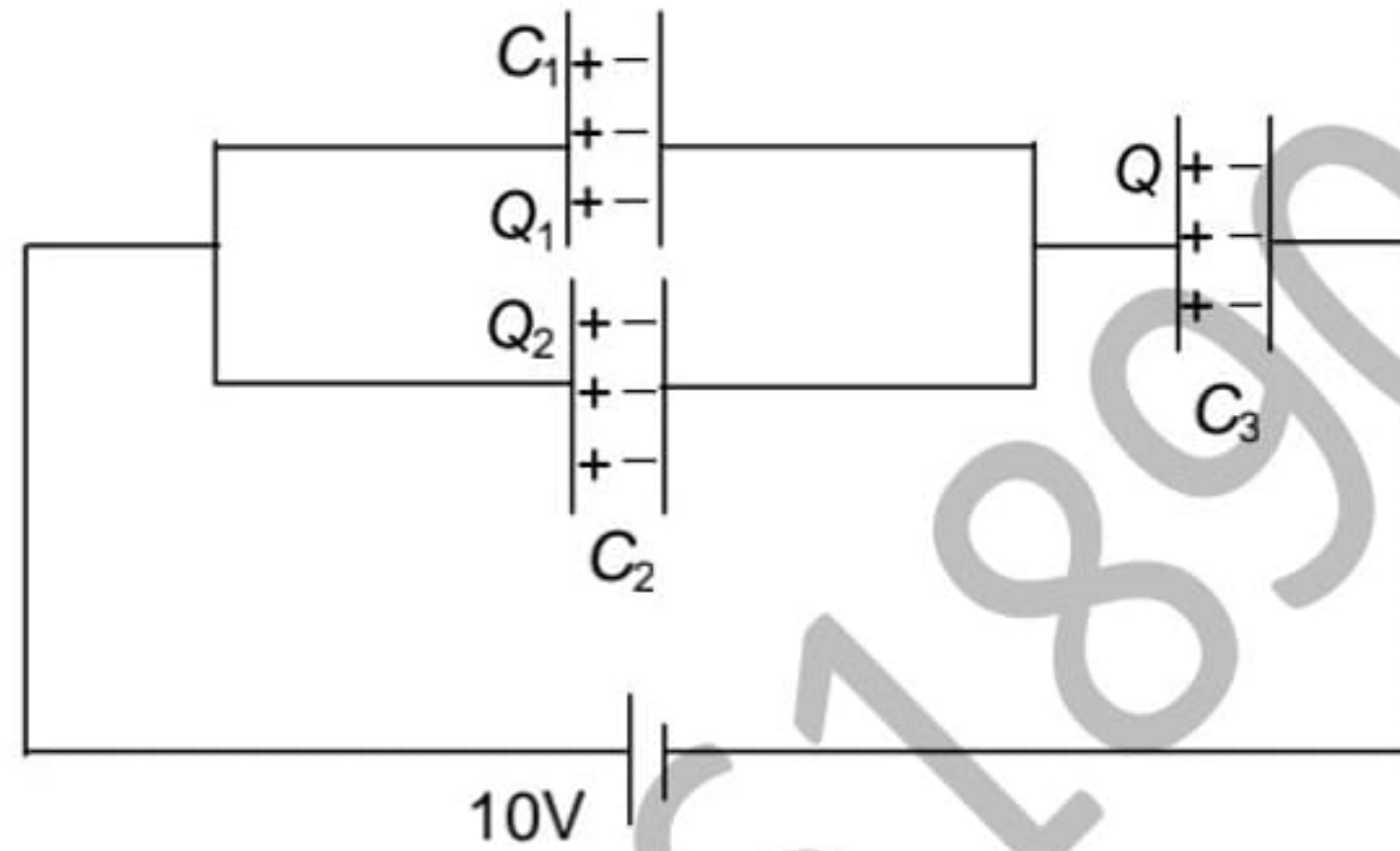


Illustration 25

- Question:** In the circuit shown above, the capacitors are $C_1 = 15 \mu\text{F}$; $C_2 = 10 \mu\text{F}$ and $C_3 = 25 \mu\text{F}$. Find
- the charge on each capacitor (in μC)
 - the potential difference across each capacitor (in V)



Solution:



(i) $Q = \text{total charge supplied by the cell} = CV = (12.5 \times 10) \mu\text{C} = 125$

$$\text{Charge on } C_1 = Q_1 = \left(\frac{C_1}{C_1 + C_2} \right) Q = \left(\frac{15}{15 + 10} \right) \times 125 = 75$$

$$\text{charge on } C_2 = Q_2 = \left(\frac{C_2}{C_1 + C_2} \right) Q = \left(\frac{10}{15 + 10} \right) \times 125 = 50$$

$$\text{Charge on } C_3 = Q = 125 \mu\text{C}$$

(ii) p.d. across $C_1 = V_1 = \frac{Q_1}{C_1} = \frac{75}{15} = 5$

$$\text{p.d. across } C_2 = V_2 = V_1 = 5$$

$$\text{p.d. across } C_3 = V_3 = \frac{Q_3}{C_3} = \frac{125}{25} = 5$$

25 REDISTRIBUTION OF CHARGE

If there are two spherical conductors of radii R_1 and R_2 at potentials V_1 and V_2 respectively, far apart from each-other (so that charge on one does not affect the potential of the other). The charge on them will be

$$q_1 = C_1 V_1 \text{ and } q_2 = C_2 V_2$$

The total charge of the system

$$q = q_1 + q_2$$

The total capacity of the system

$$C = C_1 + C_2$$

Now if they are connected through a wire, charge will flow from conductor at higher potential to that at lower potential till both acquire same potential.

$$V = \frac{(q_1 + q_2)}{(C_1 + C_2)} = \frac{C_1 V_1 + C_2 V_2}{C_1 + C_2} = \frac{R_1 V_1 + R_2 V_2}{R_1 + R_2} (\because C \propto R)$$

If q_1' and q_2' are the charges on two conductors after sharing, then

$$q_1' = C_1 V \text{ and } q_2' = C_2 V, \text{ where}$$

$$q_1' + q_2' = (q_1 + q_2) = q$$

So, $\frac{q_1'}{q_2'} = \frac{C_1}{C_2} = \frac{R_1}{R_2}$ [as $C \propto R$]

i.e., charge is shared in proportion to capacity.

25.1 LOSS OF ENERGY DURING REDISTRIBUTION OF CHARGE

Initial potential energy of the system is

$$U_i = \frac{1}{2} C_1 V_1^2 + \frac{1}{2} C_2 V_2^2$$

Final potential energy = $U_f = \frac{1}{2} (C_1 + C_2) V^2$

Putting $V = \frac{C_1 V_1 + C_2 V_2}{C_1 + C_2}$ and simplifying, we get

$$U_f - U_i = -\frac{C_1 C_2}{2(C_1 + C_2)} (V_1 - V_2)^2$$

Now as C_1 , C_2 and $(V_1 - V_2)^2$ are always positive, there is decrease in energy of the system, i.e., in sharing energy is lost. This energy is lost mainly as heat when charge flows from one body to the other through the connecting wire and also as light and sound if sparking takes place.

Illustration 26

Question: Two isolated metallic solid spheres of radius R and $2R$ are charged such that both of these have same charge density σ . The spheres are located far away from each other and connected by a thin conducting wire. Find the new charge density (in SI units) on the bigger sphere. ($\sigma = 6$ SI units)

Solution:

As charge density σ on both spheres is same, total charge

$$q = q_1 + q_2 = 4\pi (R)^2 \sigma + 4\pi (2R)^2 \sigma = 20\pi R^2 \sigma \quad \dots (i)$$

Now in sharing, charge is shared in proportion to capacity i.e., radius, so charge on the bigger sphere

$$q_2' = \left(\frac{R_2}{R_1 + R_2} \right) q = \left(\frac{2R}{R + 2R} \right) q = \frac{2q}{3}$$

So charge density on bigger sphere after sharing

$$\sigma_2' = \frac{q_2'}{4\pi (2R)^2} = \frac{\left(\frac{2}{3} \right) q}{16\pi R^2} = \frac{q}{24\pi R^2}$$

Putting the value of q from equation (i), we get

$$\sigma_2' = \frac{20\pi R^2 \sigma}{24\pi R^2} = \frac{5\sigma}{6} = 5$$

(not in cbse)

26 VAN DE GRAFF GENERATOR

Van de graff generator is a machine that can build up high voltages of the order of a few million volts. The resulting large electric fields are used to accelerate charged particles like electrons, protons and ions to high energies needed for nuclear transmutation of one element into other. The high energy particles can be used to probe the small scale structure of matter.

PRINCIPLE

Let us consider a large spherical conducting shell of radius R with uniform charge density. Let the charge on the shell is Q . The corresponding potential due to the shell at various points having distance r from the centre of the shell is given by

$$v = \frac{Q}{4\pi\epsilon_0 r} \quad r \geq R$$

$$v = \frac{Q}{4\pi\epsilon_0 R} \quad r \leq R$$

Next imagine that a sphere of radius r_0 ($r_0 < R$) carrying a total charge q (uniformly distributed over it) is introduced in the larger conducting shell and placed at its centre. Potential due to inner sphere at all points distant r from centre is given by

$$v = \frac{q}{4\pi\epsilon_0 r} \quad r \geq r_0$$

Applying superposition theorem, the potential due to the system (sphere inside the shell) is

$$v(R) = \frac{1}{4\pi\epsilon_0} \left[\frac{Q}{R} + \frac{q}{r} \right],$$

$$v(r_0) = \frac{1}{4\pi\epsilon_0 r} \left[\frac{Q}{R} + \frac{q}{r_0} \right]$$

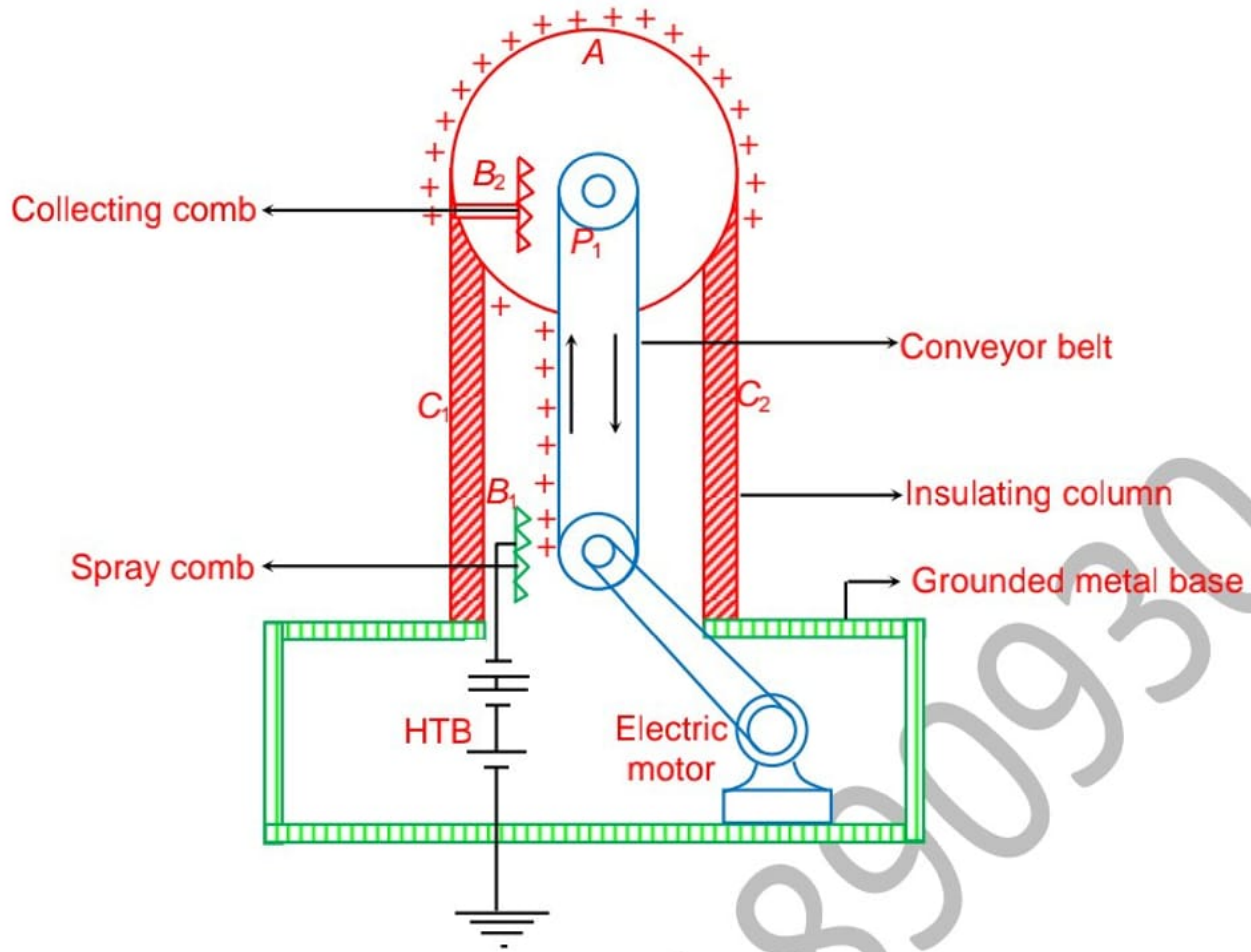
the potential difference between the points $r = r_0$ and $r = R$ is

$$v(r_0) - v(R) = \frac{q}{4\pi\epsilon_0} \left[\frac{1}{r_0} - \frac{1}{R} \right] \quad \dots (45)$$

Thus for positive value of q , whatever be the magnitude and sign of Q , the small sphere is at a higher potential than the shell. If inner and outer conductors are connected, charge would flow from the small sphere to the shell. By repeating the process, a large amount of charge can be piled up on the shell, thereby raising its potential.

CONSTRUCTION AND WORKING

To implement the principle in practice a large spherical conducting shell with radius of few metres is supported on an insulating column several metres high. The conducting shell is made highly polished and is known as metal dome. There are two pulleys, one at the centre of the shell and the other at the ground. A long narrow belt made of insulating material passes over the pulleys. Charge is sprayed on to the belt at the lower pulley by means of a discharge through a metallic brush with sharp points connected to a high voltage source. The belt is moved rapidly by a motor driving the lower pulley. The positive charge is carried upward by the belt and collected by a metallic brush connected to the shell. As more and more charge is transferred to the sphere S , its potential goes on rising. In this way, the shell builds up a huge voltage of the order of mega volts.



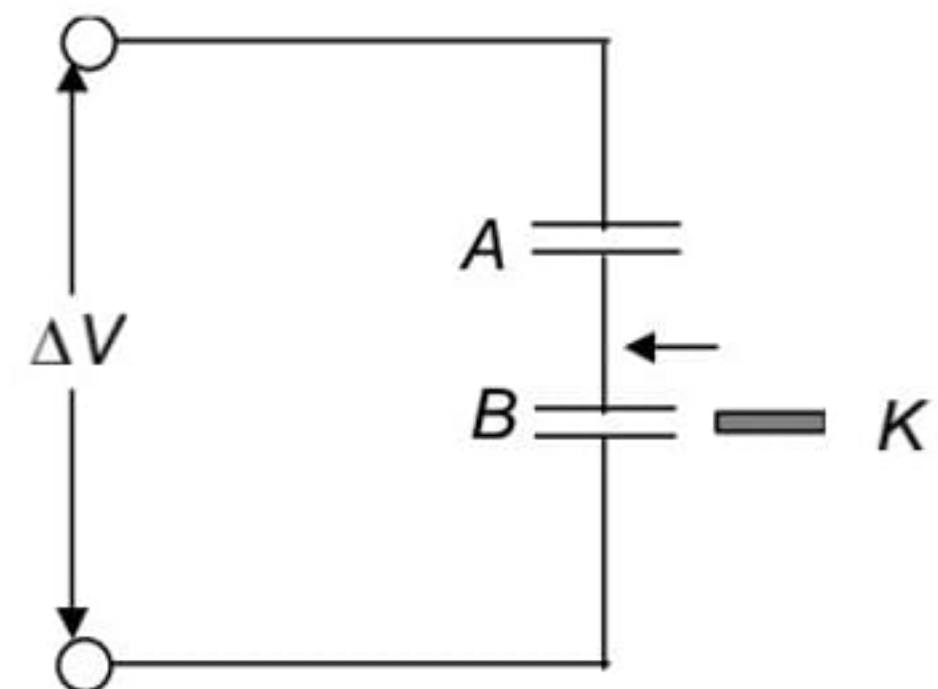
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PROFICIENCY TEST– IV

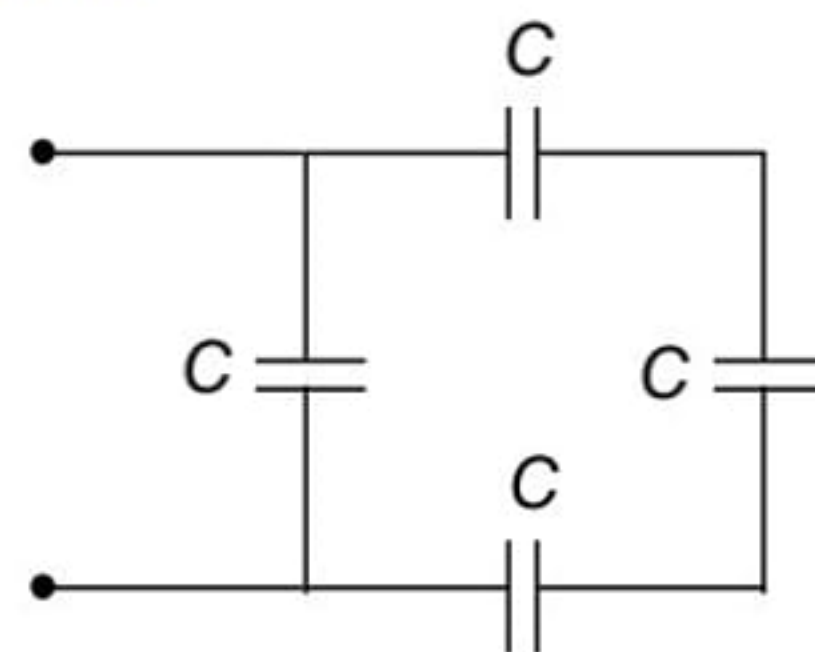
The following questions deal with the basic concepts of this section. Answer the following briefly. Go to the next section only if your score is at least 80%. Do not consult the Study Material while attempting these questions.

1. When a dielectric is inserted to fill the space between a charged parallel plate capacitor, does the stored energy increase or decrease given that (a) the battery remains connected; or (b) the battery is first disconnected?
2. The potential difference across a capacitor is doubled. How does each of the following quantities change: (a) the capacitance; (b) the stored energy; (c) the stored charge?
3. Given a battery, how would you connect two capacitors, in series or in parallel, for them to store the greater; (a) total charge; (b) total energy
4. A parallel plate capacitor with large plates is charged and then disconnected from the battery. As the plates are pulled apart, does the potential difference increase, decrease or remain the same? How is the stored energy affected?
5. A parallel-plate capacitor is connected to a battery. Consider what happens as you move the plates closer together.
(a) How are the charge, potential difference, and energy affected?
(b) Would you do positive or negative work in moving the plates?

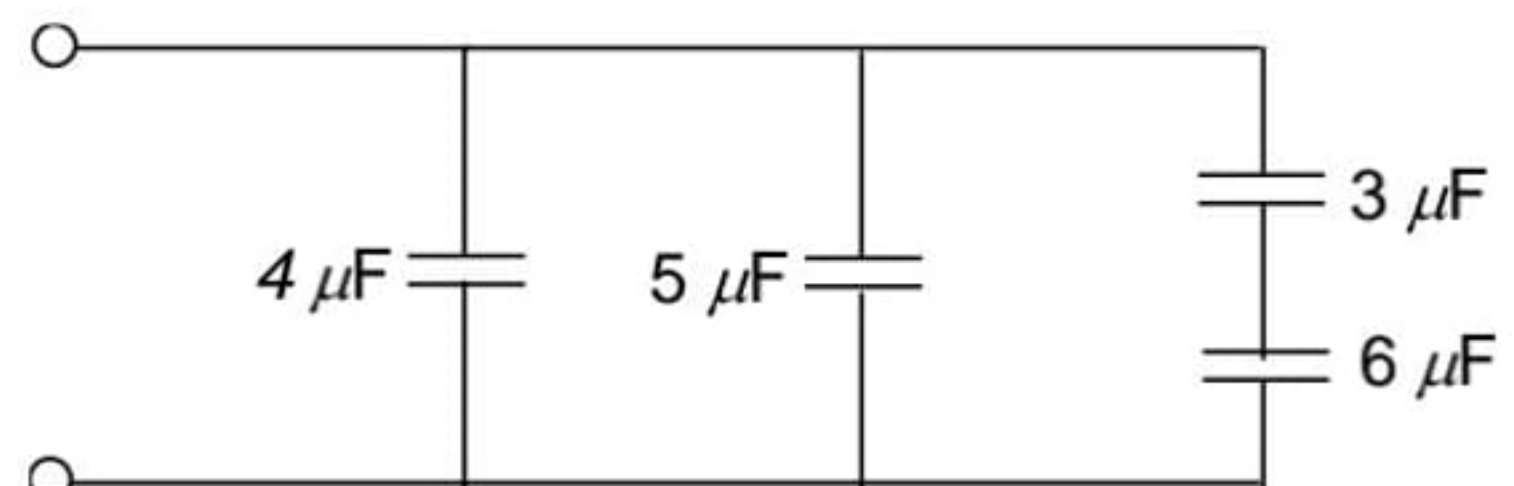
6. Two identical capacitors are connected as shown in the above diagram. A dielectric slab is inserted between the plates of one capacitor, the battery remaining connected so that a constant potential difference ΔV is maintained. Describe qualitatively what happens to the charge, the capacitance, the potential difference for each capacitor.



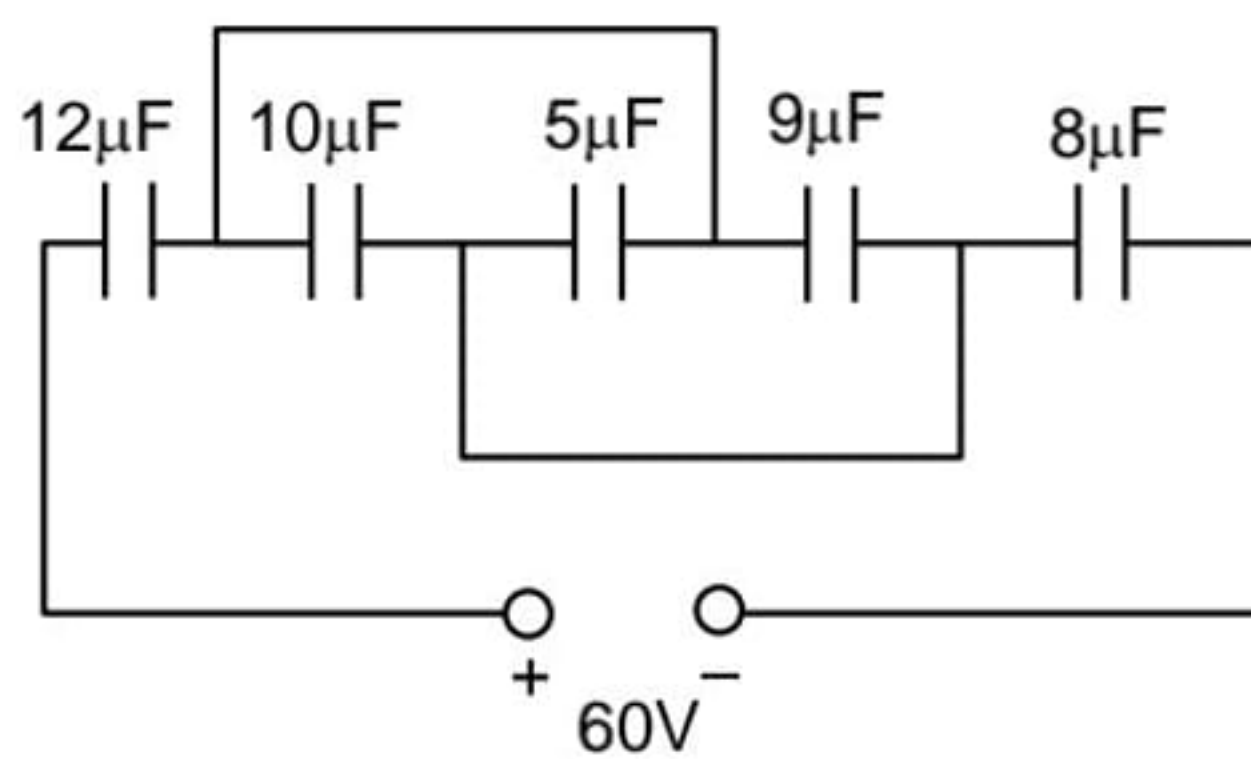
7. Given two capacitors, $C_1 = 1 \mu\text{F}$ and $C_2 = 2 \mu\text{F}$, and a 12 V battery, find the charge and potential difference for each if they are connected in series.
8. All the capacitors in the above diagram are identical, with $C = 3 \mu\text{F}$. What is their equivalent capacitance?



9. Consider the combination of capacitor in the diagram. The energy stored in the $5 \mu\text{F}$ capacitor is 200 mJ. What is the energy stored in the $4 \mu\text{F}$ capacitor.



10. Find the equivalent capacitance and charge on $5\mu\text{F}$ capacitor



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ANSWERS TO PROFICIENCY TEST- IV

1. (a) Increase
(b) Decrease
2. (a) No changed
(b) Increases four times
(c) Increases two times
3. (a) Parallel
(b) Parallel
4. (a) Potential difference increases
(b) Energy stored increases
5. (a) Charge increase, potential difference does not change, energy increases
(b) Negative work
6. Charge increases for each capacitor: the capacitance of capacitor A does not change while that of B increase: potential difference across A increases and that across B decreases.
7. $8\mu\text{C}$ for C_1 & C_2 : 8 V for C_1 & 4 V for C_2
8. $4\mu\text{F}$
9. 160 mJ
10. $4\mu\text{F}$, $50\mu\text{C}$

SOLVED OBJECTIVE EXAMPLES

Example 1:

A charge q is placed at the centre of the line joining two equal charges Q . The system of the three charges will be in equilibrium if q is equal to

- (a) $-\frac{Q}{2}$ (b) $-\frac{Q}{4}$ (c) $+\frac{Q}{4}$ (d) $+\frac{Q}{2}$

Solution:

Let $2l$ = distance between the equal charges. For equilibrium of each outer charge,

$$\frac{Qq}{4\pi\epsilon_0 l^2} + \frac{Q^2}{4\pi\epsilon_0 (2l)^2} = 0 \Rightarrow q + \frac{Q}{4} = 0$$

$$\Rightarrow q = -\frac{Q}{4}$$

\therefore (b)

Example 2:

Three point charges $4q$, Q and q are placed on a straight line of length l at points distant 0 , $\frac{l}{2}$ and l respectively. The net force on charge q is zero. The value of Q is

- (a) $-q$ (b) $-2q$ (c) $-\frac{1}{2}q$ (d) $4q$

Solution:

$$\text{Force between charges } 4q \text{ and } q = \frac{1}{4\pi\epsilon_0} \frac{4q^2}{l^2}$$

$$\text{Force between charges } Q \text{ and } q = \frac{1}{4\pi\epsilon_0} \frac{Qq}{\left(\frac{l}{2}\right)^2}$$

$$\therefore \frac{1}{4\pi\epsilon_0} \frac{4Qq}{l^2} = -\frac{1}{4\pi\epsilon_0} \frac{4q^2}{l^2}$$

$$Q = -q$$

\therefore (a)

Example 3:

A charge Q is placed at each of the two opposite corners of a square. A charge q is placed at each of the other two corners. If the resultant electric force on Q is zero, then Q is equal to

- (a) $\frac{2\sqrt{2}}{q}$ (b) $\frac{-q}{2\sqrt{2}}$ (c) $-2\sqrt{2}q$ (d) $2\sqrt{2}q$

Solution:

Obviously Q and q should be of opposite signs and the resultant intensity

$$\vec{E}_1 + \vec{E}_2 + \vec{E}_3 = 0$$

$$|\vec{E}_1| = |\vec{E}_2| = \frac{1}{4\pi\epsilon_0} \frac{Qq}{a^2}$$

where ' a ' is the side of the square.

$$|\vec{E}_3| = \frac{1}{4\pi\epsilon_0} \frac{Q^2}{(a\sqrt{2})^2}$$

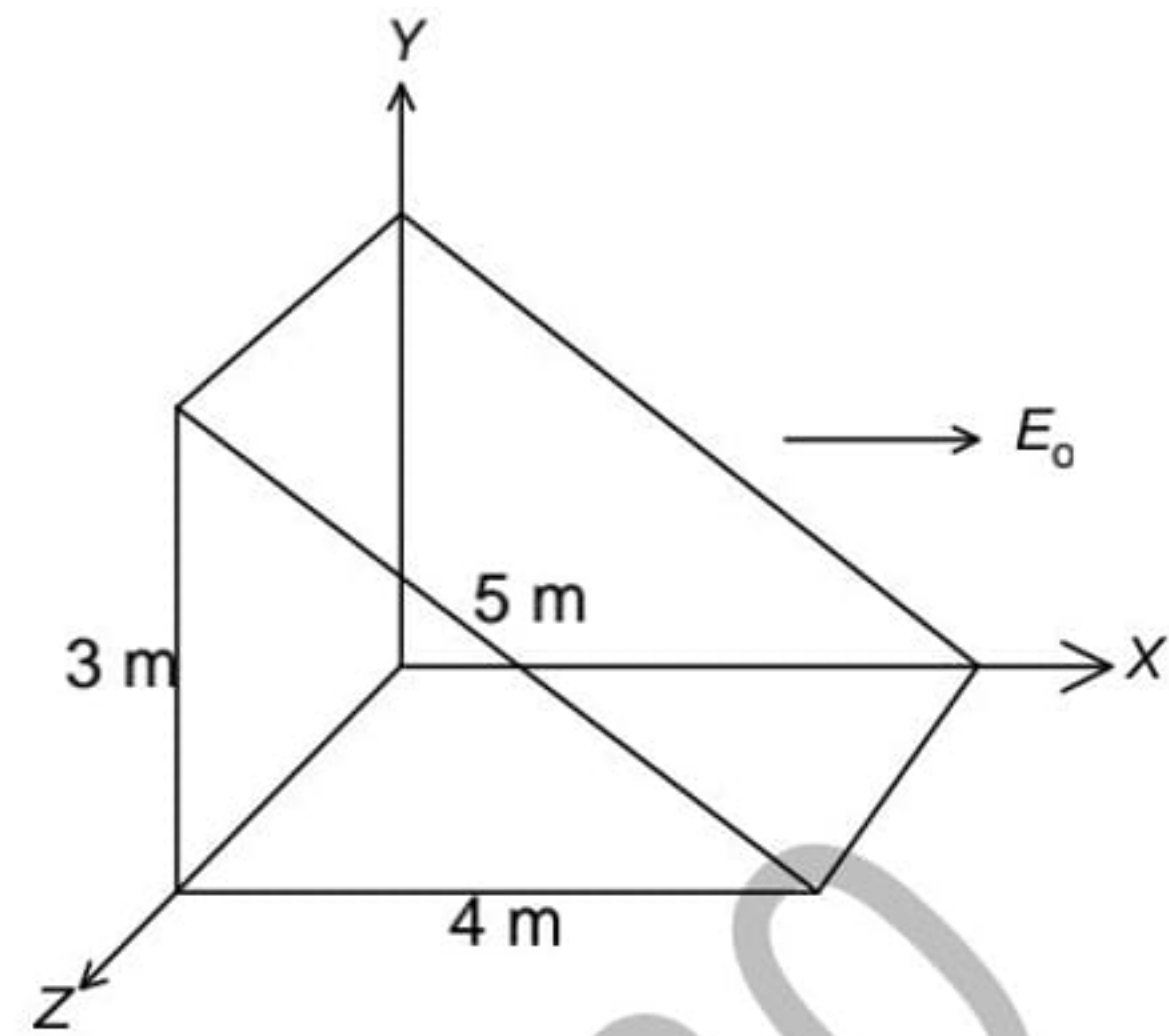
$$\text{Now } |\vec{E}_1 + \vec{E}_2| = E_1\sqrt{2} = |\vec{E}_3| \text{ which gives } Q = -2\sqrt{2}q$$

\therefore (c)

Example 4:

The wedge-shaped surface in figure is in a region of uniform electric field E_0 along x axis. The net electric flux for the entire closed surface is

- (a) $9 E_0$
- (b) $15 E_0$
- (c) $12 E_0$
- (d) zero



Solution:

Since field is uniform, the net flux for the closed surface is zero.

\therefore (d)

Example 5:

A charge Q is placed at the centre of a cube. The flux of the electric field through the six surfaces of the cube is

- (a) $\frac{Q}{6\epsilon_0}$
- (b) $\frac{Q}{\epsilon_0}$
- (c) $\frac{Q}{6L^2}$
- (d) $\frac{Q}{3L^2}$

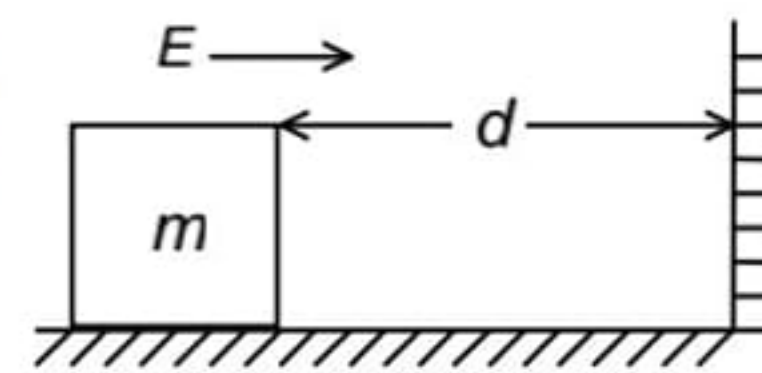
Solution:

From Gauss's law $\phi_E = \frac{Q_{enc}}{\epsilon_0}$

\therefore (b)

Example 6:

A block of mass m carrying a positive charge q is placed on a smooth horizontal table, which ends in a vertical wall situated at a distance d from block. An electric field E is switched on towards right. Assuming elastic collisions, find the time period of resultant oscillation.



- (a) $\sqrt{\frac{2qEd}{m}}$
- (b) $\sqrt{\frac{8md}{qE}}$
- (c) $\sqrt{\frac{2md}{qE}}$
- (d) $\sqrt{\frac{md}{qE}}$

Solution:

Acceleration of the block $a = \frac{qE}{m}$

$$d = \frac{1}{2}at^2$$

$$\text{Required time} = 2t = \sqrt{\frac{8md}{qE}}$$

\therefore (b)

Example 7:

An electric dipole is placed in an electric field generated by a point charge. Then

- (a) the net electric force on the dipole must be zero
- (b) the net electric force on the dipole may be zero
- (c) the torque on the dipole due to the field may be zero
- (d) the torque on the dipole due to the field must be zero

Solution:

The field is not uniform. However, the torque on the dipole can be zero if it is aligned along the line of force.

∴ (c)

Example 8:

An electron having a charge $-e$ located at A in the presence of a point charge $+Q$ located at B is moved to a point C so that ABC is an equilateral triangle. The work done in this process is

- (a) $\frac{1}{4\pi\epsilon_0} \frac{Q}{AC}$ (b) $\frac{1}{4\pi\epsilon_0} \frac{Qe}{AC}$ (c) $\frac{1}{4\pi\epsilon_0} \frac{-Qe}{AB}$ (d) zero

Solution:

Electron is moved from A to C. A and C are equidistant from B and hence the potential at A due to charge $+Q$ = potential at C due to the same charge. Since there is no potential difference between A and C no work is done in moving a charge from A to C.

∴ (d)

Example 9:

An infinite number of charges each equal to q are placed along the x-axis at $x = 1, x = 2, x = 4, x = 8$ and so on. The resultant potential at $x = 0$ will be

- (a) $\frac{q}{2\pi\epsilon_0}$ (b) $\frac{q}{4\pi\epsilon_0}$ (c) $\frac{q}{8\pi\epsilon_0}$ (d) $\frac{q}{\epsilon_0}$

Solution:

$$V = \frac{q}{4\pi\epsilon_0} \left[1 + \frac{1}{2} + \frac{1}{2^2} + \frac{1}{2^3} + \dots \right] = \frac{q}{4\pi\epsilon_0} \left(1 - \frac{1}{2} \right)$$
$$= \frac{q}{2\pi\epsilon_0}$$

∴ (a)

Example 10:

A solid conducting sphere of charge Q is surrounded by an uncharged concentric conducting spherical shell. The potential difference between the sphere and the shell is V . If the shell is now given a charge of $-3Q$, the new potential difference between them will be

- (a) V (b) $2V$ (c) $4V$ (d) $-2V$

Solution:

The potential difference depends only on the charge on the inner sphere.

∴ (a)

Example 11:

In a parallel plate capacitor, the plate separation of 10 mm is very small compared with the size of the plates. A potential difference of 5.0 kV is maintained across the plates. The electric field intensity between the plates is

- (a) 500 V/m (b) 2.5×10^5 V/m (c) 5×10^5 V/m (d) 2.5×10^3 V/m

Solution:

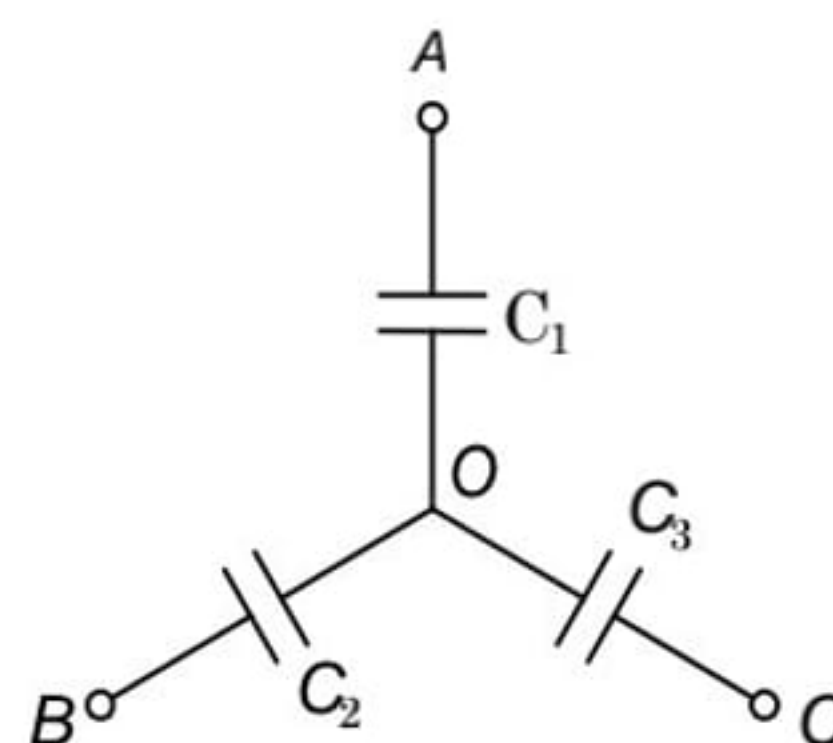
$$E = \frac{V}{d} = \frac{5 \times 10^3}{10 \times 10^{-3}} = 5 \times 10^5 \text{ V/m}$$

∴ (c)

Example 12:

Three uncharged capacitors of capacities C_1, C_2, C_3 are connected as shown in figure to one another and to points A, B and C at potentials V_1, V_2 and V_3 . Then the potential at O will be

- (a) $\frac{V_1 C_1 + V_2 C_2 + V_3 C_3}{C_1 + C_2 + C_3}$ (b) $\frac{V_1 + V_2 + V_3}{C_1 + C_2 + C_3}$
 (c) $\frac{V_1(V_2 + V_3)}{C_1(C_2 + C_3)}$ (d) $\frac{V_1 V_2 V_3}{C_1 C_2 C_3}$



Solution:

Taking into account the relation between capacitance, voltage and charge of a capacitor, we can write the following equations for the three capacitors.

$$V_1 - V_0 = \frac{q_1}{C_1}, \quad V_2 - V_0 = \frac{q_2}{C_2}, \quad V_3 - V_0 = \frac{q_3}{C_3}$$

where C_1, C_2 and C_3 are the capacitances of corresponding capacitors and q_1, q_2 and q_3 are charges on the plates. According to charge conservation law, $q_1 + q_2 + q_3 = 0$ and hence the potential V_0 of the common

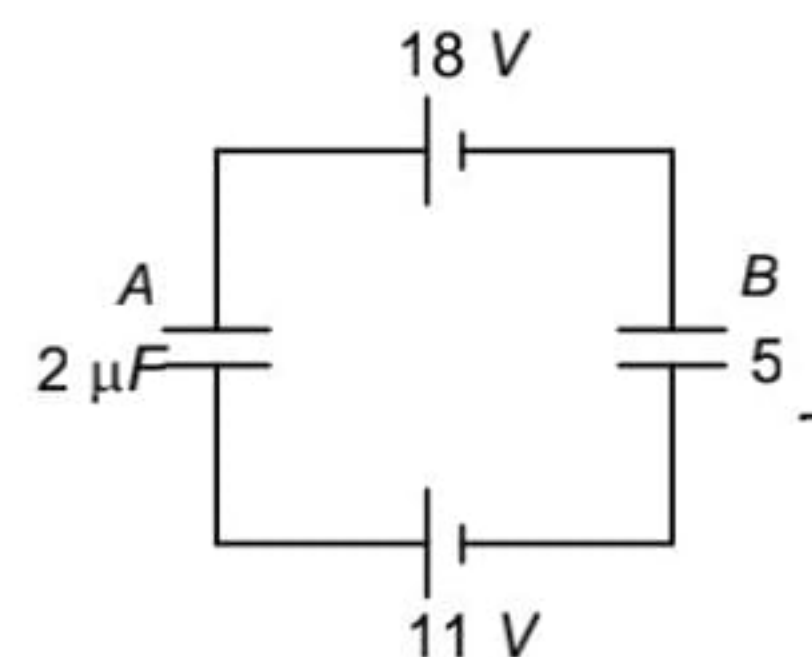
point is $V_0 = \frac{V_1 C_1 + V_2 C_2 + V_3 C_3}{C_1 + C_2 + C_3}$.

∴ (a)

Example 13:

Two capacitors A ($2 \mu\text{F}$) and B ($5 \mu\text{F}$) are connected to two batteries as shown in the figure. Then the potential difference in volts between the plates of A is

- (a) 2 (b) 5
 (c) 11 (d) 18



Solution:

$$(18 - 11) = \frac{Q}{2\mu\text{F}} + \frac{Q}{5\mu\text{F}} = \frac{7Q}{10\mu\text{F}}$$

$$Q = 10\mu\text{C}$$

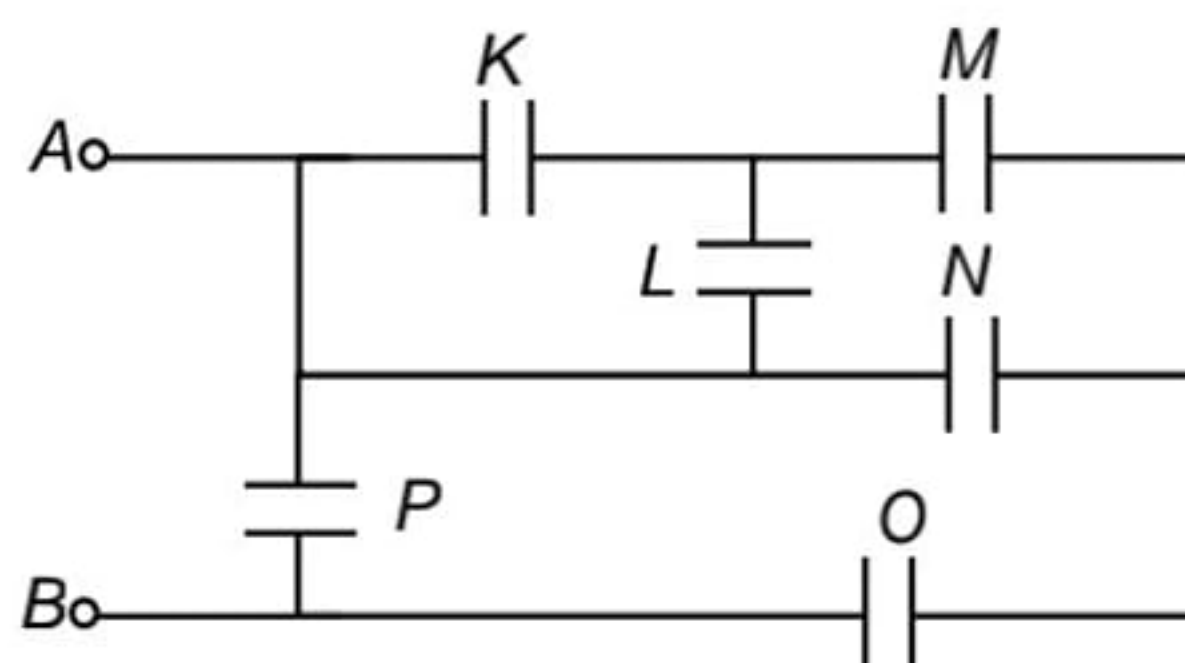
$$V_A = \frac{Q}{C_A} = \frac{10\mu\text{C}}{2\mu\text{F}} = 5 \text{ V}$$

∴ (b)

Example 14:

The effective capacitance between A and B is (each capacitor is of $1 \mu\text{F}$)

- (a) $\frac{15}{2} \mu\text{F}$
 (b) $\frac{17}{3} \mu\text{F}$
 (c) $\frac{13}{8} \mu\text{F}$
 (d) $\frac{19}{8} \mu\text{F}$

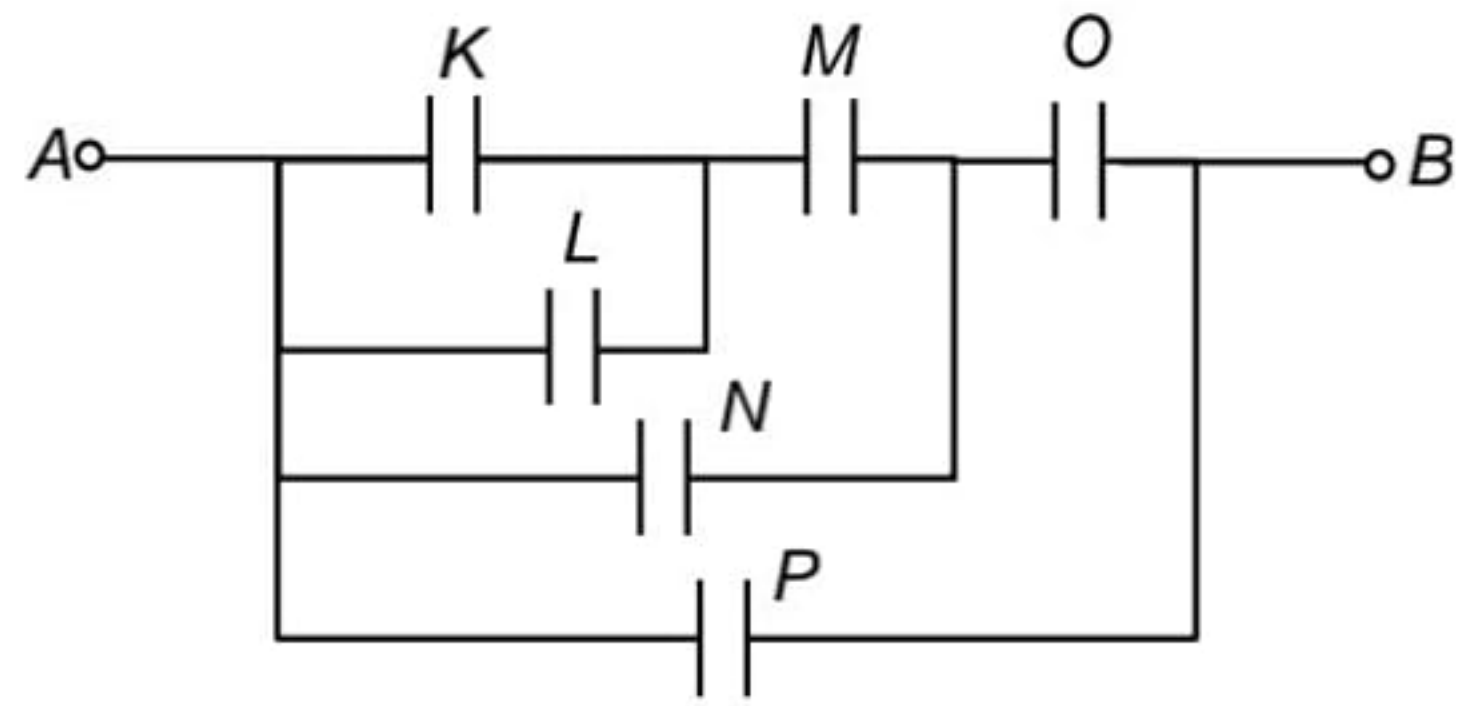


Solution:

Circuit can be redrawn as

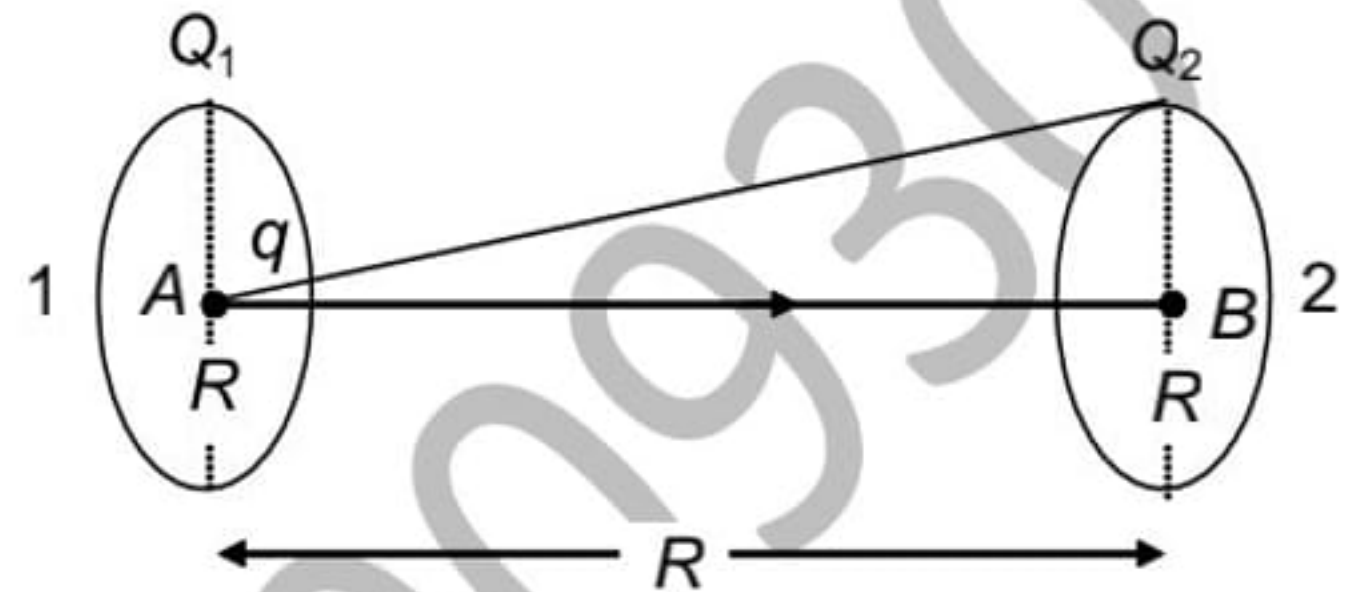
$$\therefore C_{eq} = \frac{13}{8} \mu\text{F}$$

\therefore (c)



Example 15:

Two identical thin rings, each of radius R metres are coaxially placed at a distance R metres apart. If Q_1 and Q_2 charges are spread uniformly on the two rings, the work done in moving a charge q from the centre of one ring to that of the other is



(a) zero

(b) $q(Q_1 - Q_2) (\sqrt{2} - 1) / \sqrt{2} (4\pi\epsilon_0 R)$

(c) $q\sqrt{2}(Q_1 + Q_2) / (4\pi\epsilon_0 R)$

(d) $q(Q_1 + Q_2) (\sqrt{2} + 1) / \sqrt{2} (4\pi\epsilon_0 R)$

Solution:

$$V_B = \frac{KQ_2}{R} + \frac{KQ_1}{\sqrt{2}R}, \quad V_A = \frac{KQ_1}{R} + \frac{KQ_2}{\sqrt{2}R}$$

$$\therefore V_A - V_B = \frac{KQ_1}{R} \left(1 - \frac{1}{\sqrt{2}}\right) + \frac{KQ_2}{R} \left(\frac{1}{\sqrt{2}} - 1\right)$$

$$\therefore V_A - V_B = \frac{K}{R} \left(1 - \frac{1}{\sqrt{2}}\right) (Q_1 - Q_2), \text{ where } K = \frac{1}{4\pi\epsilon_0}$$

$$\therefore W = q(V_A - V_B)$$

\therefore (b)

SOLVED SUBJECTIVE EXAMPLES

Example 1:

Two charged balls are attached by silk threads of length l to the same point. Their velocity is $\frac{K}{\sqrt{x}}$, where

K is a constant and x is the distance between the balls, x is very small in comparison to l . Find the rate of leakage of charge in 10^{-5} C/s.

(take $\frac{l}{mg} = 10$, $k = 4\sqrt{2}$)

Solution:

Let T be the tension in each of the silk threads.

$$T \sin \theta = F, \quad T \cos \theta = mg$$

$$\tan \theta = \frac{F}{mg} = \frac{q^2}{4\pi\epsilon_0 x^2} \cdot \frac{1}{mg}$$

Since θ is small, $\tan \theta = \sin \theta = \frac{x}{2l}$

$$x = \frac{2lF}{mg} = \frac{2l}{mg} \cdot \frac{q^2}{4\pi\epsilon_0 x^2}$$

$$x^3 = \frac{2l}{mg} \cdot \frac{q^2}{4\pi\epsilon_0} = \frac{l}{2\pi\epsilon_0 mg} \cdot q^2$$

$$x = \left(\frac{l}{2\pi\epsilon_0 mg} \right)^{1/3} q^{2/3} \quad \dots (i)$$

$$\frac{dx}{dq} = \frac{dx/dt}{dq/dt} = \left(\frac{l}{2\pi\epsilon_0 mg} \right)^{1/3} \frac{2}{3} q^{-1/3}$$

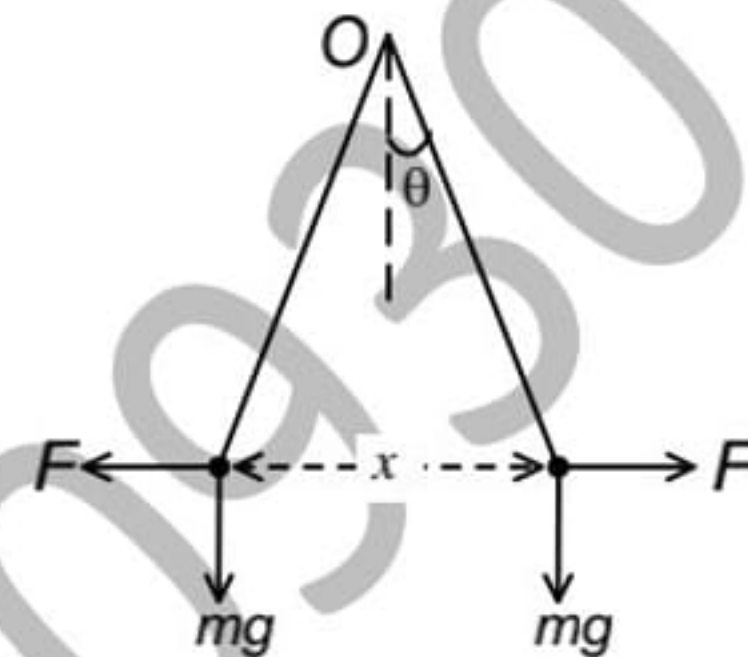
$$\frac{dq}{dt} = q^{1/3} \frac{dx}{dt} \left/ \frac{2}{3} \left(\frac{l}{2\pi\epsilon_0 mg} \right)^{1/3} \right. \quad \dots (ii)$$

It is given, $\frac{dx}{dt} = \frac{K}{\sqrt{x}} = \frac{K}{\left(\frac{l}{2\pi\epsilon_0 mg} \right)^{1/6} q^{1/3}} \quad \dots (iii)$

From equations (2) and (3), we get,

$$\begin{aligned} \frac{dq}{dt} &= \frac{K}{\frac{2}{3} \left(\frac{l}{2\pi\epsilon_0 mg} \right)^{1/2}} \\ &= \frac{3K}{2} \left[\frac{2\pi\epsilon_0 mg}{l} \right]^{1/2} = 2 \times 10^{-5} \end{aligned}$$

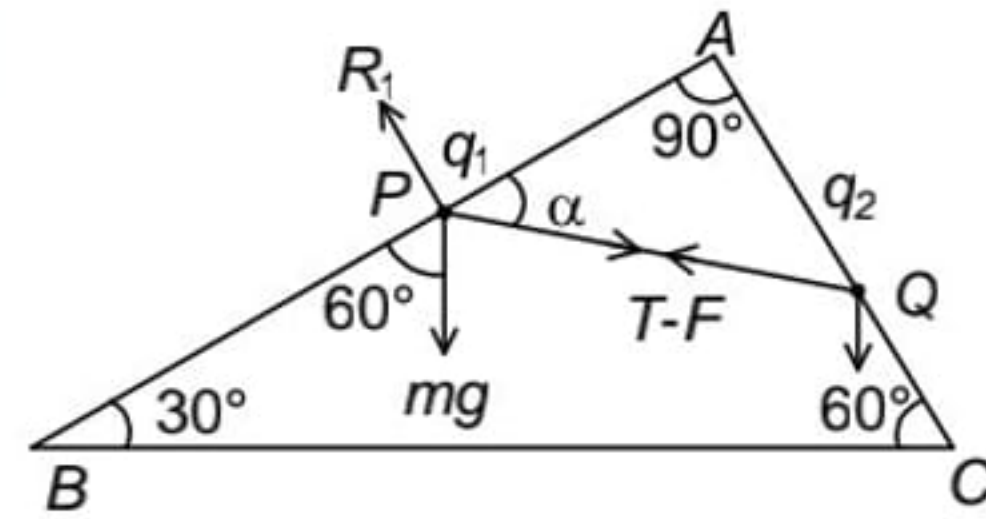
$\therefore 20 \mu\text{C/s}$



Example 2:

A rigid insulated wire frame in the form of a right-angled triangle BAC is set in a vertical plane as shown in the Figure.

Two beads of equal masses $m = 1 \text{ kg}$ each and carrying the charges $q_1 = 10 \mu\text{C}$ and $q_2 = 100 \mu\text{C}$ are connected by a cord of length $l = 1 \text{ m}$ and can slide without friction on the wires. Considering the case when the beads are stationary determine (1) angle α , (2) tension in cord and (3) normal reaction on beads. ($\sqrt{3} = 1.7$)



Solution:

The bead is at P, having charge q_1 and weight mg acting vertically downwards. The tension in the string is acting along PQ. The electrical force F between the beads acting along length PQ is

$$F = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{l^2}$$

R_1 is the normal reaction of the wire on the bead. The forces acting are resolved along and perpendicular to AB.

For the equilibrium of bead at P,

$$mg \cos 60^\circ = (T-F) \cos \alpha \quad (\text{parallel to AB}) \quad \dots (i)$$

$$R_1 = mg \cos 30^\circ + (T-F) \sin \alpha \quad \dots (ii)$$

For equilibrium of bead at Q,

$$mg \sin 60^\circ = (T-F) \sin \alpha \quad \dots (iii)$$

$$R_2 = mg \sin 30^\circ + (T-F) \cos \alpha \quad \dots (iv)$$

Dividing equation (iii) by equation (i) $\tan 60^\circ = \tan \alpha$

This gives $\alpha = 60^\circ$

From equation (3), $T-F = mg$

$$\text{or } T - \frac{q_1 q_2}{4\pi\epsilon_0 l^2} = mg$$

$$\text{or } T = mg + \frac{q_1 q_2}{4\pi\epsilon_0 l^2} = 19 \text{ N} \quad \dots (v)$$

From equations (2) and (4)

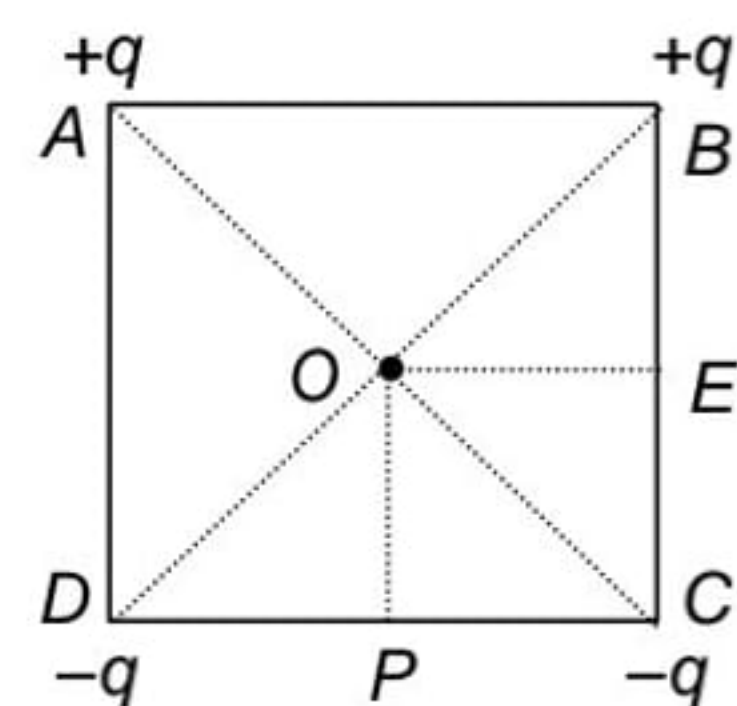
$$R_1 = mg \cos 30^\circ + (T-F) \sin 60^\circ = mg \cos 30^\circ + mg \sin 60^\circ = \sqrt{3} mg = 17 \text{ N}$$

$$R_2 = mg \sin 30^\circ + mg \cos 60^\circ = mg = 10 \text{ N.}$$

Example 3:

Four charges $+q, +q, -q$ and $-q$ are placed respectively at the corners A, B, C and D of a square of side $a = (\sqrt{5} - 1) \text{ cm}$ arranged in the given order. If E and P are the midpoints of sides BC and CD respectively, what will be the work done in carrying a charge q_0 from O to E and from O to P?

(take $q = 10 \mu\text{C}$, $q_0 = \sqrt{5} \mu\text{C}$)



Solution:

ABCD is the given square of side a . The charges are placed at the corners as shown. O is the midpoint of square.

$$OA = OB = OC = OD = r \text{ (say)} = \frac{a}{\sqrt{2}}$$

$$\text{Potential at O due to the charges at the corners} = \frac{1}{4\pi\epsilon_0} \left(\frac{q}{r} + \frac{q}{r} - \frac{q}{r} - \frac{q}{r} \right) = 0$$

Therefore O is at zero potential. The electric field at O due to charge at A

$$= \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{r^2} \text{ along OC.}$$

To find the work done in carrying a charge e from O to E

Potential at $O = 0$

$$\text{Potential at } E = \frac{q}{4\pi\epsilon_0} \left[\frac{1}{AE} + \frac{1}{BE} - \frac{1}{DE} - \frac{1}{CE} \right]$$

Since $AE = DE$ and $BE = CE$ the summation in bracket vanishes. So potential at $E = 0$.

Hence no work is done in moving the charge from O to E .

To find the work done in carrying the charge from O to P

$$\text{Potential at } P = \frac{q}{4\pi\epsilon_0} \left[\frac{1}{AP} + \frac{1}{BP} - \frac{1}{DP} - \frac{1}{CP} \right] = \frac{2q}{4\pi\epsilon_0} \left[\frac{1}{AP} - \frac{1}{DP} \right]$$

$$\text{Now } AP = \sqrt{AD^2 + DP^2} = \sqrt{a^2 + \left(\frac{a}{2}\right)^2} = \frac{\sqrt{5}}{2}a$$

$$DP = \frac{a}{2}$$

Potential at P

$$V = \frac{2q}{4\pi\epsilon_0} \left[\frac{2}{\sqrt{5}a} - \frac{2}{a} \right] = \frac{2q}{4\pi\epsilon_0} \cdot \frac{2-2\sqrt{5}}{\sqrt{5}a} = \frac{q}{4\pi\epsilon_0} \frac{4(1-\sqrt{5})}{\sqrt{5}a}$$

$$\text{Potential difference between } O \text{ and } P = 0 - \frac{q}{4\pi\epsilon_0} \frac{4(1-\sqrt{5})}{\sqrt{5}a} = \frac{q}{4\pi\epsilon_0} \frac{4(\sqrt{5}-1)}{\sqrt{5}a}$$

$$\text{Work done in carrying a charge } e \text{ from } O \text{ to } P = \frac{1}{4\pi\epsilon_0} \frac{4qe(\sqrt{5}-1)}{\sqrt{5}a} \text{ J} = 36 \text{ J}$$

Example 4:

A particle of positive charge $Q = 8q_0$, is having a fixed position P . Another charged particle of mass m and charge $q = 10 \mu\text{C}$ moves at a constant speed in a circle of radius $r_1 = 2 \text{ cm}$ with centre at P . Find the work that must be done to increase the radius of circle to $r_2 = 4 \text{ cm}$.

Solution:

Let q orbit round Q in a circle of radius r .

$$\text{K.E. of orbiting particle} = \frac{1}{2}mv^2. \quad \dots \text{ (i)}$$

where v is orbital velocity.

$$\text{Potential energy of } q = -\frac{1}{4\pi\epsilon_0} \frac{qQ}{r} \quad \dots \text{ (ii)}$$

P.E. is negative since q is negative.

$$\text{Electrostatic attraction on } q = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r^2} \quad \dots \text{ (iii)}$$

This is used as centripetal force required for circular motion.

$$\frac{mv^2}{r} = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r^2}$$

$$mv^2 = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r} \quad \dots \text{ (iv)}$$

From (1) and (4)

$$\text{K.E.} = \frac{1}{2}mv^2 = \frac{1}{4\pi\epsilon_0} \frac{Qq}{2r}$$

Total energy of the orbiting charge

= K.E. + P.E.

$$= \frac{1}{2} \left(\frac{1}{4\pi\epsilon_0} \frac{Qq}{r} \right) - \frac{1}{4\pi\epsilon_0} \frac{Qq}{r} = -\frac{1}{2} \frac{1}{4\pi\epsilon_0} \frac{Qq}{r}$$

The total energy of q when in orbit of radius r_1

$$E_1 = -\frac{1}{2} \cdot \frac{1}{4\pi\epsilon_0} \cdot \frac{Qq}{r_1}$$

When it is in orbit of radius r_2

$$E_2 = -\frac{1}{2} \cdot \frac{1}{4\pi\epsilon_0} \cdot \frac{Qq}{r_2}$$

The work done on q = change in energy

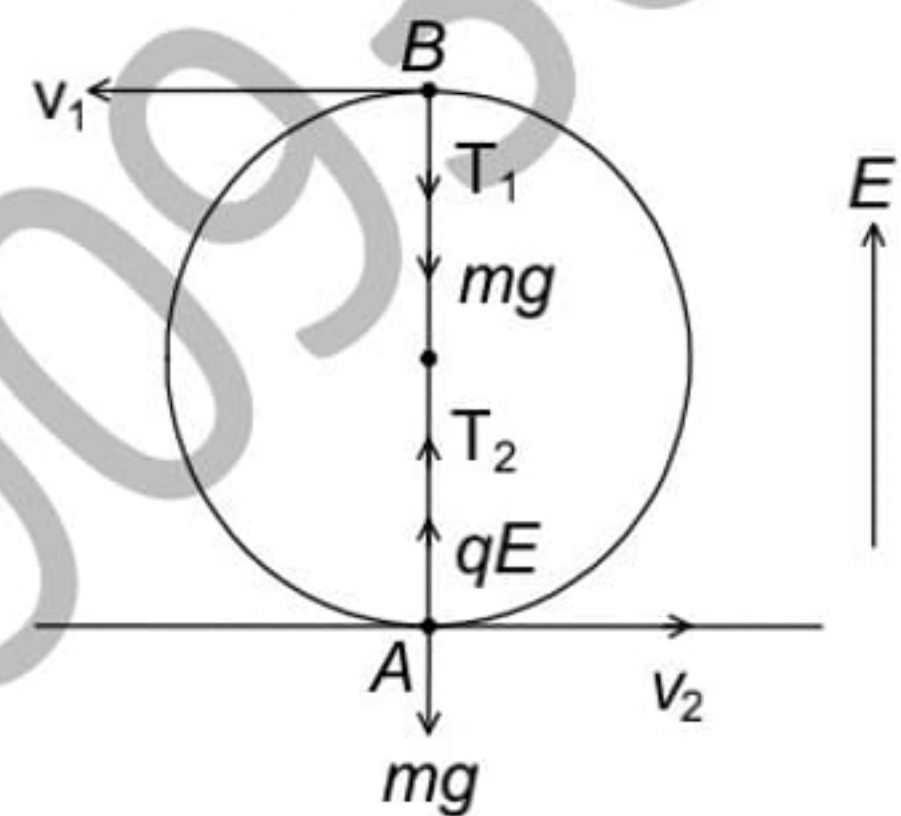
$$= E_2 - E_1$$

$$= -\frac{1}{2} \cdot \frac{1}{4\pi\epsilon_0} \cdot \frac{Qq}{r_2} - \left(-\frac{1}{2} \cdot \frac{1}{4\pi\epsilon_0} \cdot \frac{Qq}{r_1} \right) = \frac{Qq}{8\pi\epsilon_0} \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$$

$$= \frac{8q_0^2}{8\pi\epsilon_0} \left(\frac{1}{r_1} - \frac{1}{r_2} \right) = 90 \text{ J}$$

Example 5:

A ball of mass $m = 100 \text{ gm}$ with a charge q can rotate in a vertical plane at the end of a string of length $l = 1 \text{ m}$ in a uniform electrostatic field whose lines of force are directed upwards. What horizontal velocity must be imparted to the ball in the upper position so that the tension in the string in the lower position of the ball is 15 times the weight of the ball? (given $qE = 3mg$)



Solution:

As per principle of conservation of energy,

K.E. at B + P.E. at B = K.E. at A + P.E. at A.

Gain in K.E. = K.E. at A - K.E. at B

$$= \frac{1}{2} m(v_2^2 - v_1^2) \quad \dots (i)$$

Loss in P.E. = P.E. at B - P.E. at A.

= loss in gravitational P.E. at B - gain in electrical energy at A

$$= mg(2l) - (qE) \cdot 2l = (mg - qE)2l \quad \dots (ii)$$

P.E. at B - P.E. at A = K.E. at A - K.E. at B

$$\text{i.e., } (mg - qE)2l = \frac{1}{2} m(v_2^2 - v_1^2) \quad \dots (iii)$$

$$\text{Centripetal force at A} = \frac{mv_2^2}{l} = (T_2 + qE - mg) \quad \dots (iv)$$

$$\text{From equation (3)} \quad mv_2^2 = 2(mg - qE)2l + mv_1^2$$

$$\text{From equation (4)} \quad mv_2^2 = l(T_2 + qE - mg)$$

$$\text{i.e., } 2(mg - qE)2l + mv_1^2 = l(T_2 + qE - mg)$$

$$\text{i.e., } 4mg - 4qE + \frac{mv_1^2}{l} = T_2 + qE - mg \quad \dots (v)$$

Given in problem, $T_2 = 15mg$

$$\therefore 4mg - 4qE + \left(\frac{m}{l}\right)v_1^2 = 15mg + qE - mg$$

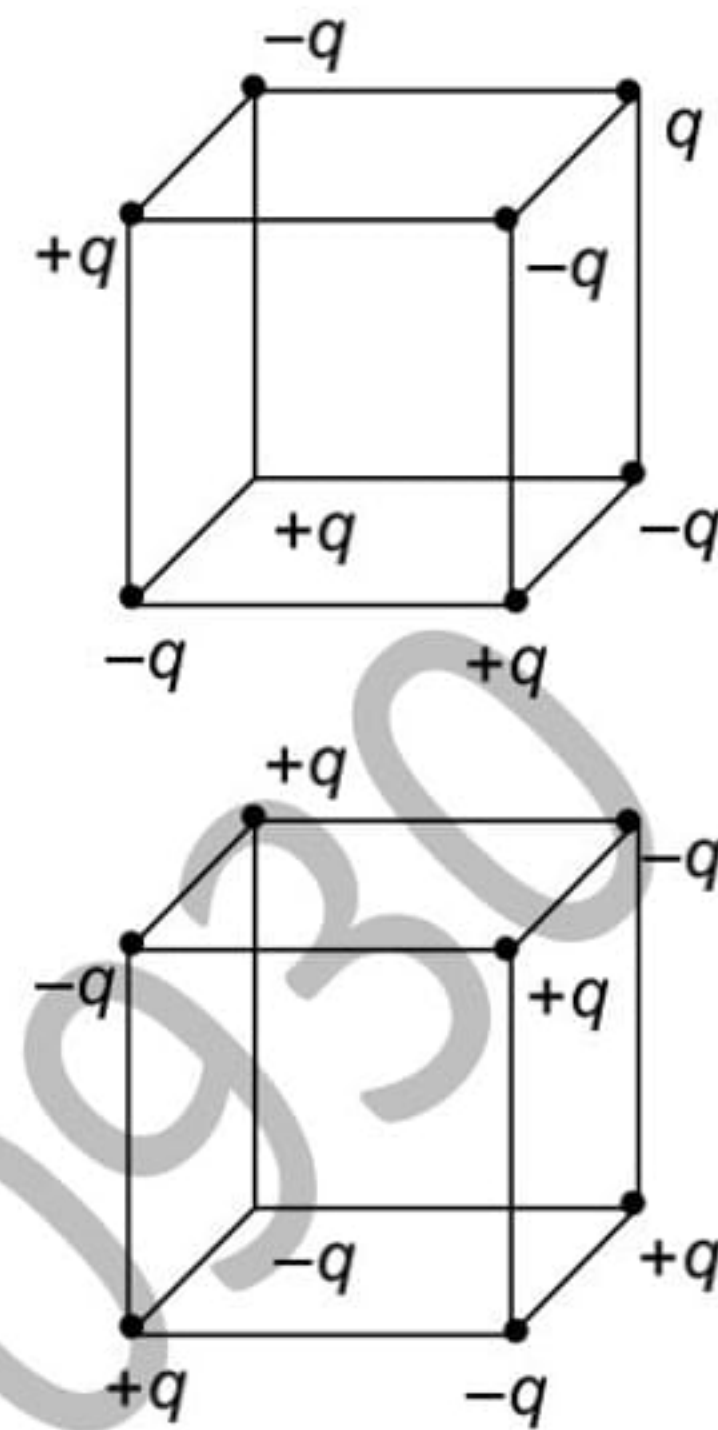
$$\text{or } \left(\frac{m}{l}\right)v_1^2 = 10mg + 5qE$$

$$\text{or } v_1^2 = \frac{l}{m} (10mg + 5qE)$$

Horizontal velocity to be imparted to the ball, $v_1 = \left[\frac{1}{m}(10mg + 5qE) \right]^{1/2} = 50 \text{ m/s}$

Example 6:

In the figure shown alternative positive and negative charges of magnitude $q = 10\mu\text{C}$ are placed at the corners of a cube of side length $a = 1\text{m}$. What is the work done (in mJ) in moving the charges far from each other.



Solution:

Initial electrostatics potential energy of the system

$$U_i = \frac{-12 \times Kq^2}{a} + \frac{12Kq^2}{\sqrt{2}a} - \frac{4Kq^2}{\sqrt{3}a}$$

$$= \frac{Kq^2}{a} \left[-12 + 6\sqrt{2} - \frac{4}{\sqrt{3}} \right]$$

$$= \frac{Kq^2}{\sqrt{3}a} [6\sqrt{6} - 12\sqrt{3} - 4]$$

Final electrostatics potential energy of the system is zero.

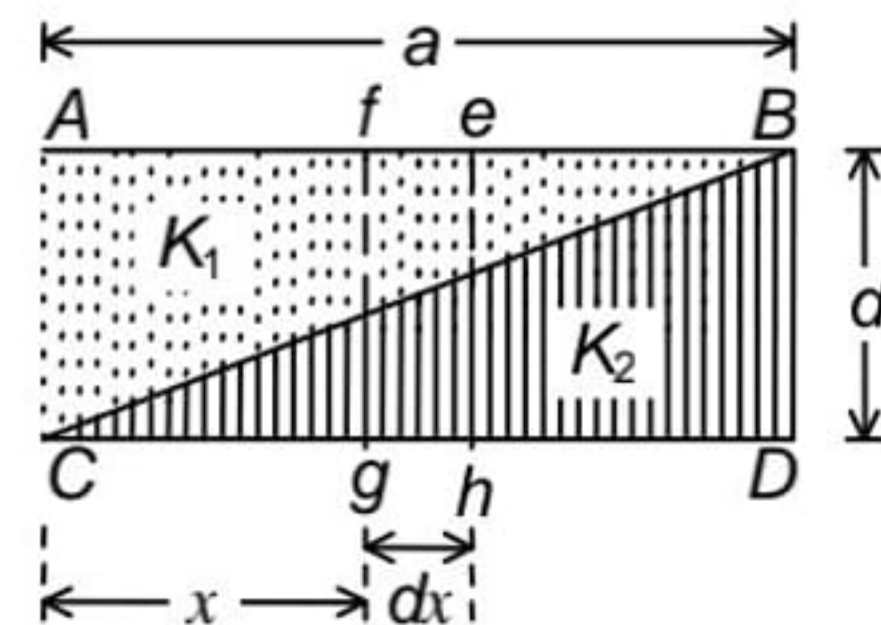
i.e., $U_f = 0$

$$\therefore W = \frac{Kq^2}{\sqrt{3}a} [-6\sqrt{6} + 12\sqrt{3} + 4]$$

$$\therefore \text{work done} = \frac{2Kq^2}{\sqrt{3}a} [6\sqrt{3} + 2 - 3\sqrt{6}] = 5357 \text{ J}$$

Example 7:

A capacitor is formed by two square metal plates of edge a separated by a distance $d = 0.061\text{m}$. The dielectrics of dielectric constants $K_1 = 20$ and $K_2 = 40$ are filled within the gap, as shown in Figure. Find the equivalent capacitance in nF. ($\log_e 2 = 0.69$, $\epsilon_0 = 8.85 \times 10^{-12}$)



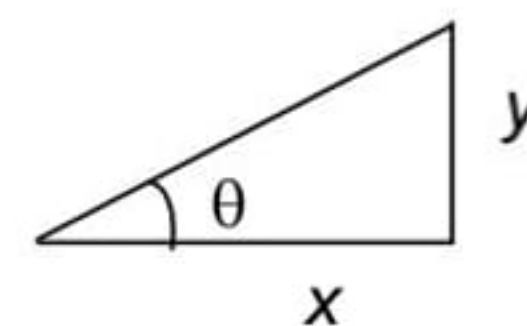
Solution:

Let us consider a capacitor $efgh$ at distance x from C and of width dx . The capacitor is made of two small capacitors in series, one of dielectric constants K_1 and the other of dielectric constant K_2 . Let dC_1 and dC_2 be the capacitances of the small capacitors.

$$dC_1 = \frac{K_1 \epsilon_0 a dx}{(d-y)}; dC_2 = \frac{K_2 \epsilon_0 a dx}{y}$$

$$y = x \tan \theta = x \cdot \frac{d}{a}$$

$$dC_1 = \frac{K_1 \epsilon_0 a dx}{\left(d - \frac{xd}{a}\right)} = \frac{K_1 \epsilon_0 a^2 dx}{d(a-x)}$$



... (i)

$$dC_2 = \frac{K_2 \epsilon_0 a dx}{\frac{xd}{a}} = \frac{K_2 \epsilon_0 a^2 dx}{xd}$$

The equivalent capacitance of $efgh$

$$\begin{aligned} &= \frac{1}{dC} = \frac{1}{dC_1} + \frac{1}{dC_2} = \frac{d(a-x)}{K_1 \epsilon_0 a^2 dx} + \frac{xd}{K_2 \epsilon_0 a^2 dx} \\ &= \frac{K_2 d(a-x) + K_1 xd}{K_1 K_2 \epsilon_0 a^2 dx} \end{aligned}$$

$$\begin{aligned} \text{i.e. } dC &= \frac{K_1 K_2 \epsilon_0 a^2 dx}{K_2 d(a-x) + K_1 xd} = \frac{K_1 K_2 \epsilon_0 a^2 dx}{K_2 da + (K_1 - K_2) dx} \\ &= \frac{K_1 K_2 \epsilon_0 a^2 dx}{d \{K_2 a + (K_1 - K_2)x\}} \end{aligned}$$

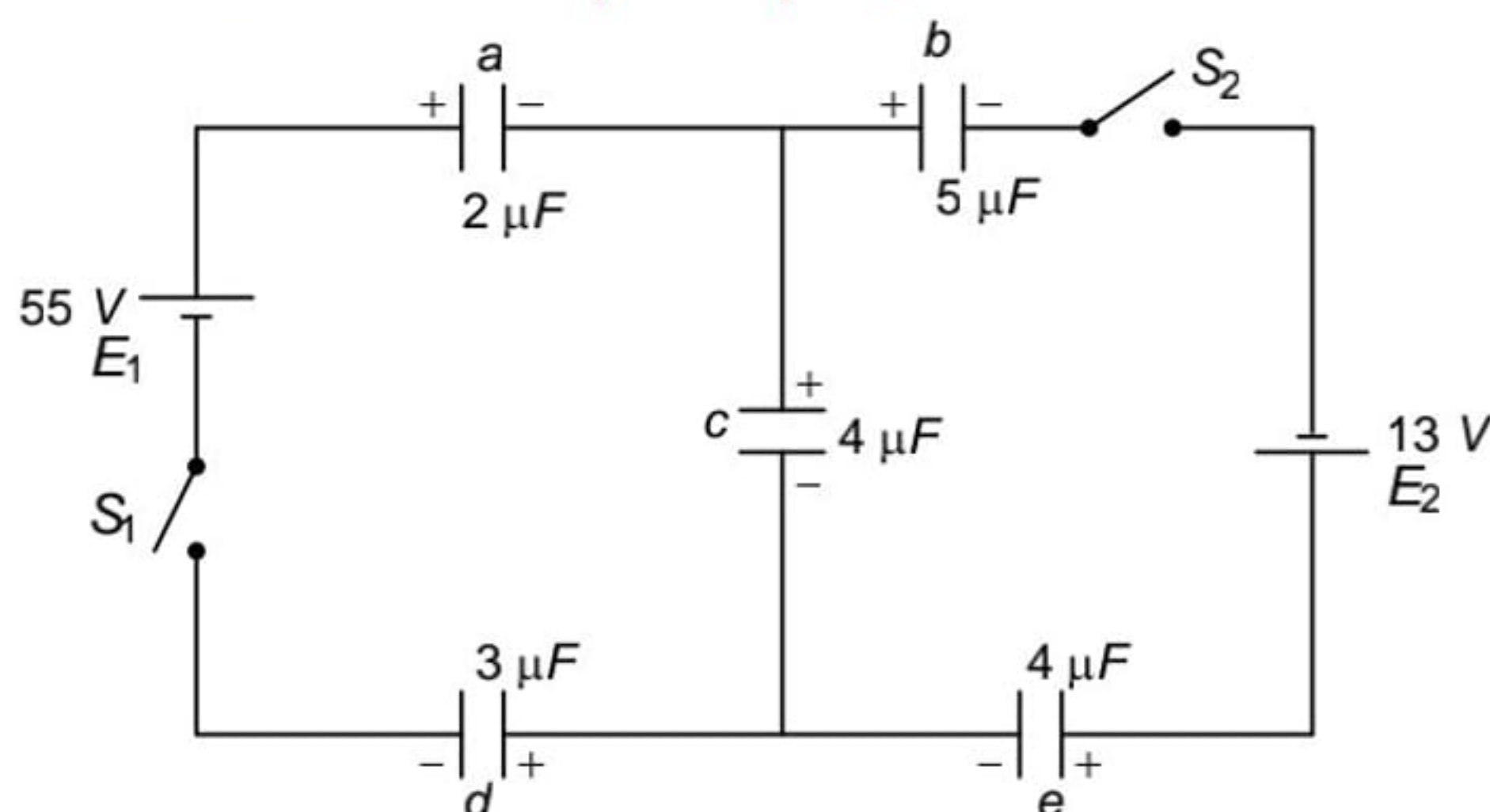
The differential capacitors are in parallel and x varies from 0 to a . The effective equivalent capacitance C is

$$\begin{aligned} C &= \frac{K_1 K_2 \epsilon_0 a^2}{d} \int_0^a \frac{dx}{K_2 a + (K_1 - K_2)x} \\ &= \frac{K_1 K_2 \epsilon_0 a^2}{d} \left\{ \log_e \left\{ \frac{K_2 a + (K_1 - K_2)x}{K_1 - K_2} \right\} \right\}_0^a \\ &= \frac{K_1 K_2 \epsilon_0 a^2}{(K_1 - K_2)d} \{ \log_e [K_2 a + (K_1 - K_2)a] - \log_e K_2 a \} \\ &= \frac{K_1 K_2 \epsilon_0 a^2}{(K_1 - K_2)d} \log_e \left(\frac{K_1 a}{K_2 a} \right) \\ &= \frac{K_1 K_2 \epsilon_0 a^2}{(K_1 - K_2)d} \log_e \left(\frac{K_1}{K_2} \right) \end{aligned}$$

$$\text{or } C = \frac{K_1 K_2 \epsilon_0 a^2}{(K_2 - K_1)d} \log_e \left(\frac{K_2}{K_1} \right) = 4 \text{ nF}$$

Example 8:

Five capacitors, two batteries and two switches are connected as shown in the Figure. Initially S_1 and S_2 are open and all the capacitors are uncharged. After S_1 and S_2 are closed and steady state is attained, find the p.d. between the terminals of the $3 \mu\text{F}$ and $5 \mu\text{F}$ capacitor.



Solution:

Assume that the p.d. across the capacitor C connected in the middle is V .

Effective p.d. across left branch = $(55 - V) V$

$$\text{Equivalent capacity } C = \frac{2 \times 3}{2+3} = \frac{6}{5} \mu F$$

$$\therefore \text{ charge in } 2 \mu F \text{ capacitor } Q = CV = (55 - V) \times \frac{6}{5}$$

Effective p.d. across $5 \mu F$ capacitor = $(13 + V) V$

$$\text{Equivalent capacity of the right branch} = \frac{5 \times 4}{5+4} = \frac{20}{9} \mu F$$

$$\text{Charge in } 5 \mu F \text{ capacitor} = \frac{20}{9}(13+V)$$

$$\text{Equating the charges in the capacitors, } (55 - V) \times \frac{6}{5} = \frac{20}{9}(13+V) + 4V$$

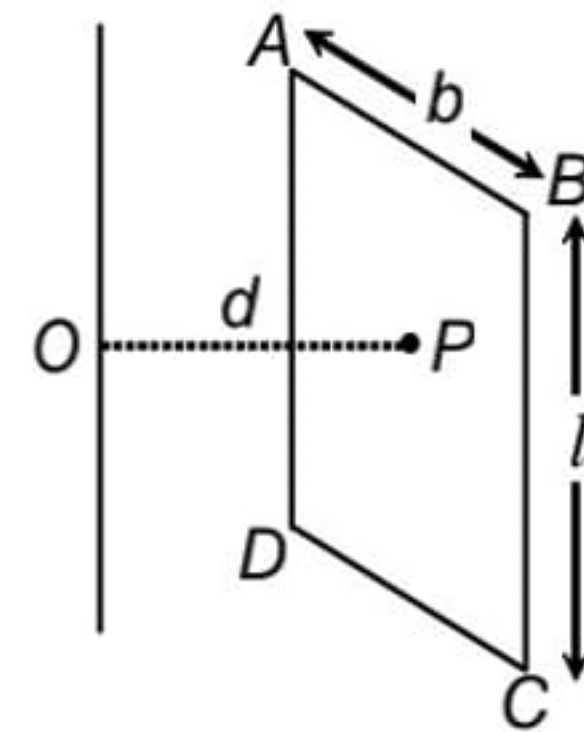
$$\text{i.e., } \frac{20}{9}(13+V) + 4V = \frac{6}{5}(55 - V)$$

$$\frac{260 + 20V + 36V}{9} = \frac{330 - 6V}{5}$$

$$\text{or } 1300 + 100V + 180V = 2970 - 54V \text{ or } 334V = 1670 \text{ or } V = 5$$

$$\text{P.d. across } 3 \mu F \text{ capacitor} = \frac{Q}{C} = (55 - 5) \times \frac{2}{5} = 20 \text{ V}$$

$$\text{P.d. across } 5 \mu F \text{ capacitor} = (13+5) \times \frac{4}{9} = 8 \text{ V}$$



Example 9:

Find the electric flux crossing the wire frame $ABCD$ of length $l = 1\text{m}$ width b and whose center is at a distance $OP = d (= b/2)$ from an infinite line of charge with linear charge density $\lambda = \pi \times 10^{-9} \text{ C/m}$. Consider that the plane of frame is perpendicular to line OP .

Solution:

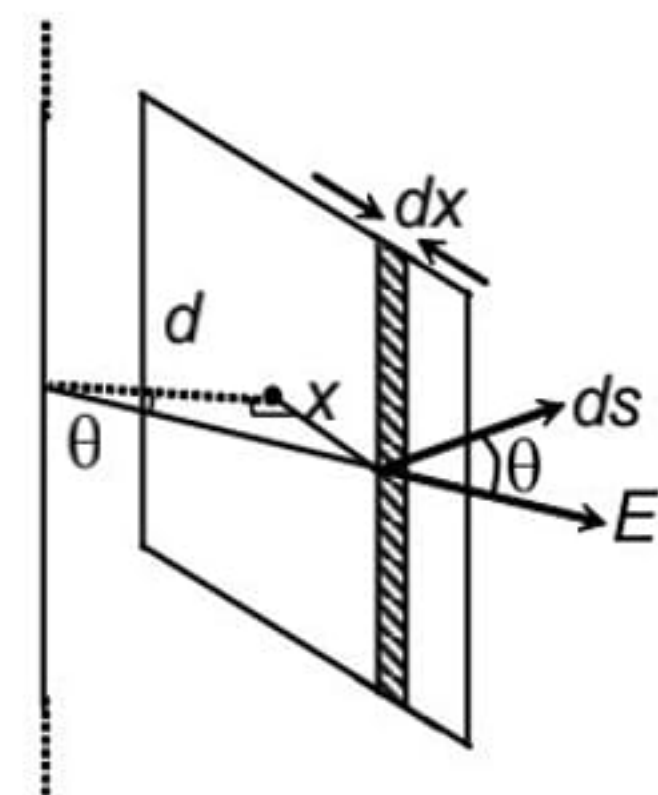
Flux through the element of width dx as shown in figure is

$$\phi = \int \vec{E} \cdot d\vec{s}, \quad E = \frac{\lambda}{2\pi\epsilon_0 d \sec \theta} \text{ and } ds = l dx$$

$$\phi = \int_{-b/2}^{b/2} \frac{\lambda}{2\pi\epsilon_0 d \sec \theta} \cos \theta l dx$$

$$= \frac{\lambda l}{2\pi\epsilon_0 d} \int_{-b/2}^{b/2} \left(\frac{d}{\sqrt{x^2 + d^2}} \right)^2 dx$$

$$= \frac{\lambda l}{\pi\epsilon_0} \tan^{-1} \left(\frac{b}{2d} \right) = 90$$



Example 10:

A capacitor of capacitance $C_1 = 1 \mu\text{F}$ can withstand a maximum voltage of $V_1 = 6\text{ kV}$ and another capacitor of capacitance $C_2 = 2 \mu\text{F}$ can withstand a maximum voltage of $V_2 = 4 \text{ kV}$. If they are connected in series what maximum voltage (in volts) will the system withstand.

Solution:

Maximum charge C_1 can hold, $Q_1 = C_1 V_1 = 1 \times 10^{-6} \times 6 \times 10^3$, $Q_1 = 6 \times 10^{-3} \text{ C}$ and maximum charge C_2 can hold $Q_2 = C_2 V_2 = 2 \times 10^{-6} \times 4 \times 10^3$, $Q_2 = 8 \times 10^{-3} \text{ C}$ when connected in series, both will have equal charges and so each can have charge Q_1 which is smaller of the two.

In this case

Voltage across $C_1 = 6 \text{ kV}$

$$\text{And voltage across } C_2 = \frac{Q_1}{C_2} = \frac{6 \times 10^{-3}}{2 \times 10^{-6}} = 3 \text{ kV}$$

\therefore maximum voltage across the system = $(6 + 3) \text{ kV} = 9000 \text{ V}$

MIND MAP

1. Coulomb's Law

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

where $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$

2. (i) Electric field intensity due to a point charge

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

(ii) Force exerted by an electric field on a charge inside it

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

3. Electric flux through a surface

$$\phi_E = \int \vec{E} \cdot d\vec{S}$$

4. Gauss's law

$$\vec{E} \cdot d\vec{S} = \frac{\sum q}{\epsilon_0}$$

5. Electric field intensity

(i) at a point near an infinite plane sheet of charge

$$E = \frac{\sigma}{2\epsilon_0}$$

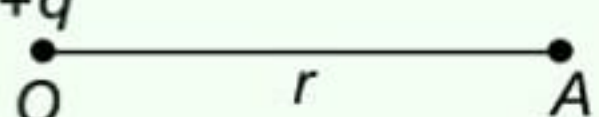
(ii) at a point near an infinite conducting sheet of charge

$$E = \frac{\sigma}{\epsilon_0}$$

ELECTRIC FIELD

MIND MAP

1. (i) **Electric potential at a point due to a point charge**

$$V = \frac{1}{4\pi\epsilon_0} \frac{q}{r}$$


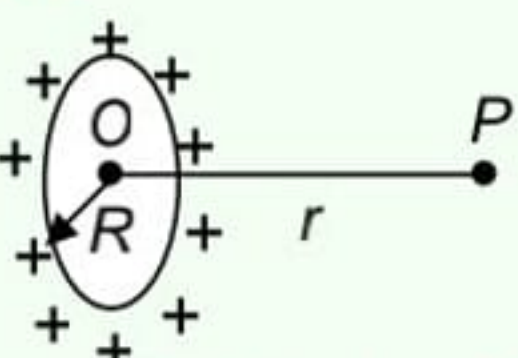
The electric potential at A is positive, if the point charge q is positive and negative if the point charge is negative.

- (ii) **Electric potential** $V = \frac{W_{ext}}{q_0}$

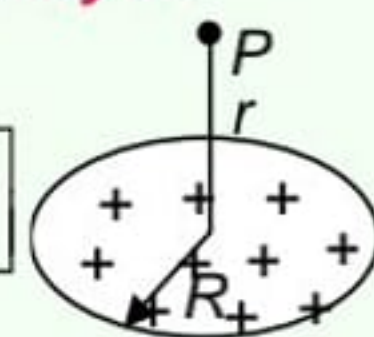
- (iii) The p.d. between two points, A and B, is given by

$$V_B - V_A = - \int_A^B \vec{E} \cdot d\vec{r}$$

2. **Electric potential at an axial point of a uniformly charged ring.**

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{\sqrt{R^2 + r^2}}$$


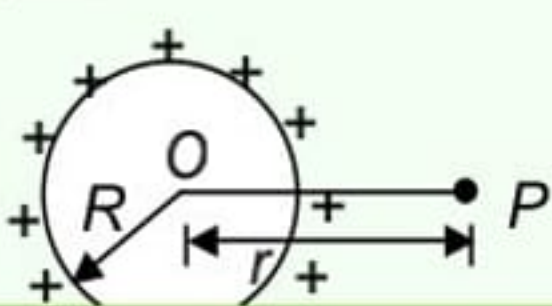
3. **Electric potential at an axial point of a uniformly charged non-conducting disc of surface charge density σ .**

$$V = \frac{\sigma}{2\epsilon_0} \left[\sqrt{R^2 + r^2} - r \right]$$


ELECTRIC POTENTIAL

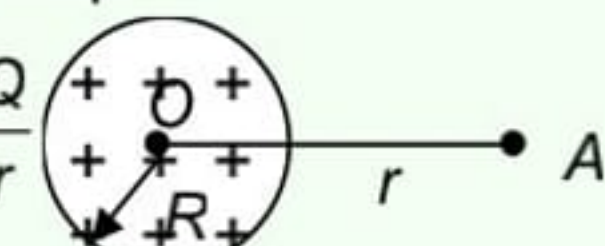
4. **Electric potential due to a uniformly charged spherical shell or conducting sphere at**

- (i) an external point

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$$


5. **Electric potential due to a uniformly charged non-conducting sphere at**

- (i) an external point

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$$


- (ii) an internal point

(iii) an internal point $V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$

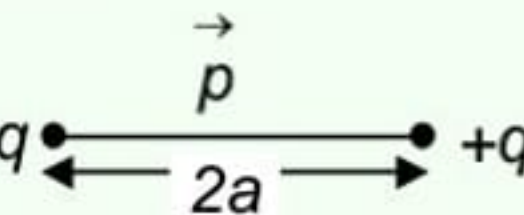
$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$



MIND MAP

1. Electric dipole

When two equal and opposite point charges are placed at a very short distance it forms an electric dipole. The magnitude of electric dipole moment

$$p = q \cdot 2a$$


Electric dipole moment is a vector quantity and is directed along the axis of the dipole from the negative to the positive charge.

3. Dipole in an uniform electric field

(i) Torque on a dipole

$$\vec{\tau} = \vec{p} \times \vec{E}$$

(ii) Potential Energy of a Dipole

$$U = -\vec{p} \cdot \vec{E}$$

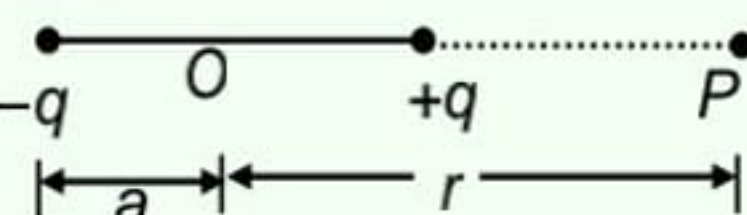
(iii) Work-done by the external agent

$$W_{\text{ext}} = pE [\cos\theta_1 - \cos\theta_2]$$

ELECTRIC DIPOLE

2. Electric potential and electric field due to an electric dipole

(i) End-on position



$$V = \frac{1}{4\pi\epsilon_0} \frac{p}{r^2}$$

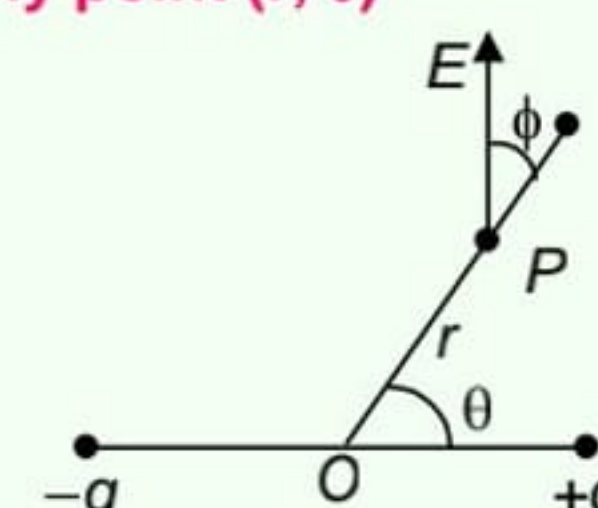
$$E = \frac{1}{4\pi\epsilon_0} \frac{2p}{r^3} \text{ (along } \vec{p} \text{)}$$

(ii) Broad-side-on-position

$$V = 0$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3} \text{ (opposite to } \vec{p} \text{)}$$

4. (iii) At any point (r, θ)



$$V = \frac{1}{4\pi\epsilon_0} \frac{p \cos\theta}{r^2}$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3} \sqrt{1 + 3\cos^2\theta}$$

MIND MAP

1. Capacitance of capacitor, $C = \frac{Q}{V}$

Capacitance of

(a) Parallel plate capacitor, $C = \frac{\epsilon_0 A}{d}$

(b) Spherical capacitor, $C = \frac{4\pi\epsilon_0 ab}{b-a}$

(b) Cylindrical capacitor, $C = \frac{2\pi\epsilon_0 l}{\ln\left(\frac{b}{a}\right)}$

2. Energy stored in a charged capacitor

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

(a) Energy density of charged capacitor

$$U = \frac{1}{2} \epsilon_0 E^2$$

(b) Force between the plates of capacitor

$$F = \frac{1}{2} \frac{q^2}{\epsilon_0 A}$$

CAPACITOR

3. Effect of dielectric

(i) When battery is disconnected

$$C = KC_0$$

$$V = \frac{V_0}{K}$$

$$q = q_0$$

$$E = \frac{E_0}{K}$$

(ii) When battery is connected

$$C = KC_0$$

$$V = V_0$$

$$q = Kq_0$$

$$E = E_0$$

4. Grouping of capacitors

(i) When capacitors are in series

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \dots$$

(ii) When capacitors are in parallel

$$C = C_1 + C_2 + C_3 \dots$$

EXERCISE – I

IIT JEE & NEET-SINGLE CHOICE CORRECT

1. In induction, the charge induced in the near surface of a dielectric is

(a) equal and similar	(b) greater and dissimilar
(c) lesser and dissimilar	(d) equal and dissimilar
2. A soap bubble is given a negative charge. Then its radius

(a) decreases	(b) increases	(c) remains unchanged	(d) will change but the information is insufficient to predict whether it will increase or decrease.
---------------	---------------	-----------------------	--
3. 64 charged drops of capacity C and potential V are put together to form a bigger drop. If each small drop had a charge q , then the charge on bigger drop will be

(a) q	(b) $4q$	(c) $16q$	(d) $64q$
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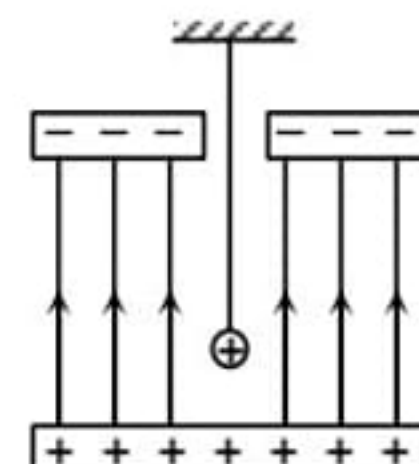
4. Charges $2Q$ and $-Q$ are placed as shown. The point at which electric field intensity is zero will be

(a) somewhere between $-Q$ and $2Q$	(b) somewhere on the left of $-Q$	(c) somewhere on the right of $2Q$	(d) somewhere on the right bisector of line joining $-Q$ and $2Q$
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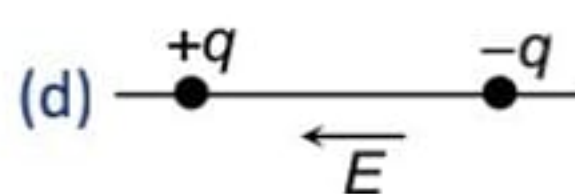
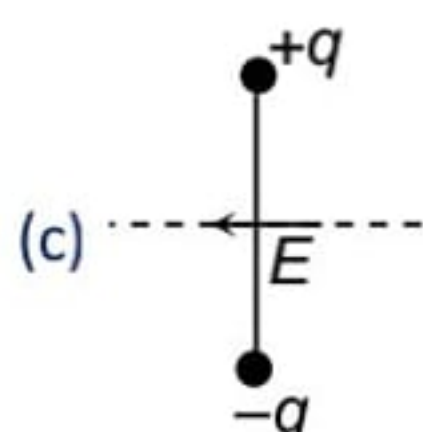
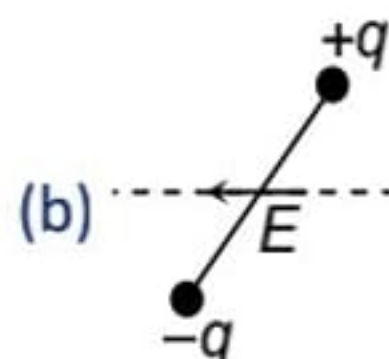
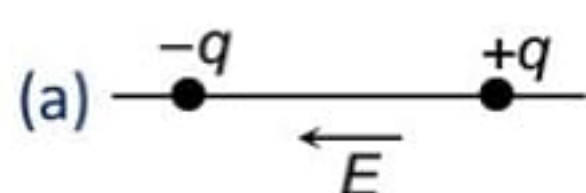


5. A positively charged pendulum is oscillating in a uniform electric field as shown in figure. Its time period as compared to that when it was uncharged

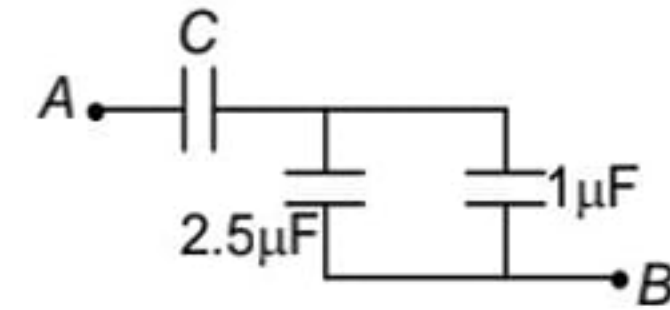
(a) will increase	(b) will decrease
(c) will not change	(d) will first increase then decrease



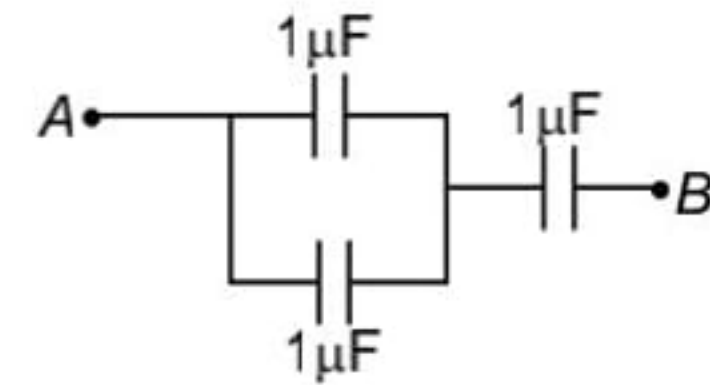
6. In which of the following states is the potential energy of an electric dipole maximum?



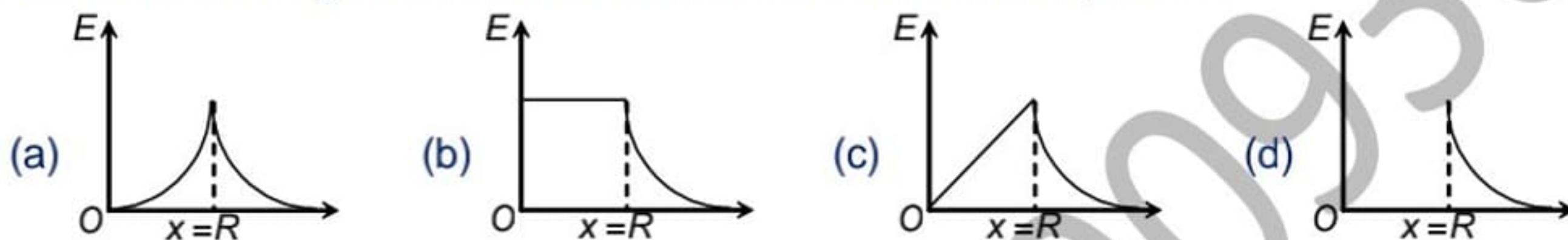
7. The equivalent capacitance between A and B in the figure is $1\mu\text{F}$. Then the value of the capacitance C is
 (a) $1.4\mu\text{F}$ (b) $2.5\mu\text{F}$
 (c) $3.5\mu\text{F}$ (d) $1.2\mu\text{F}$



8. Three capacitors each of $1\mu\text{F}$ are connected as shown. The capacitance between the points A and B is
 (a) $3\mu\text{F}$ (b) $1\mu\text{F}$
 (c) $(2/3)\mu\text{F}$ (d) $(1/3)\mu\text{F}$

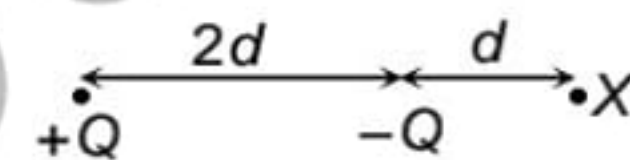


9. A hollow charged sphere of radius R has a constant surface charge density σ . The variation of the electric field strength E with distance x from the centre of the sphere is

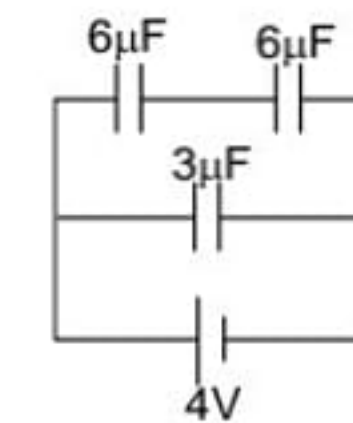


10. In the figure, the potential at X due to the charges $+Q$ and $-Q$ is, using SI units,

- (a) $\frac{-2Q}{9\pi\epsilon_0 d}$ (b) $\frac{-Q}{6\pi\epsilon_0 d}$ (c) $\frac{+3Q}{4\pi\epsilon_0 d}$ (d) $\frac{+Q}{6\pi\epsilon_0 d}$



11. The three capacitors in figure, store a total energy of
 (a) $12\mu\text{J}$ (b) $36\mu\text{J}$
 (c) $48\mu\text{J}$ (d) $80\mu\text{J}$

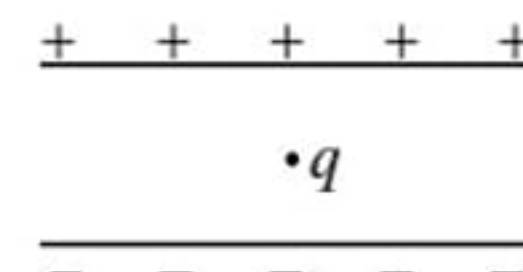


12. Four metallic plates, each having area A , are placed as shown. The distance between the consecutive plates is d . Alternate plates are connected to points A and B . The equivalent capacitance of the system between A and B is
 (a) $\epsilon_0 A/d$ (b) $2\epsilon_0 A/d$ (c) $3\epsilon_0 A/d$ (d) $4\epsilon_0 A/d$

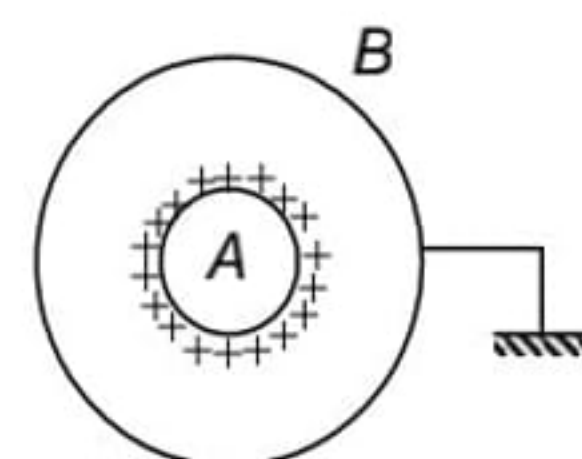


13. A particle of mass m and charge q is placed at rest in a uniform electric field E as shown and released. The kinetic energy it attains after moving a distance y is

- (a) $\frac{1}{2}qEy$ (b) qEy
 (c) qE^2y (d) $\frac{1}{2}m(qEy)$



14. A and B are two concentric spheres. If A is given a charge Q while B is earthed as shown in figure,
 (a) the charge density of A and B are same
 (b) the field inside and outside A is zero
 (c) the field between A and B is not zero
 (d) the field inside and outside B is zero

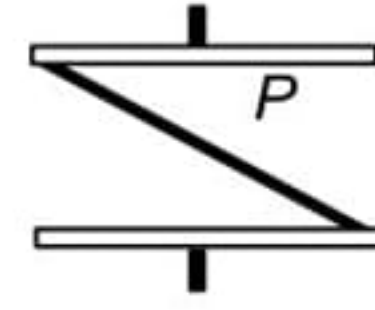


15. A capacitor connected to a 10V battery collects a charge 40 microcoulomb with air as dielectric and 100 microcoulomb with oil as dielectric. The dielectric constant of the oil is

- (a) 4 (b) 2.5
(c) 0.4 (d) 1.0

16. A dielectric slab is inserted between the plates of an isolated capacitor. The force between the plates will (Thickness of slab is less than separation between plates)
(a) increase (b) decrease
(c) remain unchanged (d) become zero

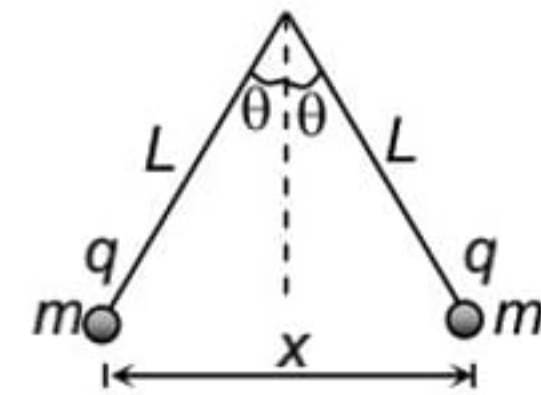
17. A thin metal plate P is inserted between the plates of a parallel-plate capacitor of capacitance C in such a way that its edges touch the two plates (see the figure). The capacitance now becomes
(a) $C/2$ (b) $2C$
(c) 0 (d) ∞



18. Three identical metallic uncharged spheres A , B and C of radius a are kept at the corners of an equilateral triangle of side d ($d \gg a$). The fourth sphere (of radius a) which has a charge q touches A and is then removed to a position far away. B is earthed and then the earth connection is removed. C is then earthed. The charge on C is

- (a) $\frac{qa}{2d} \left(\frac{2d-a}{2d} \right)$ (b) $\frac{qa}{2d} \left(\frac{2d-a}{d} \right)$
(c) $-\frac{qa}{2d} \left(\frac{d-a}{d} \right)$ (d) $\frac{2qa}{d} \left(\frac{d-a}{2d} \right)$

19. Two similar conducting balls of mass m are hung from silk threads of length L and carry similar charges q as shown in the figure. Assuming θ to be small, the distance x between the balls is



- (a) $\left[\frac{q^2 L}{4\pi\epsilon_0 mg} \right]^{1/3}$ (b) $\left[\frac{q^2 L}{2\pi\epsilon_0 mg} \right]^{1/3}$
(c) $\left[\frac{q^2 L}{4\pi\epsilon_0 mg} \right]^{3/2}$ (d) $\left[\frac{q^2 L}{2\pi\epsilon_0 mg} \right]^{1/2}$

20. A charge Q is placed at each of the two opposite corners of a square. A charge q is placed at each of the other two corners. If the resultant force on Q is zero, then

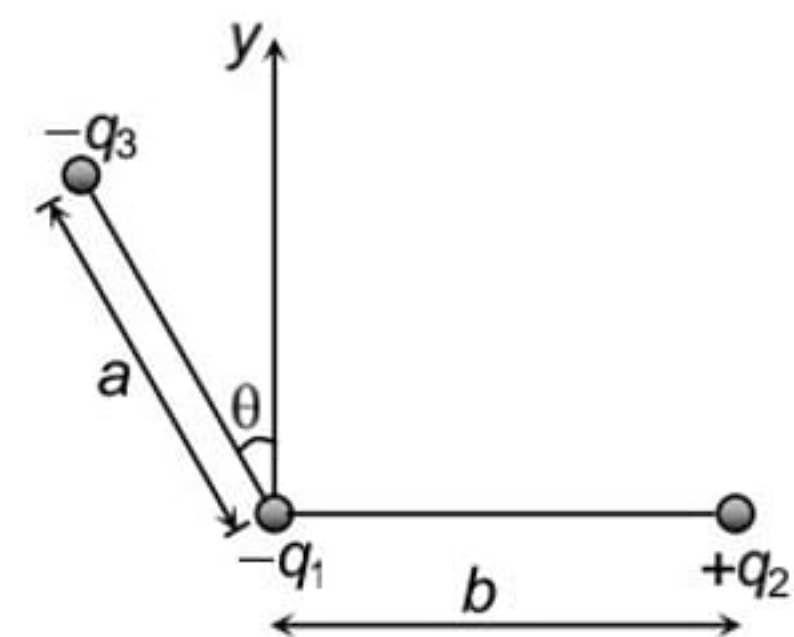
- (a) $Q = \sqrt{2} q$ (b) $Q = -\sqrt{2} q$
(c) $Q = 2\sqrt{2} q$ (d) $Q = -2\sqrt{2} q$

21. If there are n capacitors in parallel connected to V volt source, then the energy stored equal to

- (a) CV (b) $\frac{1}{2} nCV^2$
(c) CV^2 (d) $\frac{1}{2n} CV^2$

22. Three charges $-q_1$, $+q_2$ and $-q_3$ are placed as shown in the figure. The x -component of the force on $-q_1$ is proportional to

- (a) $\frac{q_2}{b^2} + \frac{q_3}{a^2} \sin\theta$ (b) $\frac{q_2}{b^2} + \frac{q_3}{a^2} \cos\theta$
(c) $\frac{q_2}{b^2} - \frac{q_3}{a^2} \sin\theta$ (d) $\frac{q_2}{b^2} - \frac{q_3}{a^2} \cos\theta$



23. If the electric flux entering and leaving an enclosed surface respectively is ϕ_1 and ϕ_2 , electric charge inside the surface will be

(a) $\frac{(\phi_1 + \phi_2)}{\epsilon_0}$

(c) $(\phi_1 + \phi_2)\epsilon_0$

(b) $\frac{(\phi_2 - \phi_1)}{\epsilon_0}$

(d) $(\phi_2 - \phi_1)\epsilon_0$

24. A thin spherical conducting shell of radius R has a charge q . Another charge Q is placed at the centre of the shell. The electrostatic potential at a point P a distance $R/2$ from the centre of the shell is

(a) $\frac{2Q}{4\pi\epsilon_0 R} - \frac{2q}{4\pi\epsilon_0 R}$

(c) $\frac{(q+Q) 2}{4\pi\epsilon_0 R}$

(b) $\frac{2Q}{4\pi\epsilon_0 R} + \frac{q}{4\pi\epsilon_0 R}$

(d) $\frac{2Q}{4\pi\epsilon_0 R}$

25. A charged particle q is shot from infinity towards another charged particle Q , which is fixed, with a speed v . It approaches Q upto a closest distance r and then returns. If q were given a speed of $2v$, the closest distance of approach would be

(a) r

(c) $r/2$

(b) $2r$

(d) $r/4$



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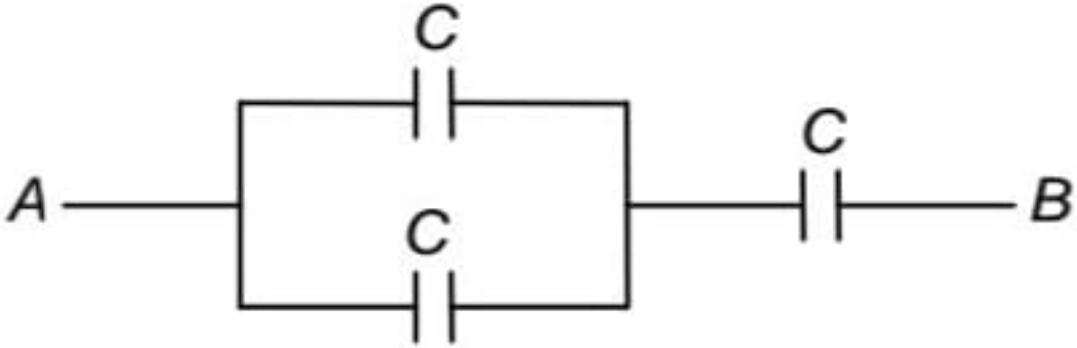
H.NO.400, Near Jain mandir old awas vikas SRE

By : Shammee pundir 9761890930/8979523510

(electrostatics question bank for Jee Main/Neet)

EXERCISE – II

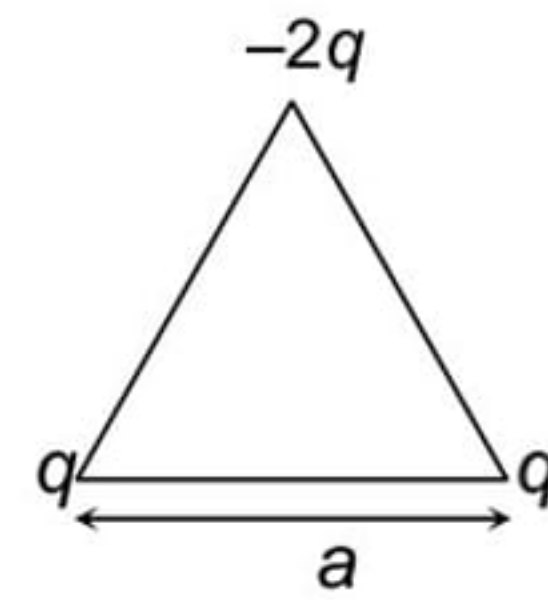
IIT-JEE-SINGLE CHOICE CORRECT

- Two small balls with like charges are suspended by light strings of equal length L from the same point. When taken to a place where they are in a state of weightlessness the separation between the balls will be
(a) $2L$ (b) $\frac{L}{\sqrt{2}}$ (c) $\sqrt{\frac{L(L+1)}{2}}$ (d) $\sqrt{L(L+1)}$
- A particle of mass m and charge q starts moving from rest along a straight line in an electric field $E = E_0 - ax$ where a is a positive constant and x is the distance from starting point. Find the distance travelled by the particle till the moment it came to instantaneous rest
(a) $\frac{2E_0}{a}$ (b) $\frac{E_0}{a}$ (c) $\frac{E_0 q}{m}$ (d) $\frac{E_0}{q}$
- The charge on a drop of water is $3 \times 10^{-8} \text{C}$. If its surface potential is 500 V, its radius must be equal to
(a) 81 cm (b) 54 cm (c) 27 cm (d) 108 cm
- A and B are two thin concentric hollow conductors having radii a and b and charges Q_1 and Q_2 respectively. Given that $a > b$ and P is a point between the two spheres and distance of P from the common centre is r ($b < r < a$). The potential at P is proportional to
(a) $\frac{Q_1 + Q_2}{r}$ (b) $\frac{Q_1}{a} + \frac{Q_2}{r}$ (c) $\frac{Q_1}{a} + \frac{Q_2}{b}$ (d) $\frac{Q_1}{b} + \frac{Q_2}{a}$
- How should 5 capacitors each of value $1 \mu\text{F}$ be connected so as to produce a total capacitance $\frac{3}{7} \mu\text{F}$?
(a) Two capacitors in parallel and the combination in series with other three capacitors
(b) Three capacitors in parallel and the combination in series with other two capacitors
(c) Four capacitors in parallel and combination in series with fifth capacitor
(d) All capacitors in parallel
- In the network shown, we have three identical capacitors. Each of them can withstand a maximum 100 V p.d. What maximum voltage can be applied across A and B so that no capacitor gets spoiled?


- (a) 150 V (b) 120 V
 (c) 180 V (d) 200 V

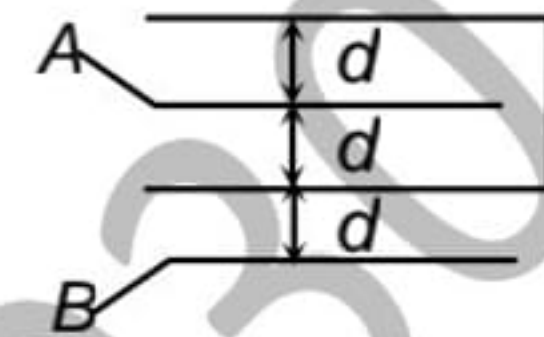
7. Three point charges $q, q, -2q$ are placed on an equilateral triangle of side a . The magnitude of dipole moment of the arrangement is

- (a) $\sqrt{3}qa$ (b) $\frac{\sqrt{3}}{2}qa$
 (c) $2\sqrt{3}qa$ (d) $2qa$



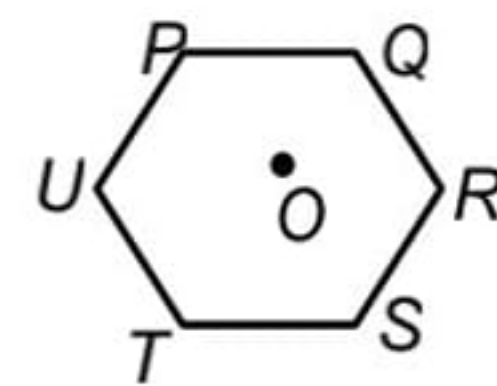
8. Four plates of area A are arranged as shown. The equivalent capacitance between A and B is

- (a) $\frac{2A\epsilon_0}{3d}$ (b) $\frac{3A\epsilon_0}{2d}$
 (c) $\frac{4A\epsilon_0}{3d}$ (d) none



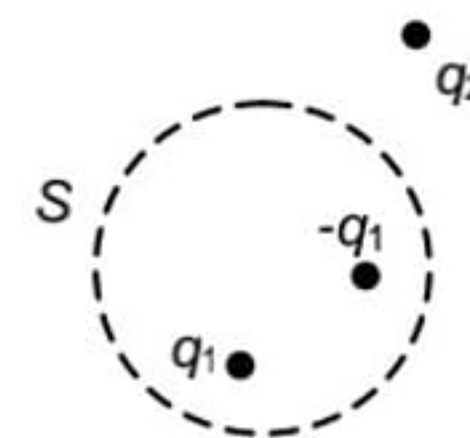
9. Three positive and three negative charges of equal magnitude are placed at the corners of a regular hexagon $PQRSTU$. If electric field at O due to all the charges is twice the field at O due to a positive charge at R only, the order in which the charges are placed at $PQRSTU$ is

- (a) $+ - + - + -$ (b) $- + + + - -$ (c) $+ + + - - -$ (d) $- + + - + -$



10. Three charges $q_1, -q_1$ and q_2 are placed as shown. S is a spherical Gaussian surface. Electric field at any point on S is

- (a) due to q_2 only (b) uniform on all the points
 (c) zero on all the points (d) due to all charges



11. One plate of a capacitor having charge Q , and plate area A , is pulled by a man keeping one plate at fixed position, as shown in figure. What force should be applied by the man such that, plate moves with constant velocity.

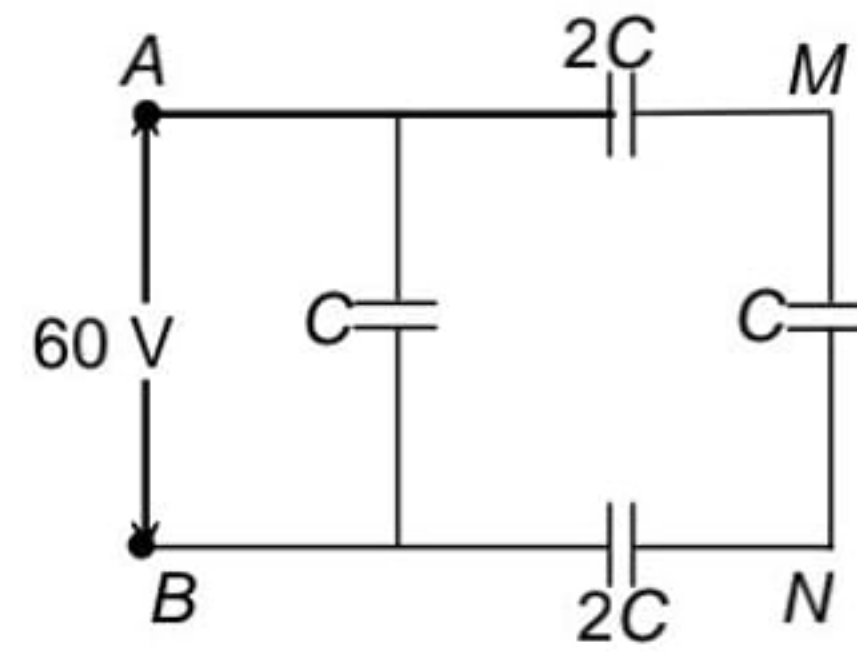
- (a) $\frac{Q^2}{A\epsilon_0}$ (b) $\frac{2}{3} \frac{Q^2}{A\epsilon_0}$ (c) zero (d) $\frac{Q^2}{2\epsilon_0 A}$



12. A particle A has charge $+q$ and particle B has charge $+4q$ with each of them having the same mass m , when allowed to fall from rest through the same electrical potential difference in a gravity free space, the ratio of their speeds v_A / v_B will become

- (a) 1 : 2 (b) 2 : 1 (c) 1 : 4 (d) 4 : 1

13. In the circuit shown, a potential difference of 60 V is applied across AB . The potential difference between the points M and N is
 (a) 10 V (b) 15 V
 (c) 20 V (d) 30 V



14. A conducting sphere of radius 10 cm is charged with $10\mu\text{C}$. Another uncharged sphere of radius 20 cm is allowed to touch it for some time. After that if the spheres are separated, then surface density of charges on the spheres will be in the ratio of
 (a) 1 : 4 (b) 1 : 3 (c) 1 : 2 (d) 1 : 1

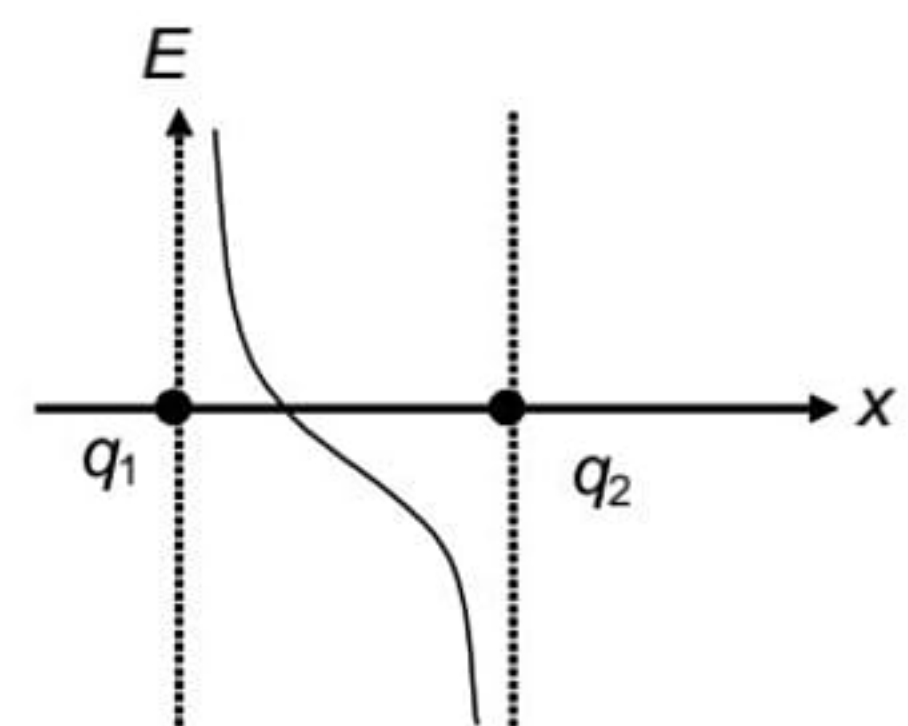
15. Five vertices of a regular hexagon of side L are occupied by five point charges. The value of each point charge is $+q$. Another point charge $-q$ is placed at the centre of the hexagon. What is the magnitude of the force on $-q$ due to all the charges placed at the vertices of hexagon?

- (a) $\frac{q^2}{4\sqrt{3}\pi\epsilon_0 L^2}$ (b) $\frac{\sqrt{3}q^2}{4\pi\epsilon_0 L^2}$ (c) zero (d) $\frac{q^2}{4\pi\epsilon_0 L^2}$

16. A, B, C, D corners of a square are occupied by $q, -q, 2Q$ and Q charges respectively. The side of square is $2a$. The field at the mid point of side CD is zero. What is the value of $\frac{q}{Q}$?

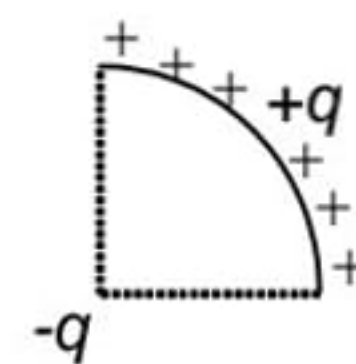
- (a) $\frac{5\sqrt{5}}{2}$ (b) $\frac{2\sqrt{2}}{5}$ (c) $\frac{2}{5}$ (d) $\frac{5}{2}$

17. The variation of electric field between the two charges q_1 and q_2 along the line joining the charges is plotted against distance from q_1 (taking rightward direction of electric field as positive) as shown in the figure. Then the correct statement is



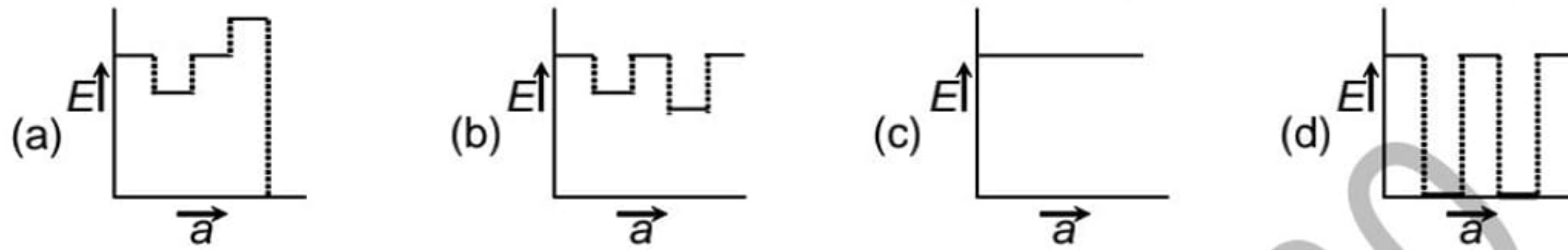
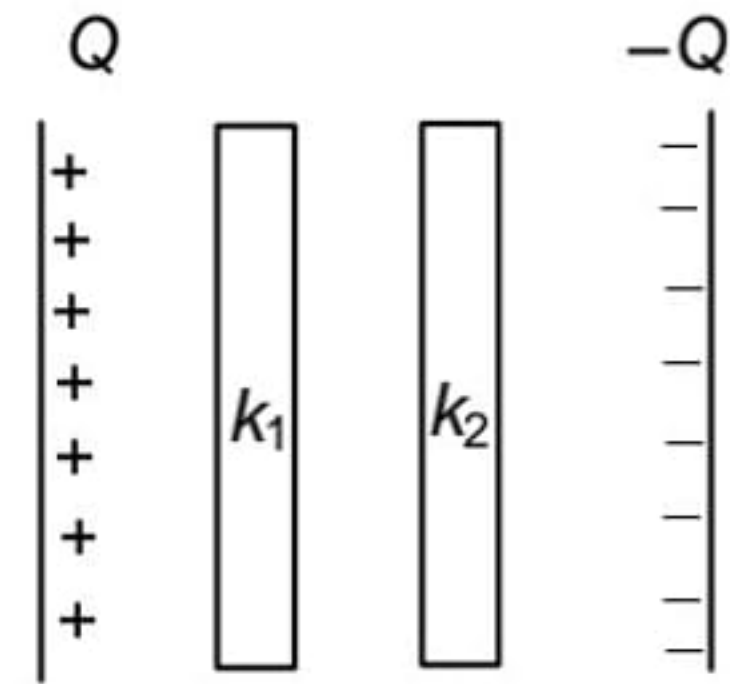
- (a) q_1 and q_2 are positive charge and $q_1 < q_2$
 (b) q_1 and q_2 are positive charges and $q_1 > q_2$
 (c) q_1 and q_2 are negative charges and $q_1 < q_2$
 (d) q_1 and q_2 are negative charges and $q_1 > q_2$

18. Charge q is distributed uniformly on an arc of radius R subtending an angle $\pi/2$ at its centre. Another charge $-q$ is placed at the centre of the arc. The electric dipole moment of the system is



- (a) $\frac{2\sqrt{2}qR}{\pi}$ (b) $\frac{\sqrt{2}qR}{\pi}$ (c) $\frac{qR}{\pi}$ (d) $\frac{2qR}{\pi}$

19. Two thin different dielectrics are inserted between a parallel plate capacitor. Then electric field verses separation graph is ($k_1 < k_2$)



20. A uniform rod of length l and mass m charged with a charge q is hanging from one of its ends as shown in figure. At $t = 0$ a horizontal electric field E is switched on in the horizontal direction perpendicular to the rod. Find the minimum value of E so that the rod rotates upto horizontal level.

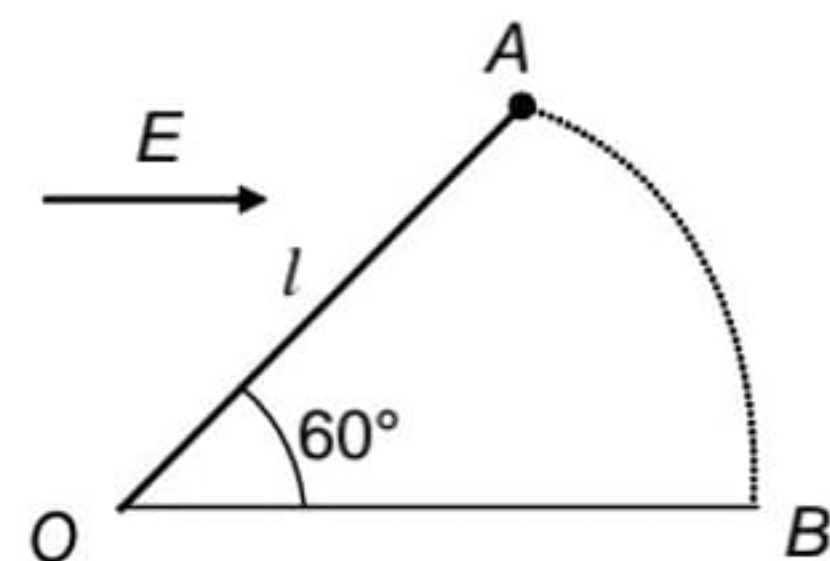


- (a) $\frac{2mg}{q}$ (b) $\frac{mg}{q}$ (c) $\frac{mg}{2q}$ (d) none

ONE OR MORE THAN ONE CHOICE CORRECT

1. Which statement(s) is/are correct?
 (a) Electric field at the equatorial point on a dipole will be anti parallel to the dipole moment.
 (b) Electric field lines begin from (+q) charge and terminate in (-q) charge.
 (c) Electric field lines intersect at only one point
 (d) Charge is always associated with mass

2. A particle of mass m and charge q is fastened to one end of a string of length l . The other end of the string is fixed to the point O . The whole system lies on a frictionless horizontal plane. Initially, the mass is at rest at A . A uniform electric field in the direction shown is then switched on. Then

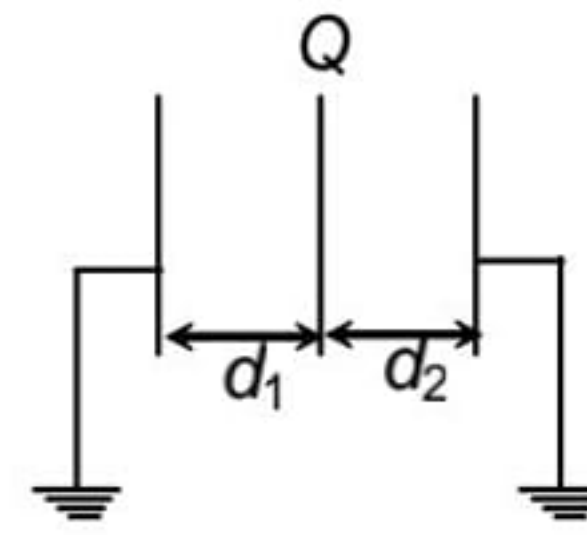


- (a) the speed of the particle when it reaches B is $\sqrt{\frac{2qEl}{m}}$
 (b) the speed of the particle when it reaches B is $\sqrt{\frac{qEl}{m}}$
 (c) the tension in the string when particles reaches at B is $2qE$
 (d) the tension in the string when the particle reaches at B is zero

3. A capacitor C is charged to a potential V by a battery. The emf of the battery is V . It is then disconnected from the battery and again connected with its polarity reversed to the battery.
 (a) the work done by the battery is $2CV^2$
 (b) The total charge that passes through battery is $2 CV$.

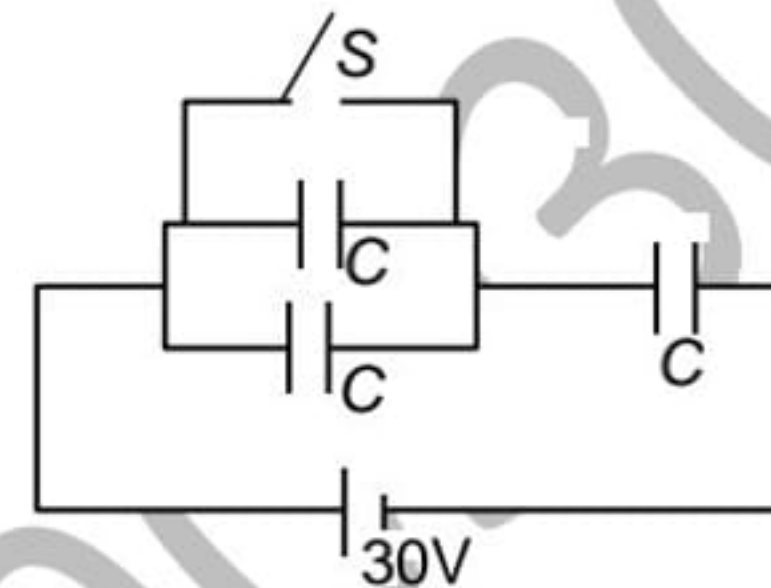
- (c) The initial energy of the capacitor is greater than the final energy of the capacitor
 (d) The heat generated in the circuit is $2CV^2$

4. Three identical metallic plates are placed at a separation of d_1 and d_2 as shown in figure. A charge Q is given to middle plate which is free to move, then



- (a) it will slide towards left if $d_2 > d_1$
 (b) it will slide towards right if $d_2 < d_1$
 (c) it will remain in equilibrium if $d_1 = d_2$
 (d) it will remain in equilibrium in all the cases

5. Three capacitors each having capacitance $C = 2\mu\text{F}$ are connected to battery of emf 30 V as shown in the figure. When the switch is closed.



- (a) the amount of charge flow through the battery is $20\mu\text{C}$
 (b) heat generated in the circuit is 0.6 mJ
 (c) work done by the battery is 0.6 mJ
 (d) the charge flow through the switch is $60\mu\text{C}$

6. Three charged particles are in equilibrium under their electrostatic force only. Then choose the correct statements

- (a) the particles must be collinear
 (b) all charges cannot have same magnitude
 (c) all charges cannot have same nature
 (d) the equilibrium is unstable

7. Charges Q_1 and Q_2 are inside and outside respectively of a closed surface S . Let E be the field at any point on S and ϕ be the flux of E over S . Then choose the correct statements

- (a) if Q_1 changes, both E and ϕ will change
 (b) if Q_2 changes, E will change but ϕ will not change
 (c) if $Q_1 = 0$ and $Q_2 = 0$, then $E \neq 0$ but $\phi = 0$
 (d) if $Q_1 = 0$ and $Q_2 = 0$, then $E = 0$ and $\phi = 0$

8. Two point charges $+q$ and $-q$ are held fixed at $(-d, 0)$ and $(d, 0)$ respectively of a (x, y) co-ordinate system, then:

- (a) The electric field \vec{E} at all points on the x -axis has the same direction.
 (b) \vec{E} at all points on the y -axis is parallel to x -axis
 (c) Work has to be done in bringing a test charge from infinity to the origin
 (d) The dipole moment is $2qd$ directed along $-ve$ x -axis.

9. A parallel plate capacitor of plate area A and plate separation d is charged to potential difference V and then the battery is disconnected. A slab of dielectric constant K is then inserted between the plates of the capacitor so as to fill the space between the plates. If Q , E and W denote respectively, the magnitude of charge on each plate, the electric field between the plates (after the slab is inserted) and work done on the system, in the process of inserting the slab, then

$$(a) Q = \frac{\epsilon_0 AV}{d}$$

$$(b) Q = \frac{\epsilon_0 KAV}{d}$$

$$(c) E = \frac{V}{Kd}$$

$$(d) W = \frac{\epsilon_0 AV^2}{2d} \left[1 - \frac{1}{K} \right]$$

10. An elliptical cavity is carved within a perfect conductor. A positive charge q is placed at the centre of the cavity. The points A and B are on the cavity surface as shown in the figure. Then
- electric field near A in the cavity = electric field near B in the cavity.
 - charge density at A = charge density at B
 - potential at A = potential at B
 - total electric field flux through the surface of the cavity is q/ϵ_0 .

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For Physics

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(electrostatics question bank for Jee Main/Neet)

EXERCISE -III

MATCH THE FOLLOWING

Note: Each statement in column – I has one or more than one match in column –II.

1. A parallel plate capacitor with air between its plates is charged using a battery and then disconnected from the battery.

Column – I	Column -II
I. Potential difference between the plates will decrease if	A. Separation between the plates is increased to $K/2$ times the initial value and space between the plates after the separation has increased, is completely filled with a dielectric (here K is the dielectric constant)
II. Electric field strength between the plates will reduce if	B. Separation between the plates is increased
III. Electric energy stored in the capacitor will decrease if	C. A dielectric with $K > 1$ is filled between the plates of capacitor.
IV. Electric energy density will decrease if	D. Separation between the plates is reduced E. Area of the plates is increased

REASONING TYPE

Directions: Read the following questions and choose

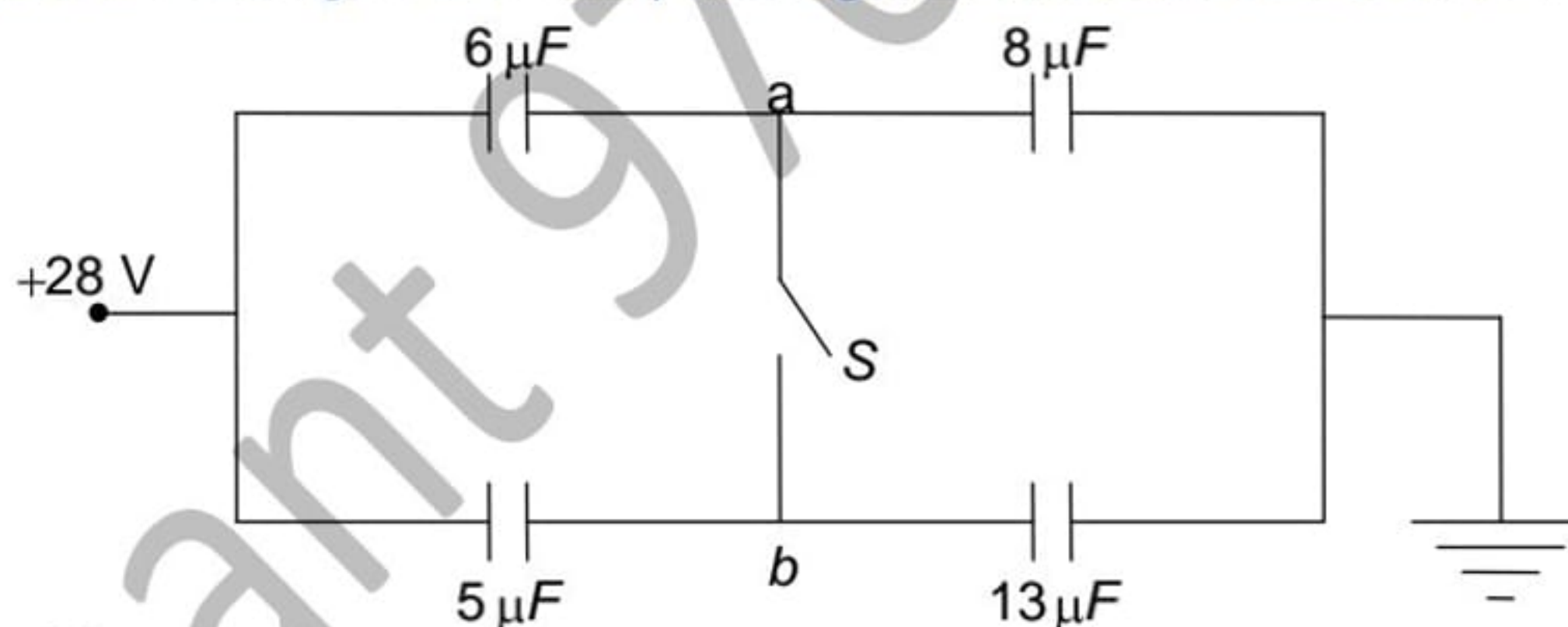
- If both the statements are true and statement-2 is the correct explanation of statement-1.
- If both the statements are true but statement-2 is not the correct explanation of statement-1.
- If statement-1 is True and statement-2 is False.
- If statement-1 is False and statement-2 is True.

1. **Statement-1:** A positively charged particle always moves along an electric line of force.
Statement-2: Force on a charged particle is tangential to electric line of force.
- (a) (A) (b) (B) (c) (C) (d) (D)

2. **Statement-1:** If the electric field intensity \vec{E} is zero at a point, then electric potential should be necessarily zero at that point (assuming potential is zero at infinity)
Statement-2: Electric field is zero at a point exactly midway between two equal and similar charge.
 (a) (A) (b) (B) (c) (C) (d) (D)
3. **Statement-1:** Electric field is discontinuous across the surface of a charged conductor.
Statement-2: Electric potential is constant on the surface of conductor.
 (a) (A) (b) (B) (c) (C) (d) (D)
4. **Statement-1:** Work done by the electrostatic field on charge moving on circular or elliptical path will be zero.
Statement-2: electrostatic field is a conservative field.
 (a) (A) (b) (B) (c) (C) (d) (D)
5. **Statement-1:** Electric lines of forces are perpendicular to equipotential surface.
Statement-2: Work done by electric field on moving a positive charge on equipotential surface is always zero.
 (a) (A) (b) (B) (c) (C) (d) (D)

LINKED COMPREHENSION TYPE

The capacitors in the figure are initially uncharged and are connected as shown.



1. What is the potential difference V_{ab} ?
 (a) 4.2 V (b) 5.2 V
 (c) 6.2 V (d) 7.2 V
2. Now the key S is closed. What is the potential of point a?
 (a) 9.2 V (b) 9.4 V
 (c) 9.6 V (d) 7.8 V
3. How much charge flowed through the switch when it was closed?
 (a) 3.36 μ C (b) 33.6 μ C
 (c) 336 μ C (d) 0.336 μ C

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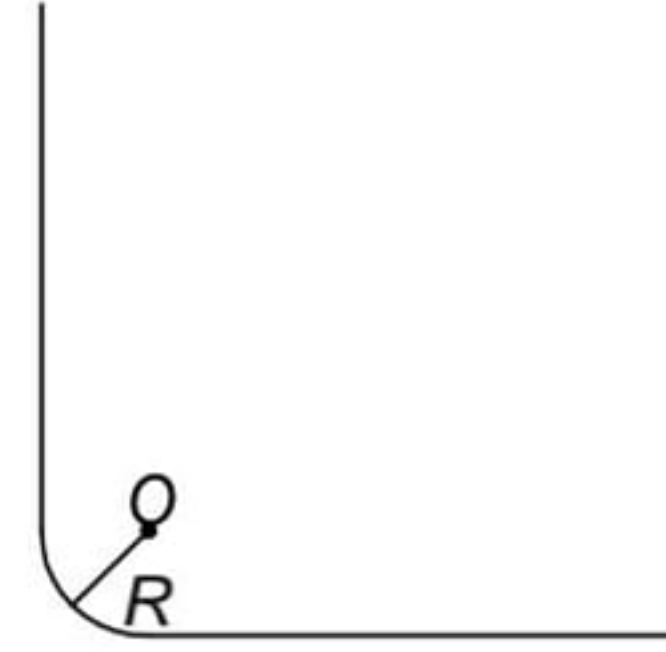
(electrostatics question bank for Jee Main/Neet)

EXERCISE – IV

SUBJECTIVE PROBLEMS

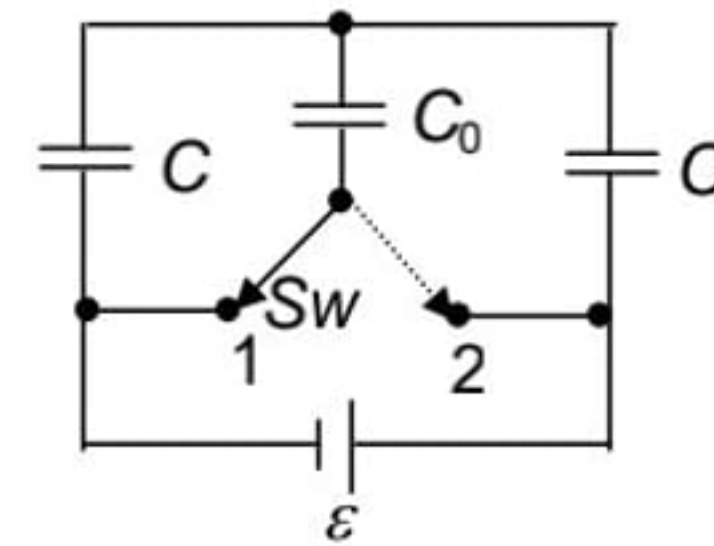
- Two charges $500 \mu\text{C}$ each are at a distance r from each other. A third charge q is placed on the line joining the above two charges such that all the three charges are in equilibrium. What is the magnitude (in μC) of charge q ?
- Two uniformly charged large plane sheets S_1 and S_2 having charge densities σ_1 and σ_2 ($\sigma_1 > \sigma_2$) are placed at a distance d parallel to each other. A charge q_0 is moved along a line of length a ($a < d$) at an angle 45° with the normal to S_1 . Calculate the work done (in Joule) by the electric field. (take $\sigma_1 - \sigma_2 = 4\sqrt{2}$ and $q_0 = \epsilon_0, a = 1$ unit)
- A particle having a charge 1.6×10^{-19} C enters midway between the plates of a parallel plate condenser. The initial velocity of the particle is parallel to the plane of the plates. A potential difference of 300 V is applied to the capacitor plates. If the length of the plates be 10 cm and the plates are separated by a distance of 2 cm, calculate the greatest initial velocity (in km/s) for which the particle will not be able to come out of the capacitor plates. The mass of the charged particle is 12×10^{-24} kg.
- Two spherical bobs of same mass and radius having equal charges are suspended from the same point by strings of same length. The bobs are immersed in a liquid of relative permittivity ϵ_r and density ρ_0 . Find the density σ of the bob (kg/m^3) for which the angle of divergence of the strings to be the same in the air and in the liquid? (Take $\rho_0 = 200 \text{ kg/m}^3, \epsilon_r = 5$)

5. A thread carrying a uniform charge $\lambda = 10^{-7} \text{ C/m}$ has the configuration shown in figure. Assuming the curvature radius $R = \sqrt{2} \text{ m}$ to be considerably less than the length of the thread, find the magnitude of the electric field strength at the point O . (in N/C)



6. Find the energy stored (in J) in the electric field produced by a metal sphere of radius 1m containing a charge of $100 \mu\text{C}$.
7. An isolated conductor initially free from charge is charged by repeated contacts with a plate which after each contact is replenished to a charge $100 \mu\text{C}$ from an electrophorus. If $20 \mu\text{C}$ is the charge on the conductor after the first operation, find the maximum charge (in μC) which can be given to the conductor.
8. A parallel plate capacitor has a capacity $C = 200 \mu\text{F}$. The gap between the plates is completely filled with a glass plate of dielectric constant $K = 6$. The system is connected across a d.c voltage source $E = 100 \text{ V}$. Find the amount of mechanical work done in removing the dielectric plate, battery still connected.

9. What amount of heat will be generated in the circuit shown in figure after the switch Sw is shifted from position 1 to position 2?
Given $C = 1\text{F}$, $C_0 = 4\text{F}$ and $\varepsilon = 12\text{V}$



10. Three concentric, conducting spherical shells A , B and C have radii $a = 10 \text{ cm}$, $b = 20 \text{ cm}$ and $c = 30 \text{ cm}$ respectively. The innermost shell A is earthed and charge $q_2 = 4 \mu\text{C}$ and $q_3 = 3 \mu\text{C}$ are given to shells B and C respectively. Calculate energy (in mJ) stored in the system.

ANSWERS

EXERCISE – I

IIT JEE & NEET-SINGLE CHOICE CORRECT

1. (c)	2. (b)	3. (d)	4. (b)	5. (a)
6. (a)	7. (a)	8. (c)	9. (d)	10. (b)
11. (c)	12. (c)	13. (b)	14. (c)	15. (b)
16. (c)	17. (d)	18. (c)	19. (b)	20. (d)
21. (b)	22. (a)	23. (d)	24. (b)	25. (d)

EXERCISE – II

IIT-JEE-SINGLE CHOICE CORRECT

1. (a)	2. (a)	3. (b)	4. (b)	5. (b)
6. (a)	7. (a)	8. (a)	9. (d)	10. (d)
11. (d)	12. (a)	13. (d)	14. (c)	15. (d)
16. (a)	17. (a)	18. (a)	19. (b)	20. (b)

ONE OR MORE THAN CHOICE CORRECT

1. (a,b,d)	2. (b,c)	3. (a,b,d)	4. (a,b,c)	5. (a,c,d)
6. (a,b,c,d)	7. (a,b,d)	8. (b, d)	9. (a,c,d)	10. (c,d)

EXERCISE – III

MATCH THE FOLLOWING

1. I – A, C, D, E; II – A, C, E; III – A, D, C, E; IV – A, C, E

ASSERTION AND REASON

1. (d)	2. (d)	3. (b)	4. (a)	5. (a)
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PASSAGE BASED PROBLEMS

1. (a)

2. (c)

3. (b)

EXERCISE – IV

1. 125
2. 2
3. 10
4. 250
5. 900
6. 45 J
7. 25
8. 5 J
9. 96 J
10. 450

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(ELECTROSTATICS)

IMPORTANT PRACTICE QUESTION SERIES FOR IIT-JEE EXAM - 1

- Q.1** The capacitance of a metallic sphere will be $1\mu\text{F}$, if its radius is nearly-
- (1) 9 km (2) 10 m
(3) 1.11 m (4) 1.11 cm
- Q.2** The energy of a charged conductor is given by the expression-
- (1) $\frac{q^2}{2C}$ (2) $\frac{q^2}{C}$ (3) $2qC$ (4) $\frac{q^2}{2C^2}$
- Q.3** No current flows between two charged bodies connected together when they have the same-
- (1) capacitance or Q/V ratio
(2) charge
(3) resistance
(4) potential or Q/C ratio
- Q.4** Two spherical conductors A and B of radii R and $2R$ respectively are each given a charge Q . When they are connected by a metallic wire. The charge will-
- (1) flow from A to B
(2) flow from B to A
(3) remain stationary on conductor
(4) none of these
- Q.5** The potential energy of a charged conductor of charge (q) and potential (V) is given by-
- (1) $\frac{1}{2} qV$ (2) $\frac{1}{2} q^2V$
(3) $\frac{1}{2} \frac{q}{V}$ (4) $\frac{1}{2} qV^2$
- Q.6** A conductor of capacitance $0.5\mu\text{F}$ has been charged to 100 volts. It is now connected to uncharged conductor of capacitance $0.2\mu\text{F}$. The loss in potential energy is nearly -
- (1) $7 \times 10^{-4} \text{ J}$ (2) $3.5 \times 10^{-4} \text{ J}$
(3) $14 \times 10^{-4} \text{ J}$ (4) $7 \times 10^{-3} \text{ J}$
- Q.7** Two spherical conductors of capacitance $3.0\mu\text{F}$ and $5.0\mu\text{F}$ are charged to potentials of 300 volt and 500 volt. The two are connected resulting in redistribution of charges. Then the final potential is -
- (1) 300 volt (2) 500 volt
(3) 425 volt (4) 400 volt

- Q.8** N drops of mercury of equal radii and possessing equal charges combine to form a big spherical drop. Then the capacitance of the bigger drop compared to each individual drop is-
- (1) N times (2) $N^{2/3}$ times
 (3) $N^{1/3}$ times (4) $N^{5/3}$ times
- Q.9** The capacity of a parallel plate condenser is C. Its capacity when the separation between the plates is halved will be-
- (1) 4C (2) 2C (3) C/2 (4) C/4
- Q.10** A parallel plate condenser has a capacitance $50\mu\text{F}$ in air and $110\mu\text{F}$, when immersed in an oil. The dielectric constant K of the oil is-
- (1) 0.45 (2) 0.55 (3) 1.10 (4) 2.20
- Q.11** The capacity of a parallel plate condenser is $5\mu\text{F}$. When glass plate is placed between the plates of the conductor, its potential becomes 1/8th of the original value. The value of dielectric constant will be -
- (1) 1.6 (2) 5 (3) 8 (4) 40
- Q.12** If the p.d. across the ends of a capacitor $4\mu\text{F}$ is 1.0 kilovolt. Then its electrical potential energy will be-
- (1) 4×10^{-3} erg (2) 2 erg
 (3) 2 joule (4) 4 joule
- Q.13** A $6\mu\text{F}$ capacitor charged from 10 volts to 20 volts. Increase in energy will be -
- (1) 18×10^{-4} J (2) 9×10^{-4} J
 (3) 4.5×10^{-4} J (4) 9×10^{-9} J
- Q.14** The energy of a charged capacitor resides in -
- (1) the electric field only
 (2) the magnetic field only
 (3) both the electric and magnetic field
 (4) neither in electric nor magnetic field
- Q.15** The capacity and the energy stored in a parallel plate condenser with air between its plates are respectively C_0 and W_0 . If the air is replaced by glass (dielectric constant = 5) between the plates, the capacity of the plates and the energy stored in it will respectively be -
- (1) $5C_0, 5W_0$ (2) $5C_0, \frac{W_0}{5}$
 (3) $\frac{C_0}{5}, 5W_0$ (4) $\frac{C_0}{5}, \frac{W_0}{5}$
- Q.16** By inserting a plate of dielectric material between the plates of a parallel plate capacitor, the energy is increased five times. The dielectric constant of the material is -
- (1) 1/25 (2) 1/5 (3) 5 (4) 25
- Q.17** A capacitor of capacity C has charge Q and stored energy is W. If the charge is increased to 2Q the stored energy will be -
- (1) 2W (2) W/2 (3) 4W (4) W/4
- Q.18** A glass slab is put with in the plates of a charged parallel plate condenser. Which of the following quantities does not change?
- (1) energy of the condenser
 (2) capacity
 (3) intensity of electric field
 (4) charge
- Q.19** A parallel plate capacitor is connected to a battery and inserted a dielectric plate between the place of plates then which quantity increase-
- (1) potential difference
 (2) electric field
 (3) stored energy

(4) E . M . F of battery

- Q.20** A parallel plate capacitor is connected to a battery and decreased the distance between the plates then which quantity is same on the parallel plate capacitor-
- (1) potential difference
 - (2) capacitance
 - (3) intensity of electric field
 - (4) stored energy
- Q.21** A parallel plate capacitor is charged by a battery after charging the capacitor , battery is disconnected. And if a dielectric plate is inserted between the place of plates. Then which one of the following statements is not correct-
- (1) increase in the stored energy
 - (2) decrease in the potential difference
 - (3) decrease in the electric field
 - (4) increase in the capacitance
- Q.22** A parallel plate capacitor has a capacity C. The separation between plates is doubled and a dielectric medium is inserted between plates. The new capacity is 3C. The dielectric constant of medium is-
- (1) 1.5 (2) 3.0 (3) 6.0 (4) 12.0
- Q.23** A parallel plate capacitor is charged by a battery after charging the capacitor, battery is disconnected and decrease the distance between the plates then which following statement is correct ?
- (1) electric field is not constant
 - (2) potential difference is increased
 - (3) decrease the capacitance
 - (4) decrease the stored energy
- Q.24** The capacitance of a parallel plate condenser does not depend upon-
- (1) the distance between the plates
 - (2) area of the plates
 - (3) medium between the plates
 - (4) metal of the plates
- Q.25** A metallic plate of thickness (t) and face area of one side (A) is inserted between the plates of a parallel plate air capacitor with a separation (d) and face are (A). Then the equivalent capacitance is -
- (1) $\frac{\epsilon_0 A}{d}$ (2) $\frac{\epsilon_0 A}{(d \times t)}$
(3) $\frac{\epsilon_0 A}{(d - t)}$ (4) $\frac{\epsilon_0 A}{(d + t)}$
- Q.26** An air capacitor of $1\mu\mu\text{F}$ is immersed in a transformer oil of dielectric constant 3. The capacitance of the oil capacitor is-
- (1) $1\mu\mu\text{F}$ (2) $\frac{1}{3}\mu\mu\text{F}$
(3) $3\mu\mu\text{F}$ (4) $2\mu\mu\text{F}$
- Q.27** Two metal plates form a parallel plate condenser. The distance between the plates in d. Now a metal plate of thickness $d/2$ and of same area is inserted completely between the plates, the capacitance -
- (1) remains unchanged
 - (2) is doubled
 - (3) is halved
 - (4) reduced to one fourth

- Q.28** The capacity of a parallel plate capacitor with air as medium is $2\mu\text{F}$. After inserting a sheet of mica of equal air thickness, it becomes $5\mu\text{F}$. The dielectric constant of mica is -
 (1) 0.1 (2) 0.4
 (3) 2.5 (4) 10
- Q.29** A parallel plate capacitor has rectangular plates of 400 cm^2 and are separated by a distance of 2 mm with air as medium. What charge will appear on the plates. If a 200 volt potential difference is applied across the condenser?
 (1) $3.54 \times 10^{-6}\text{ C}$ (2) $3.54 \times 10^{-8}\text{ C}$
 (3) $3.54 \times 10^{-10}\text{ C}$ (4) $1770.8 \times 10^{-13}\text{ C}$
- Q.30** A parallel plate condenser is immersed in an oil of dielectric constant 2. The field between the plates is-
 (1) increased proportional to 2.
 (2) decreased proportional to $1/2$
 (3) increased proportional to $\sqrt{2}$
 (4) decreased proportional to $1/\sqrt{2}$
- Q.31** A parallel plate capacitor consists of two plates of $2\text{ m} \times 1\text{ m}$. The space between the plates is of 1 mm and filled with a dielectric of relative permittivity of 7. A potential difference of 300 V is applied across the plates. Find the potential gradient -
 (1) $6 \times 10^5\text{ N/C}$ (2) $3 \times 10^5\text{ N/C}$
 (3) $18 \times 10^5\text{ N/C}$ (4) $12 \times 10^5\text{ N/C}$
- Q.32** Two conductors insulated from each other, charged by transferring electrons from one conductor to the other. After 25×10^{12} electrons have been transferred. The potential difference between the conductors is found to be 16 V . The capacitance of the system is-
 (1) $25\mu\text{F}$ (2) $.25\mu\text{F}$
 (3) 25 nF (4) 25 PF
- Q.33** The energy density in a parallel plate capacitor is given as $2.2 \times 10^{-10}\text{ J/m}^3$. The value of the electric field in the region between the plates is-
 (1) 7 NC^{-1} (2) 3.6 NC^{-1}
 (3) 72 NC^{-1} (4) 8.4 NC^{-1}
- Q.34** If a $10\mu\text{F}$ capacitor is to have an energy content of 1 Joule . It must be placed across a p.d. of (in volts)-
 (1) 900 (2) 450×10^8 (3) 200 (4) 450
- Q.35** A capacitor of capacitance $\frac{1}{3}\mu\text{F}$ is connected to a battery of 300 volt and charged. Then the energy stored in capacitor is-
 (1) $3 \times 10^{-2}\text{ joule}$ (2) $1.5 \times 10^{-2}\text{ joule}$
 (3) $6 \times 10^2\text{ joule}$ (4) $12 \times 10^2\text{ joule}$
- Q.36** The two parallel plates of a condenser have been connected to a battery of 300 V and the charge collected at each plate is $1\mu\text{C}$. The energy supplied by battery is -
 (1) $6 \times 10^{-4}\text{ J}$ (2) $3 \times 10^{-4}\text{ J}$
 (3) $1.5 \times 10^{-4}\text{ J}$ (4) $4.5 \times 10^{-4}\text{ J}$
- Q.37** The plates of a parallel plate capacitor are charged with a battery so that the plates of the capacitor have acquired the P.D. equal to e.m.f of the battery. The ratio of the work done by the battery and the energy stored in capacitor is-
 (1) 2 : 1 (2) 1 : 1 (3) 1 : 2 (4) 1 : 4
- Q.38** A parallel plate condenser has plates of area 200 cm^2 and separation 0.05 cm has been filled with a dielectric having $K = 8$ and then charged to 300 volts . The final energy of condenser is -

- (1) $1.6 \times 10^{-5} \text{ J}$ (2) $2.0 \times 10^{-6} \text{ J}$
 (3) $12.8 \times 10^{-5} \text{ J}$ (4) $64 \times 10^{-5} \text{ J}$

Q.39 Three capacitors of capacity C_1, C_2, C_3 are connected in series. Their total capacity will be-

- (1) $C_1 + C_2 + C_3$ (2) $\frac{1}{(C_1 + C_2 + C_3)}$
 (3) $(C_1^{-1} + C_2^{-1} + C_3^{-1})$ (4) none of these

Q.40 Three capacitors each of capacitance $1\mu\text{F}$ are connected in parallel. To this combination a fourth capacitor of capacitance $1\mu\text{F}$ connected in series. The resultant capacitance of the system is-

- (1) $4\mu\text{F}$ (2) $2\mu\text{F}$
 (3) $4/3\mu\text{F}$ (4) $3/4\mu\text{F}$

Q.41 Two capacitances of capacity C_1 and C_2 are connected in series and potential difference V is applied across it. Then the potential difference across C_1 will be-

- (1) $V \frac{C_2}{C_1}$ (2) $V \frac{C_1 + C_2}{C_1}$
 (3) $V \frac{C_2}{C_1 + C_2}$ (4) $V \frac{C_1}{C_1 + C_2}$

Q.42 Two condensers of capacities $1\mu\text{F}$ and $2\mu\text{F}$ are connected in series and system charged to 120 volts. Then the P.D on $1\mu\text{F}$ capacitor (in volts) will be-

- (1) 40 (2) 60 (3) 80 (4) 120

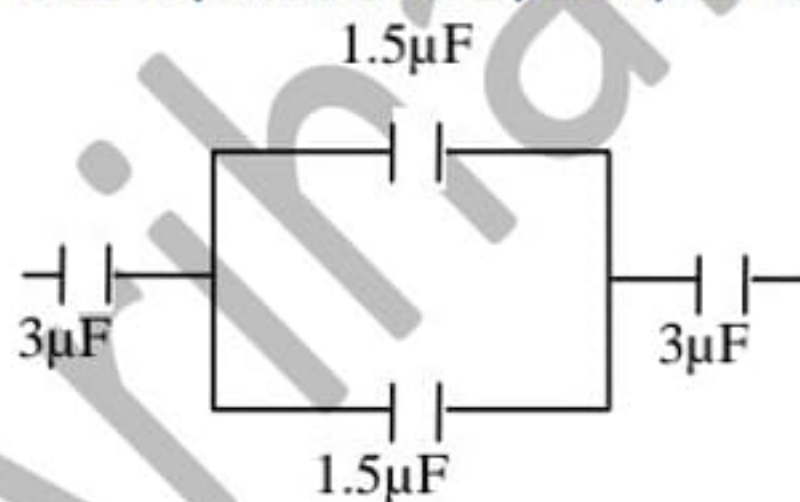
Q.43 Two condensers of capacity $0.3\mu\text{F}$ and $0.6\mu\text{F}$ respectively are connected in series. The combination is connected across a potential of 6 volts. The ratio of energies stored by the condensers will be -

- (1) $1/2$ (2) 2 (3) $1/4$ (4) 4

Q.44 Three capacitors $C_a < C_b < C_c$ are connected in series. Their resultant capacitance will be-

- (1) equivalent capacitance greater than C_c
 (2) equivalent capacitance less than C_c but greater than C_a
 (3) equivalent capacitance less than C_a
 (4) equivalent capacitance is infinite

Q.45 The equivalent capacity in the system of capacitance will be-

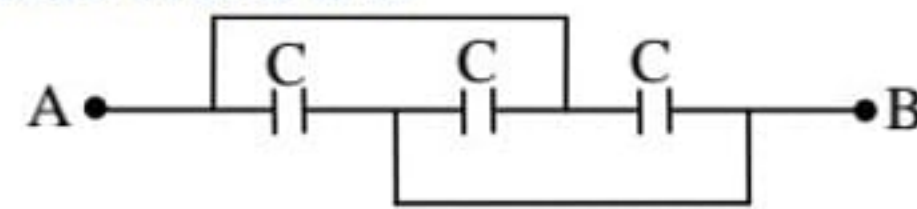


- (1) $1\mu\text{F}$ (2) $2\mu\text{F}$ (3) $1.5\mu\text{F}$ (4) $3\mu\text{F}$

Q.46 Three capacitors of capacitance $3\mu\text{F}$, $9\mu\text{F}$ and $18\mu\text{F}$ are connected once in series and another time in parallel. The ratio of equivalent capacitance in the two cases $\left(\frac{C_s}{C_p}\right)$ will be -

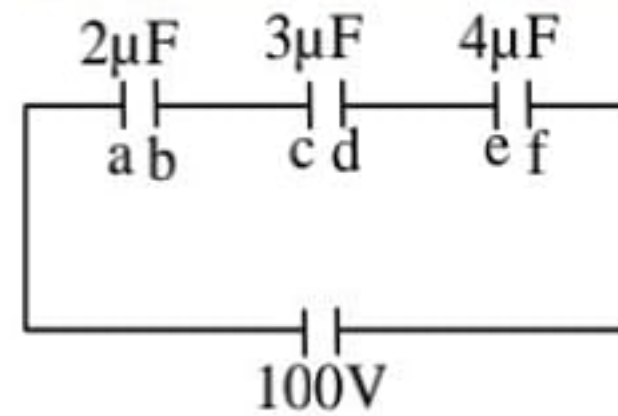
- (1) 1 : 15 (2) 15 : 1
 (3) 1 : 1 (4) 1 : 3

Q.47 Three equal capacitors, each with capacitance C are connected as shown in figure. Then the equivalent capacitance between A and B is -



- (1) C (2) $3C$
 (3) $C/3$ (4) $3C/2$

Q.48 Three capacitors are connected to D.C. source of 100 volts as shown in the adjoining figure. If the charge accumulated on plates of C_1 , C_2 and C_3 are $q_a, q_b, q_c, q_d, q_e, q_f$ respectively then -



- (1) $q_b + q_d + q_f = 100/9$ Coulomb
 (2) $q_b + q_d + q_f = 0$
 (3) $q_a + q_c + q_e = 50$ Coulomb
 (4) $q_b = q_d = q_f$

Q.49 A capacitor $C_1 = 4\mu F$ is connected in series with another capacitor $C_2 = 1\mu F$. The combination is connected across a d.c. source of voltage 200V. The ratio of potential across C_1 and C_2 is -

- (1) 1 : 4 (2) 4 : 1 (3) 1 : 2 (4) 2 : 1

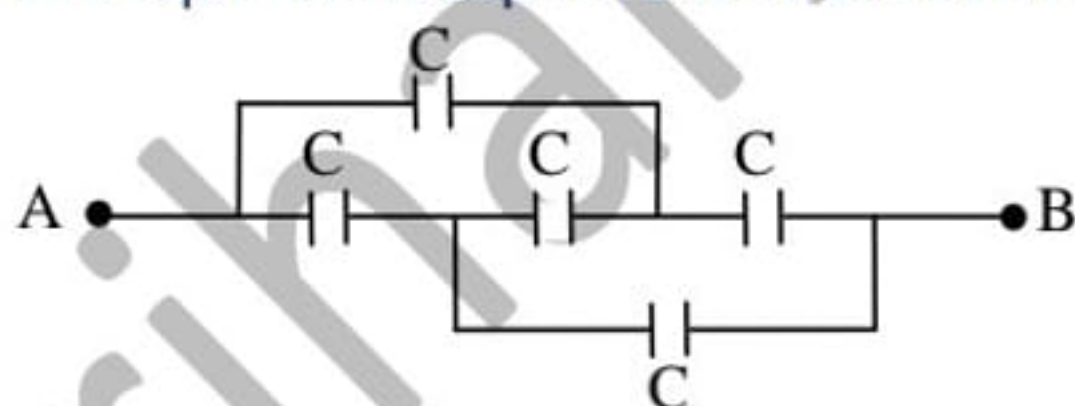
Q.50 Two condensers of 20 and 30 microfarads are connected in series across a 200 volt D.C. supply. Find the charge on each condenser ?

- (1) $2400 \mu C$ (2) $4200 \mu C$
 (3) $2600 \mu C$ (4) $3000 \mu C$

Q.51 The three condensers of capacitances 10, 20 and $30\mu F$ are first connected in series and then connected in parallel. The ratio of the resultant capacitance in the two cases is -

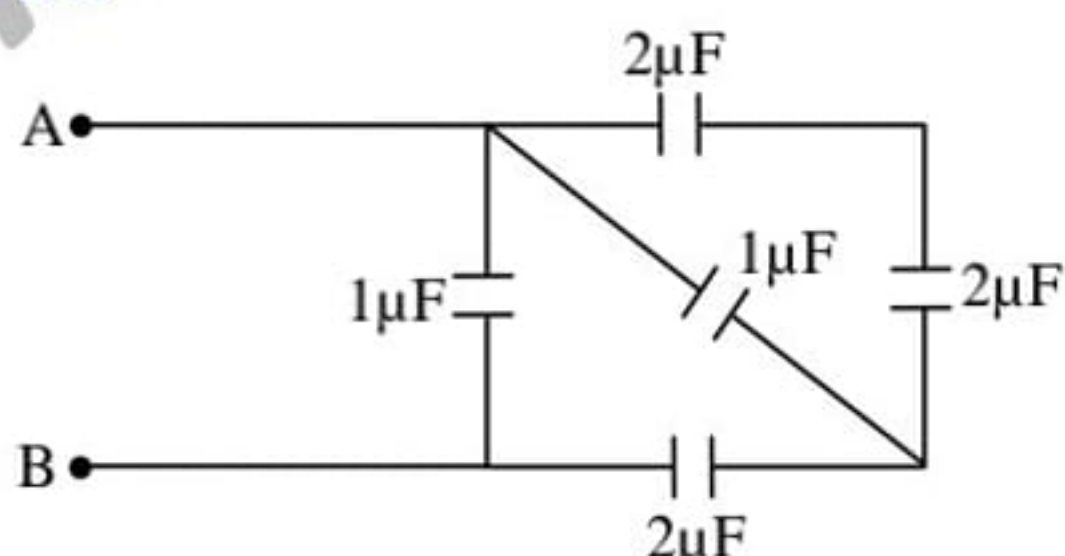
- (1) 1 : 11 (2) 11 : 1
 (3) 1 : 6 (4) 6 : 1

Q.52 Five equal capacitors, each with capacitance (C) are connected as shown in the adjoining fig. Then the equivalent capacitance between A and B is -



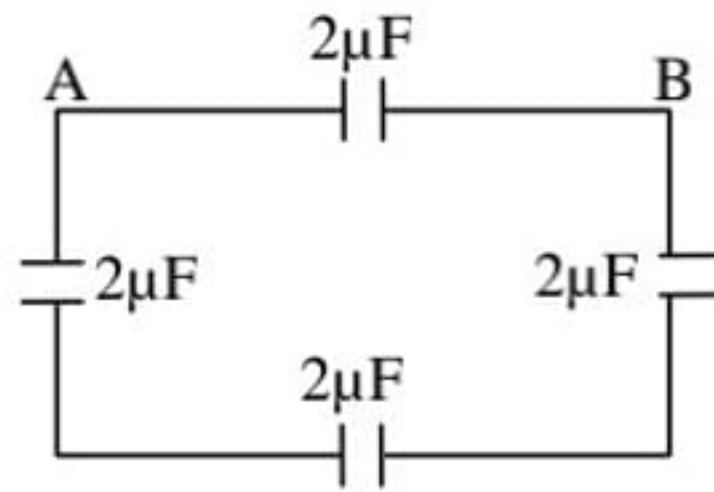
- (1) C (2) $5C$ (3) $C/5$ (4) $3C$

Q.53 The total capacity of the system of capacitors shown in adjoining figure between the points A and B is -



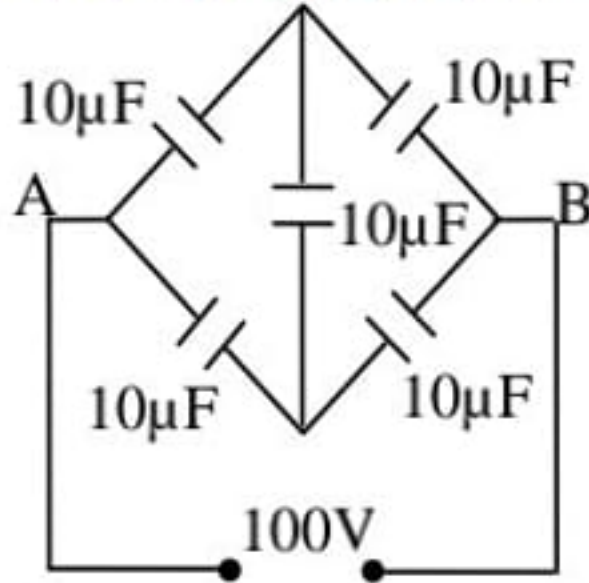
- (1) $1\mu F$ (2) $2\mu F$ (3) $3\mu F$ (4) $4\mu F$

Q.54 The equivalent capacitance between the points A and B in the given diagram is -



- (1) $8\mu\text{F}$ (2) $6\mu\text{F}$ (3) $\frac{8}{3}\mu\text{F}$ (4) $\frac{3}{8}\mu\text{F}$

Q.55 Five capacitors of $10\mu\text{F}$ capacitor each are connected to a D.C. potential of 100 volts as shown in the adjoining figure. The equivalent capacitance between the points A and B will be equal to-



- (1) $40\mu\text{F}$ (2) $20\mu\text{F}$
 (3) $30\mu\text{F}$ (4) $10\mu\text{F}$

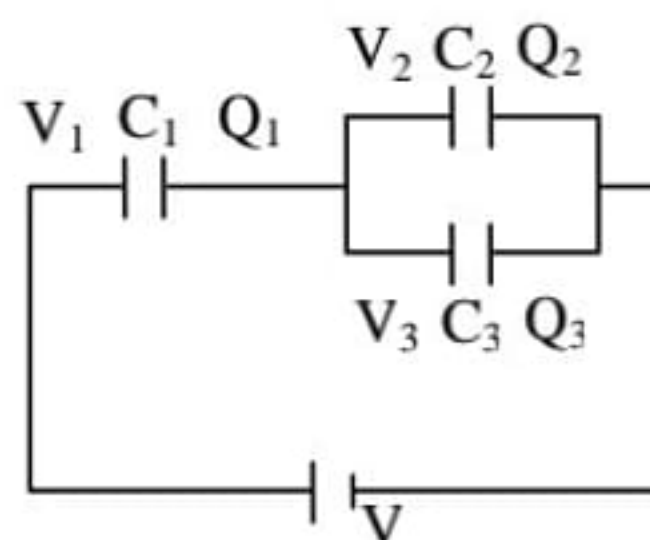
Q.56 Three capacitors of capacity $10\mu\text{F}$, $5\mu\text{F}$ and $5\mu\text{F}$ are connected in parallel. The total capacity will be-

- (1) $10\mu\text{F}$ (2) $5\mu\text{F}$
 (3) $20\mu\text{F}$ (4) none of the above

Q.57 Two capacitors connected in parallel having the capacities C_1 and C_2 are given 'q' charge, which is distributed among them. The ratio of the charge on C_1 and C_2 will be -

- (1) $\frac{C_1}{C_2}$ (2) $\frac{C_2}{C_1}$
 (3) $C_1 C_2$ (4) $\frac{1}{C_1 C_2}$

Q.58 In an adjoining figure are shown three capacitors C_1 , C_2 and C_3 joined to battery. The correct condition will be-



- (1) $Q_1 = Q_2 = Q_3$ and $V_1 = V_2 = V_3 = V$
 (2) $Q_2 = Q_2 + Q_3$ and $V = V_1 + V_2 + V_3$
 (3) $Q_1 = Q_2 + Q_3$ and $V = V_1 + V_2$
 (4) $Q_2 = Q_3$ and $V_2 = V_3$

(Symbols have their usual meanings)

Q.59 Two capacitors of equal capacity are first connected in parallel and then in series. The ratio of the total capacities in the two cases will be -

- (1) 2 : 1 (2) 1 : 2 (3) 4 : 1 (4) 1 : 4

Q.60 A $4\mu\text{F}$ condenser is connected in parallel to another condenser of $8\mu\text{F}$. Both the condensers are then connected in series with a $12\mu\text{F}$ condenser and charged to 20 volts. The charge on the plate of $4\mu\text{F}$ condenser is-

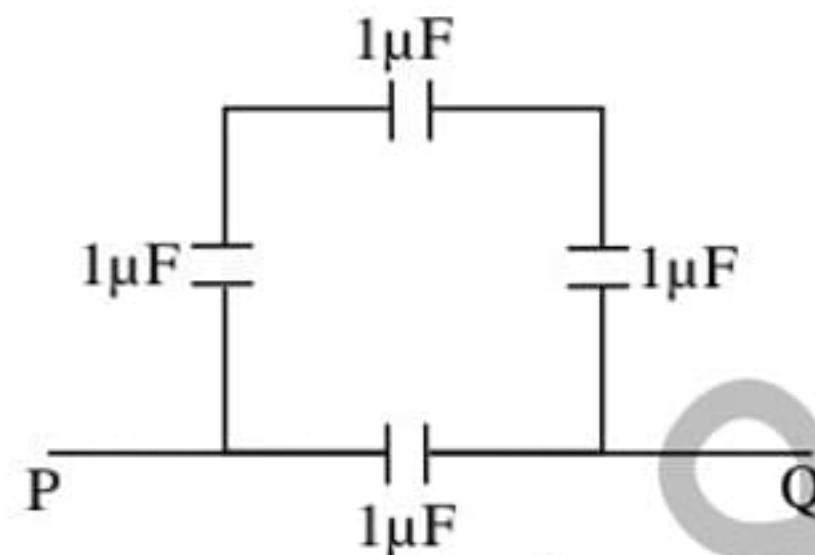
- (1) $3.3\mu\text{C}$ (2) $40\mu\text{C}$

- (3) $80 \mu\text{C}$ (4) $240 \mu\text{C}$

- Q.61** If three capacitors each of capacity $1\mu\text{F}$ are connected in such a way that the resultant capacity is $1.5\mu\text{F}$ then-
- (1) all the three are connected in series
 - (2) all the three are connected in parallel
 - (3) two of them are in parallel and then connected in series to the third
 - (4) two of them are in series and then connected in parallel to the third

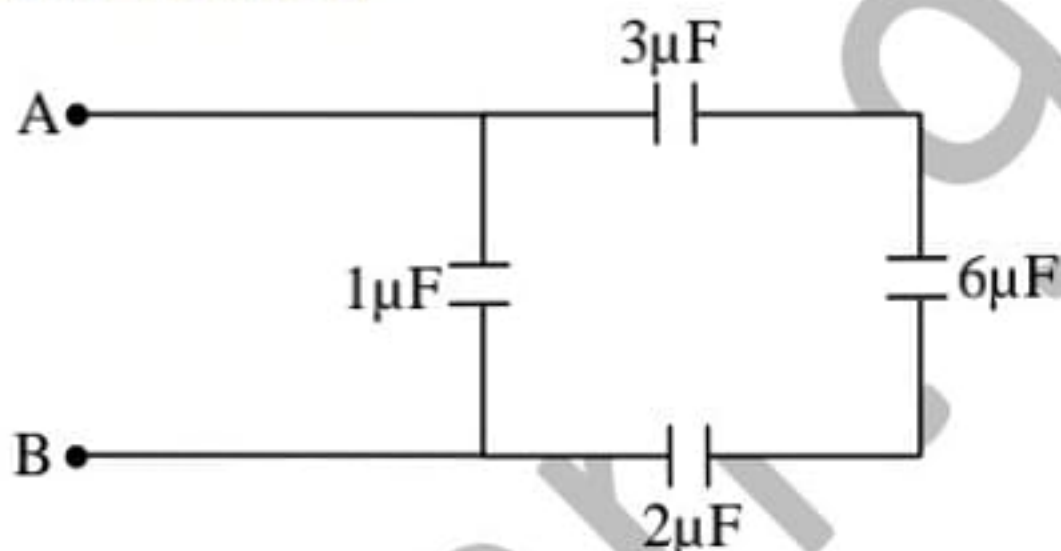
- Q.62** Two capacitor each of $1\mu\text{F}$ capacitance are connected in parallel and are then charged by 200 volts D.C. supply. The total energy of their charges (in joule is)-
- (1) 0.01 (2) 0.02
 - (3) 0.04 (4) 0.06

- Q.63** Four capacitors are connected as shown in the fig. The equivalent capacitance between the points P and Q is-



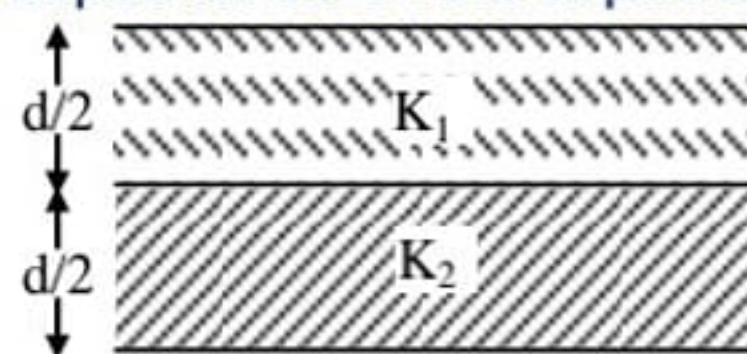
- (1) $4\mu\text{F}$ (2) $1/4 \mu\text{F}$
- (3) $3/4 \mu\text{F}$ (4) $4/3 \mu\text{F}$

- Q.64** The total capacity of the system of capacitors shown in the adjoining figure between the points A and B will be-



- (1) $1\mu\text{F}$ (2) $2\mu\text{F}$
- (3) $3\mu\text{F}$ (4) $4\mu\text{F}$

- Q.65** Two dielectric slabs of constant K_1 and K_2 have been filled in between the plates of a capacitor as shown below. What will be the capacitance of the capacitor -



- (1) $\frac{2\epsilon_0 A}{d} (K_1 + K_2)$ (2) $\frac{2\epsilon_0 A}{d} \left(\frac{K_1 + K_2}{K_1 \times K_2} \right)$ (3) $\frac{d}{2\epsilon_0 A}$ (4) $\frac{2\epsilon_0 A}{d} \left(\frac{K_1 \times K_2}{K_1 + K_2} \right)$

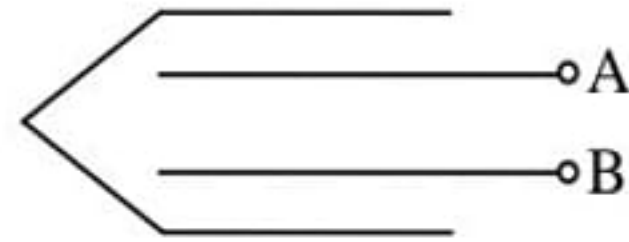
- Q.66** A parallel plate capacitor with air as medium between the plates has a capacitance of $10\mu\text{F}$. The area of capacitor is divided into two equal halves and filled with two media having dielectric constant $K_1 = 2$ and $K_2 = 4$. The capacitance of the system will now be-
- (1) $10\mu\text{F}$ (2) $20 \mu\text{F}$ (3) $30 \mu\text{F}$ (4) $40 \mu\text{F}$

- Q.67** Separation between the plates of a parallel plate capacitor is d and the area of each plate is A . When a slab of material of dielectric constant K and thickness t ($t < d$) is introduced between the plates, its capacitance becomes-

$$(1) \frac{\epsilon_0 A}{d+t\left(1-\frac{1}{K}\right)} \quad (2) \frac{\epsilon_0 A}{d+t\left(1+\frac{1}{K}\right)}$$

$$(3) \frac{\epsilon_0 A}{d-t\left(1-\frac{1}{K}\right)} \quad (4) \frac{\epsilon_0 A}{d-t\left(1+\frac{1}{K}\right)}$$

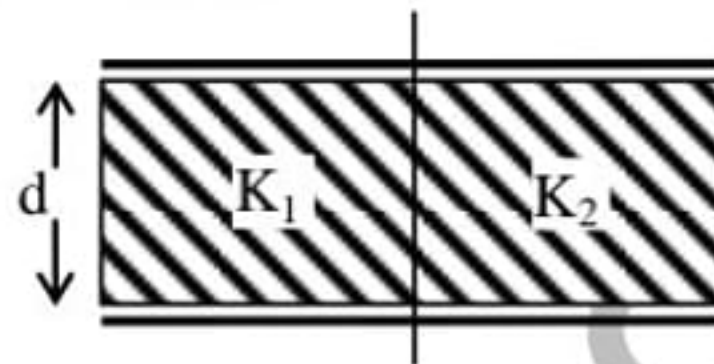
Q.68 If area of each plate is A and plates are separated from each other by a distance d then C_{eq} between A and B is -



$$(1) \frac{3\epsilon_0 A}{d} \quad (2) \frac{\epsilon_0 A}{3d}$$

$$(3) \frac{3\epsilon_0 A}{2d} \quad (4) \frac{2\epsilon_0 A}{3d}$$

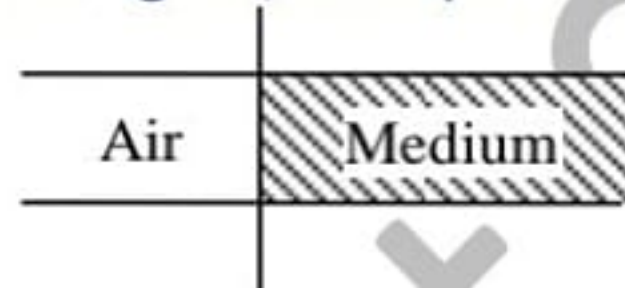
Q.69 The capacitance of a capacitor, filled with two dielectrics of same dimensions but of dielectric constants K_1 and K_2 respectively as shown will be -



$$(1) \frac{\epsilon_0 A}{2d} (K_1 + K_2) \quad (2) \frac{\epsilon_0 A}{d} (K_1 + K_2)$$

$$(3) \frac{\epsilon_0 A}{2d} \left(\frac{K_1 K_2}{K_1 + K_2} \right) \quad (4) \frac{\epsilon_0 A}{d} \left(\frac{K_1 K_2}{K_1 + K_2} \right)$$

Q.70 The capacitance of a parallel plate capacitor is $2.5\mu\text{F}$ when it is half filled with a dielectric as shown in the figure, its capacitance becomes $5\mu\text{F}$, the dielectric constant of the dielectric is -



$$(1) 7.5 \quad (2) 3.0 \quad (3) 0.33 \quad (4) 4.0$$

Q.71 The capacitance of a spherical condenser is $1\mu\text{F}$. If the spacing between the two spheres is 1mm, then the radius of the outer sphere is -

$$(1) 30\text{cm} \quad (2) 6\text{m} \quad (3) 5\text{cm} \quad (4) 3\text{m}$$

Q.72 The capacitance (C) for an isolated conducting sphere of radius (a) is given by $4\pi\epsilon_0 \cdot a$. If the sphere is enclosed with an earthed concentric sphere. The ratio of the radii of the sphere being $(n/n-1)$ then the capacitance of such a sphere will be increased by a factor -

$$(1) n \quad (2) n/(n-1)$$

$$(3) (n-1)/n \quad (4) a \cdot n$$

Q.73 A_1 is a spherical conductor of radius (r) placed concentrically inside a thin spherical hollow conductor A_2 of radius (R). A_1 is earthed and A_2 is given a charge +Q then the charge on A_1 is -

$$(1) -Q \quad (2) Qr/R$$

$$(3) -rQ/R \quad (4) -Q(R-r)/R$$

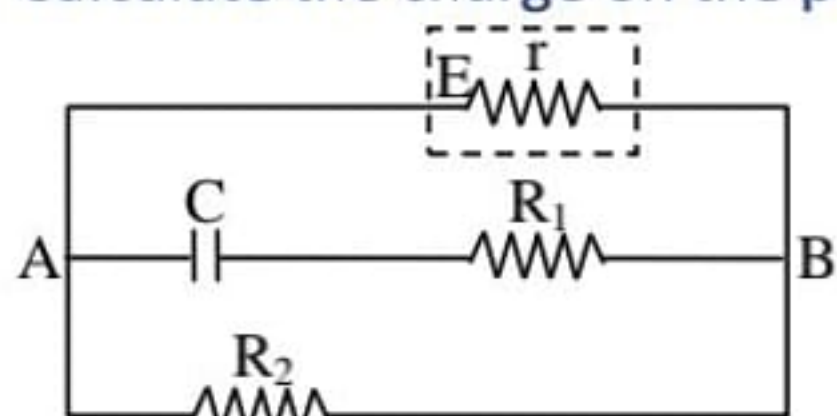
Q.74 Two spherical conductors A_1 and A_2 of radii (r_1) and (r_2) ($r_2 > r_1$) are placed concentrically in air. A_1 is given a charge +Q while A_2 is earthed. Then the capacitance of the system is -

$$(1) 4\pi\epsilon_0 \frac{r_1 \cdot r_2}{r_2 - r_1} \quad (2) 4\pi\epsilon_0 (r_1 + r_2)$$

$$(3) 4\pi\epsilon_0 \cdot r_2 \quad (4) 4\pi\epsilon_0 \frac{r_2^2}{r_2 - r_1}$$

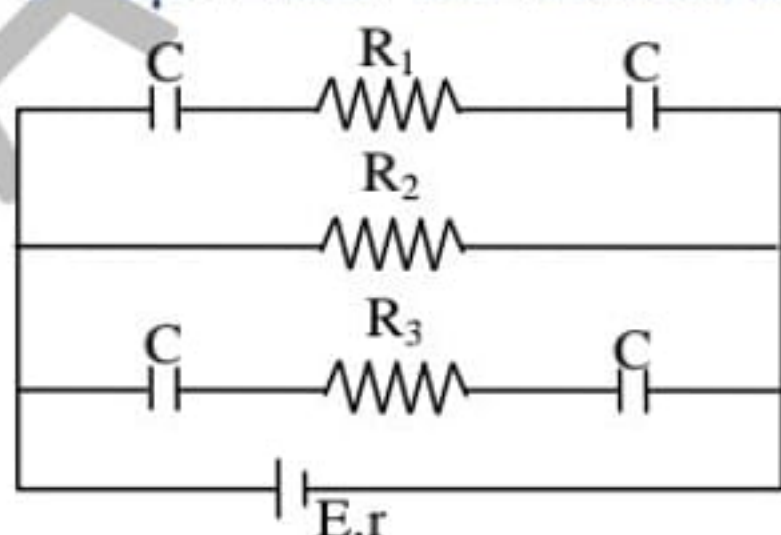
- Q.75** A capacitor of capacitance $100\mu\text{F}$ is charged by connecting it to a battery of emf 12V and internal resistance 2Ω . The time taken before 99% of the maximum charge is stored on the capacitor-
- (1) 0.92 ms (2) 0.4 ms
 (3) 0.8 ms (4) 0.1 ms
- Q.76** A capacitor of capacitance $0.1\mu\text{F}$ is charged to certain potential and allow to discharge through a resistance of $10\text{ M}\Omega$. How long will it take for the potential to fall to one half of its original value-
- (1) 0.1 s (2) 0.2346 s
 (3) 1.386 s (4) 0.693 s
- Q.77** A $500\mu\text{F}$ capacitor is charged at a steady rate of $100\mu\text{C}/\text{sec}$. The potential difference across the capacitor will be 10V after an interval of-
- (1) 5 sec . (2) 20 sec . (3) 25 sec . (4) 50 sec .
- Q.78** A C. R series circuit is connected to a battery of e.m.f E. The time required by the capacitor to acquire maximum charge, depends upon -
- (1) R only
 (2) C only
 (3) RC
 (4) applied potential difference

- Q.79** Calculate the charge on the plates of the capacitor C in the given circuit -



- (1) $C \times \frac{ER_2}{R_2 + r}$ (2) $C \times \frac{ER_1}{R_1 + r}$
 (3) $C \times \frac{ER_1 \cdot R_2}{R_1 + R_2}$ (4) $C \times \frac{ER_1}{R_2 + r}$

- Q.80** In the adjoining circuit diagram $E = 5\text{ volt}$,
 $r = 1\text{ ohm}$, $R_2 = 4\text{ ohm}$, $R_1 = R_3 = 1\text{ ohm}$ and
 $C = 3\mu\text{F}$. Then the numerical value of the charge on each plate of the capacitor is –



- (1) $24\mu\text{C}$ (2) $12\mu\text{C}$
 (3) $6\mu\text{C}$ (4) $3\mu\text{C}$
- Q.81** Two condensers of capacities $2C$ and C are joined in parallel and charged upto potential V . The battery is removed and the condenser of capacity C is filled completely with a medium of dielectric constant K . The p.d. across the capacitors will now be -

- (1) $\frac{3V}{K+2}$ (2) $\frac{3V}{K}$
 (3) $\frac{V}{K+2}$ (4) $\frac{V}{K}$

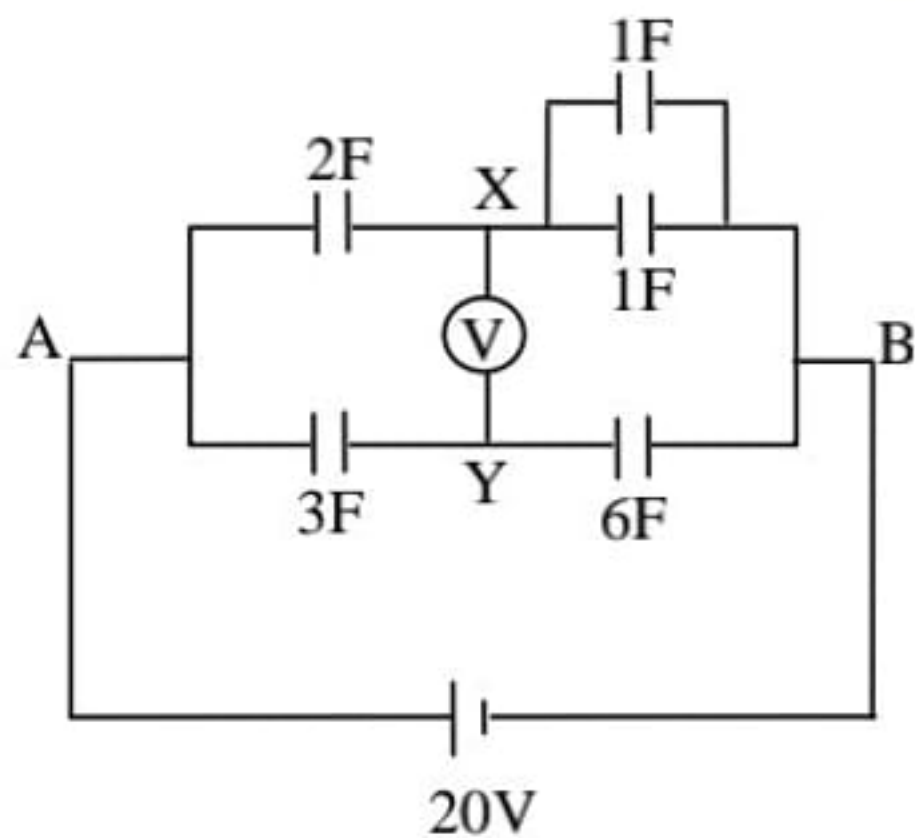
- Q.82** 0.2F capacitor is charged to 600V by a battery. On removing the battery. It is connected with another parallel plate condenser (1.0F). The potential decreases to-
 (1) 100 volts (2) 120 volts
 (3) 300 volts (4) 600 volts
- Q.83** A $0.01\mu\text{F}$ capacitor is charged to a potential of 500v. It is then connected to an instrument of input capacitance $1.0\mu\text{F}$. The p.d across the instrument in V is now-
 (1) 1.00 (2) 4.95 (3) 5.00 (4) 50.0
- Q.84** A condenser of capacitance $10\mu\text{F}$ has been charged to 100V. It is now connected to another uncharged condenser. The common potential becomes 40V. The capacitance of another condenser is -
 (1) $5\mu\text{F}$ (2) $10\mu\text{F}$ (3) $15\mu\text{F}$ (4) $20\mu\text{F}$
- Q.85** A capacitor having capacitance C is charged to a voltage V. It is then removed and connected in parallel with another identical capacitor which is uncharged. The new charge on each capacitor is now-
 (1) CV (2) CV/2 (3) 2CV (4) CV/4
- Q.86** Two capacitors of capacities C_1 and C_2 are charged to voltages V_1 and V_2 respectively. There will be no exchange of energy in connecting them in parallel. If-
 (1) $C_1 = C_2$ (2) $C_1V_1 = C_2V_2$
 (3) $V_1 = V_2$ (4) $\frac{C_1}{V_1} = \frac{C_2}{V_2}$

IMPORTANT PRACTICE QUESTION SERIES FOR IIT-JEE EXAM - 2

- Q.1** A parallel plate capacitor is charged and kept connected with the battery. If now a dielectric slab is inserted between the plates to fill the entire space between the plates then what will be the change in the charge, potential difference and electric field intensity between the plates respectively -
- (1) increases , constant, increases
 - (2) increases, constant , constant
 - (3) increases , constant , decreases
 - (4) constant, decreases , decreases.
- Q.2** A parallel plate air capacitor is connected to a battery. The quantities charge, voltage electric field, and energy associated with this capacitor are given by Q_0, V_0, E_0 and U_0 respectively. A dielectric slab is now introduced to fill the space between the plates with battery still in connection. The corresponding quantities now given by $Q, V, E,$ and U are related of the previous one as -
- (1) $Q > Q_0$
 - (2) $V > V_0$
 - (3) $E > E_0$
 - (4) $U \geq U_0$
- Q.3** A battery charges a parallel plate capacitor of thickness (d) so that an energy [U_0] is stored in the system. A slab of dielectric constant (K) and thickness (d) is then introduced between the plates of the capacitor. The new energy of the system is given by -
- (1) KU_0
 - (2) $K^2 U_0$
 - (3) $\frac{U_0}{K}$
 - (4) U_0/K^2
- Q.4** Two spheres of radii R_1 and R_2 have equal charge are joint together with a copper wire. If the potential on each sphere after they are separated to each other is V , then initial charge on any sphere was ($k = \frac{1}{4\pi\epsilon_0}$) -

- (1) $\frac{V}{k} (R_1 + R_2)$ (2) $\frac{V}{2k} (R_1 + R_2)$
 (3) $\frac{V}{k} (R_1 + R_2)$ (4) $\frac{V (R_1 R_2)}{k (R_1 + R_2)}$

Q.5 Calculate the reading of voltmeter between X and Y then $(V_X - V_Y)$ is equal to -



- (1) 10 V (2) 13.33V
 (3) 3.33 V (4) 10.33 V

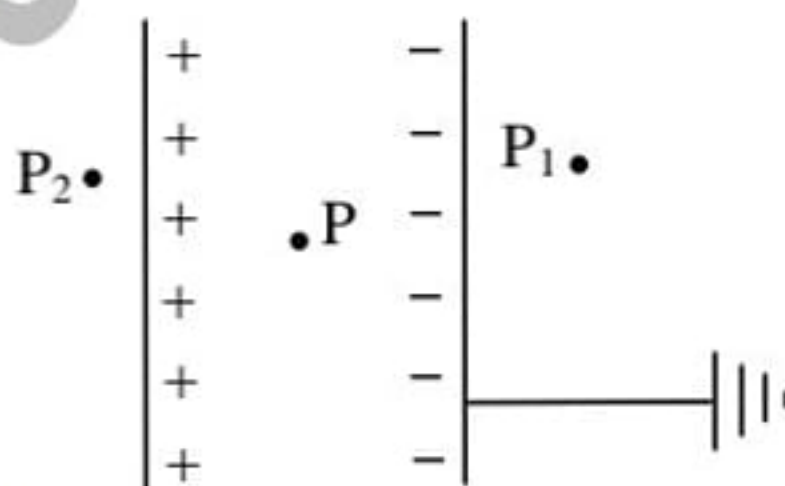
Q.6 The capacitance of two capacitors was compared with the aid of an electrometer. The capacitors were charged to potential of $V_1 = 300V$ and $V_2 = 100V$ and were connected in parallel. The potential difference between the plates measured by the electrometer was 250V. The capacitance ratio is -

- (1) 3 : 1 (2) 1 : 3
 (3) 1 : 2.5 (4) 2.5 : 1

Q.7 Three capacitors 2, 3 and $4\mu F$ are connected in series with 6V battery. When the current stops, the charge on the $3\mu F$ capacitor is

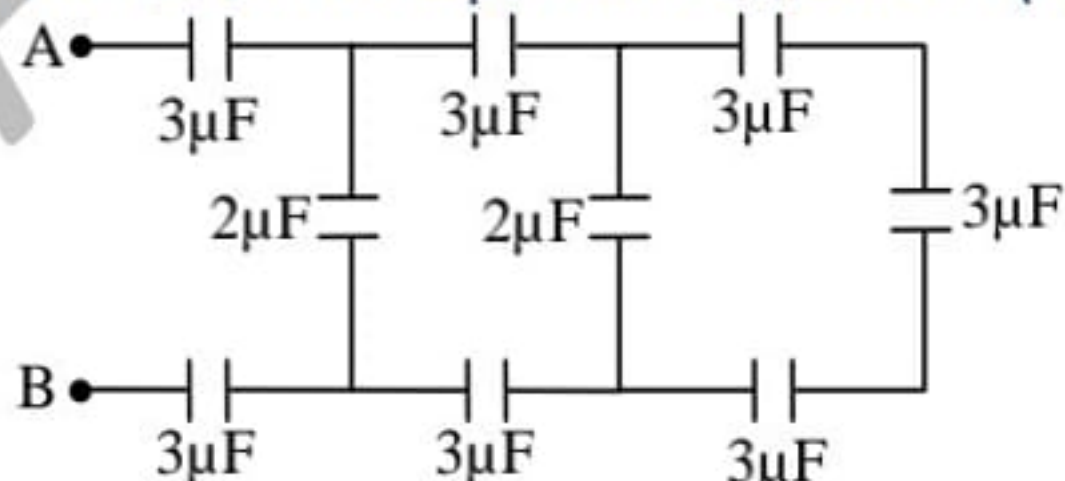
- (1) $5.5 \mu C$ (2) $4.4 \mu C$
 (3) $3.3 \mu C$ (4) $2.2 \mu C$

Q.8 There are two metallic plates of a parallel plate capacitor. One plate is given a charge $+q$ while the other is earthed as shown. Points P , P_1 and P_2 are taken as shown in adjoining figure. Then the electric intensity is not zero at -



- (1) P only (2) P_1 only
 (3) P_2 only (4) P, P_1 and P_2

Q.9 The resultant capacitance between (A) and (B) in the following figure is -



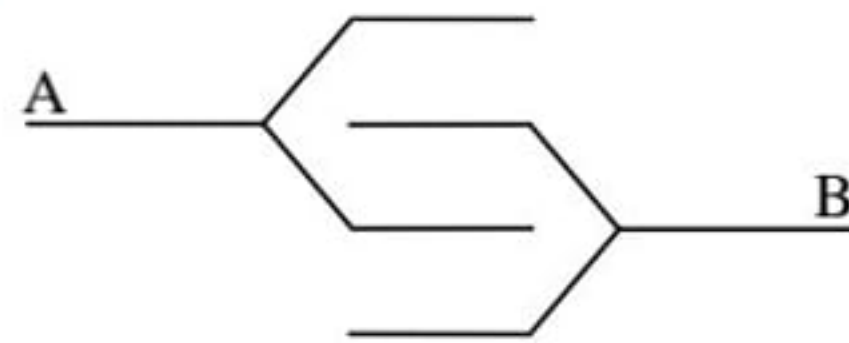
- (1) $1\mu F$ (2) $3\mu F$
 (3) $2\mu F$ (4) $1.5\mu F$

Q.10 The diameter of the plate of a parallel plate condenser is 6 cm. If its capacity is equal to a sphere of diameter 200 cm, the separation between the plates of the condenser is -

- (1) $4.5 \times 10^{-4}m$ (2) $2.25 \times 10^{-4}m$

- (3) $6.75 \times 10^{-4} \text{ m}$ (4) $9 \times 10^{-4} \text{ m}$

Q.11 Four metallic plates of each with a surface area of one side (A), are placed at a distance (d) from each other. The alternate plate are connected to point (A) and (B) as shown in the fig. The capacitance of the system is



- (1) $\frac{\epsilon_0 A}{d}$ (2) $\frac{2\epsilon_0 A}{d}$
 (3) $\frac{3\epsilon_0 A}{d}$ (4) $\frac{4\epsilon_0 A}{d}$

Q.12 A sheet of aluminium foil of negligible thickness is placed between the plates of a capacitor of capacitance C as shown in the figure then capacitance of capacitor becomes

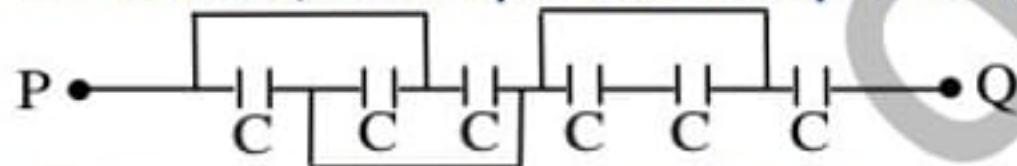


- (1) 2C (2) C (3) C/2 (4) zero

Q.13 In above problem if foil is connected to any one plate of capacitor by means of conducting wire then capacitance of capacitor becomes -

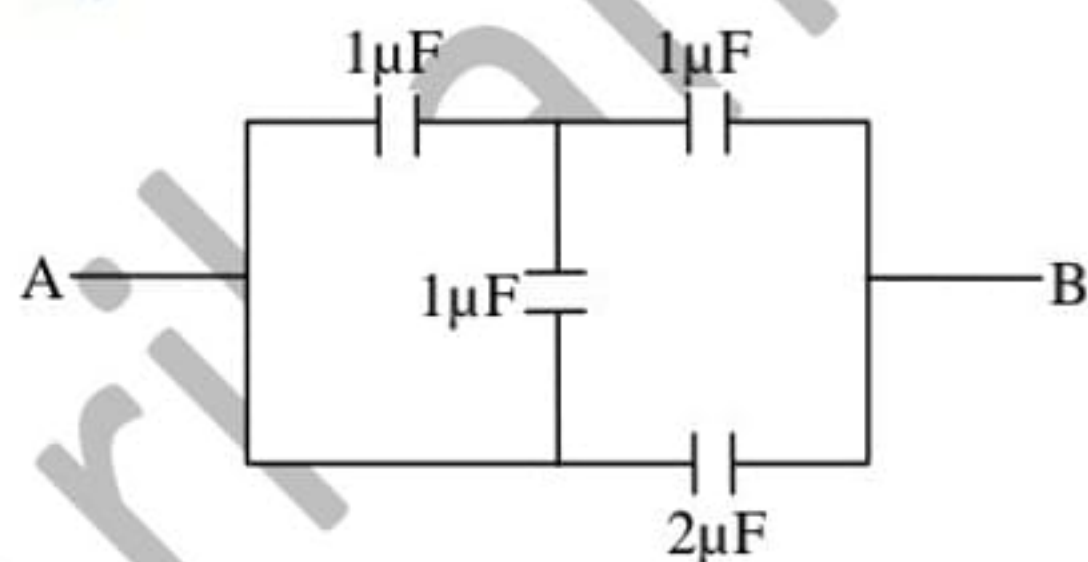
- (1) 2C (2) C (3) C/2 (4) zero

Q.14 For circuit, the equivalent capacitance between P and Q is -



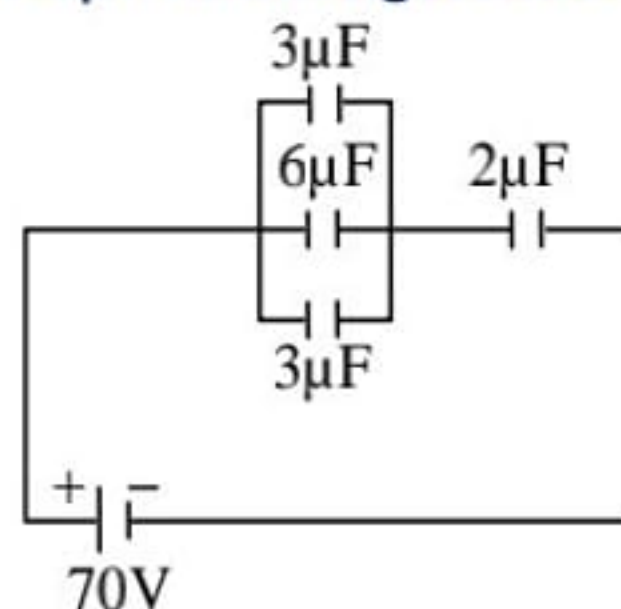
- (1) 6C (2) 4C (3) 3C/2 (4) 3C/4

Q.15 The figure shows a circuit consisting of four capacitors. The effective capacitance between A and B is -



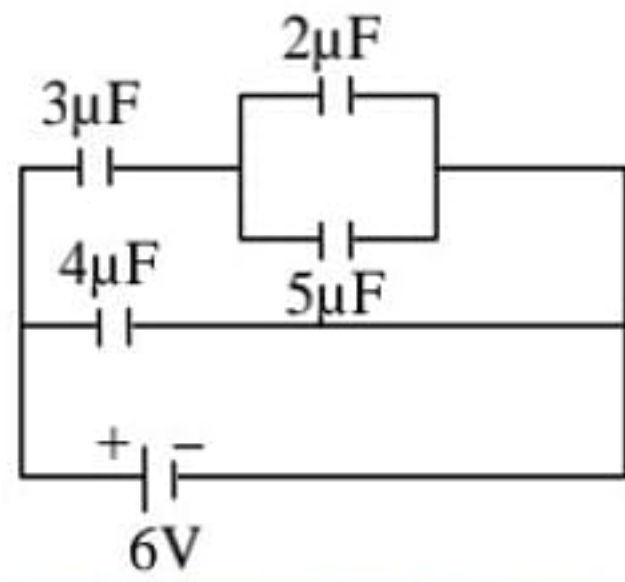
- (1) $\frac{5}{6} \mu\text{F}$ (2) $\frac{7}{6} \mu\text{F}$ (3) $\frac{8}{3} \mu\text{F}$ (4) $1 \mu\text{F}$

Q.16 The p.d. across the capacitance of $2 \mu\text{F}$ in the figure along with is -



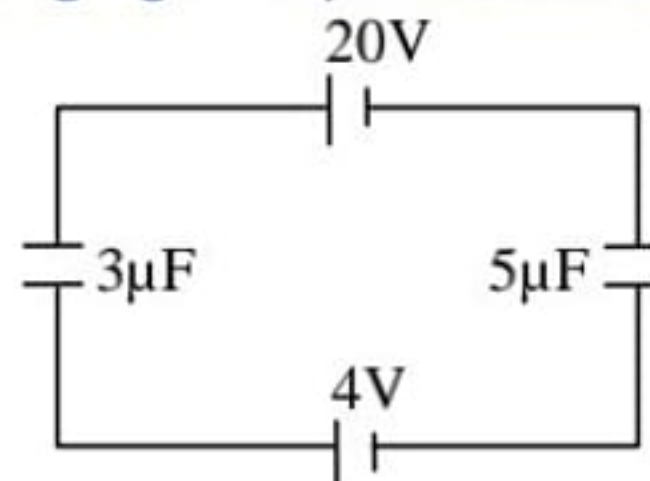
- (1) 10V (2) 60V (3) 28 V (4) 56V

Q.17 A circuit is shown in the figure below. Find out the charge of the condenser having capacity $5 \mu\text{F}$ -



- (1) $4.5 \mu\text{C}$ (2) $6.0 \mu\text{C}$ (3) $9.0 \mu\text{C}$ (4) $30 \mu\text{C}$

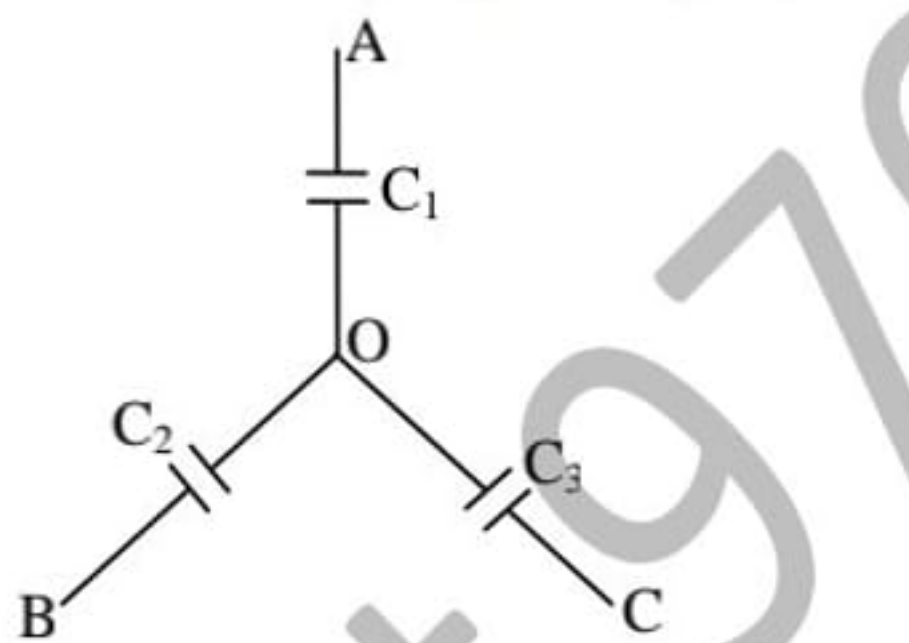
Q.18 In the circuit shown in the following fig. The p.d across $3\mu\text{F}$ capacitor is -



- (1) 4 V (2) 6 V (3) 10 V

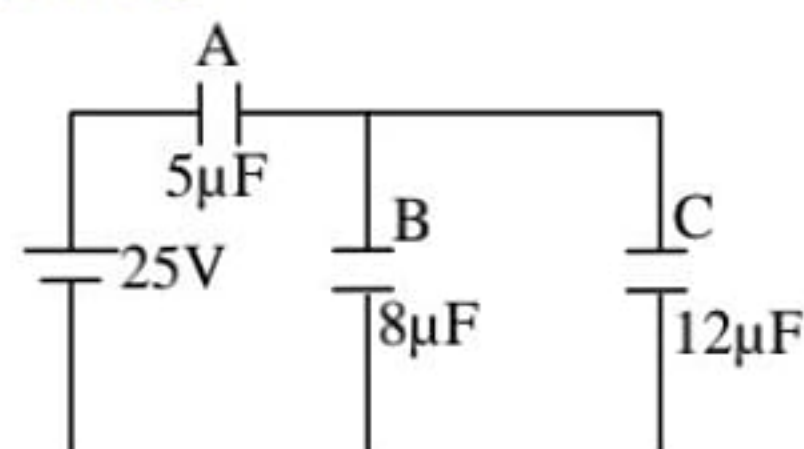
- (4) 16 V

Q.19 Three capacitors of capacitors C_1 , C_2 , C_3 are connected as shown in the figure. The points A, B and C are at potential V_1 , V_2 and V_3 respectively. Then the potential at O will be -



- (1) $\frac{V_1 + V_2 + V_3}{2}$ (2) $\frac{V_1 V_2 + V_2 V_3 + V_3 V_1}{V_1 + V_2 + V_3}$
 (3) $\frac{V_1 C_1 + V_2 C_2 + V_3 C_3}{C_1 + C_2 + C_3}$ (4) zero

Q.20 Three capacitors A, B and C are connected to a battery of 25volt as shown in the figure. The ratio of charges on capacitors A, B and C will be -



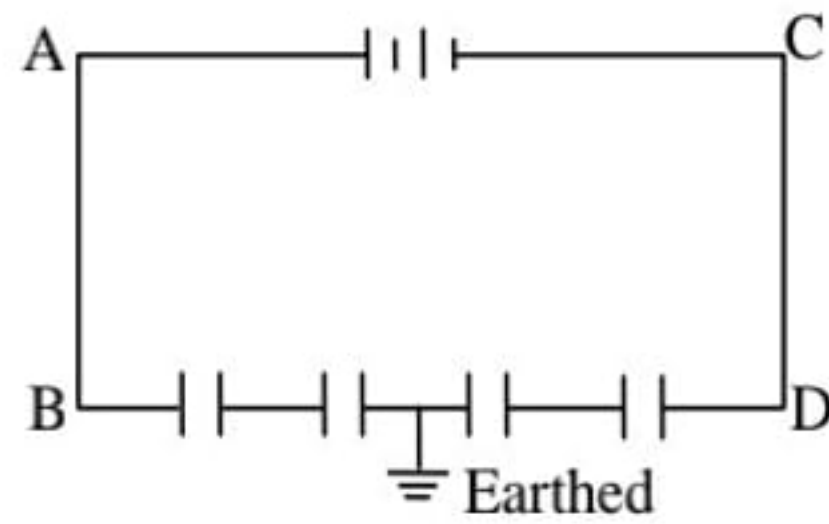
- (1) 5 : 2 : 3

- (2) 5 : 3 : 2

- (3) 2 : 5 : 3

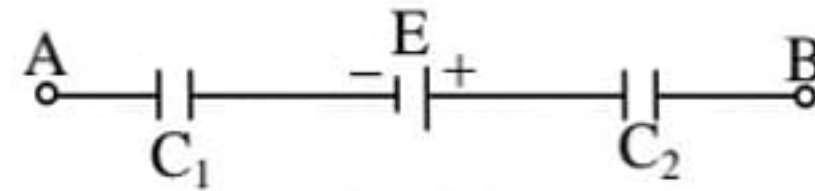
- (4) 2 : 3 : 5

Q.21 Four equal capacitors, each with a capacitance (C) are connected to a battery of E.M.F 10volts as shown in the adjoining figure. The mid point of the capacitor system is connected to earth. Then the potentials of B and D are respectively-



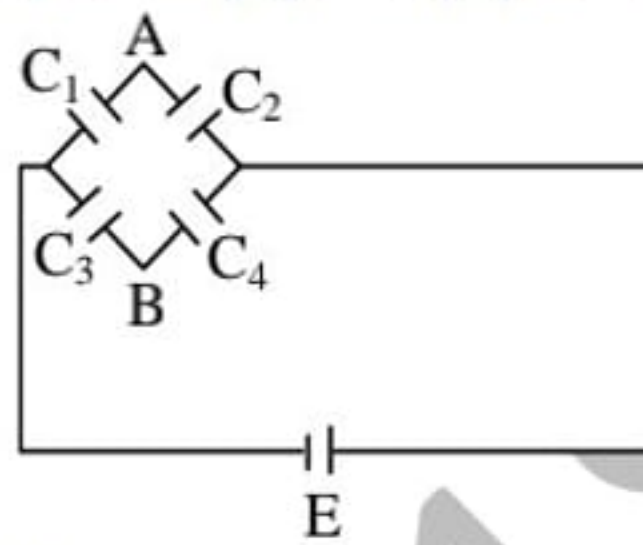
- (1) +10 volt , zero volt (2) +5 volt , -5 volt
 (3) -5 volt, +5 volt (4) zero volt, 10 volt

Q.22 A circuit has a section AB as shown in the fig. With $E = 10V$, $C_1 = 1.0\mu F$, $C_2 = 2.0\mu F$ and the potential difference $V_A - V_B = 5V$. The voltage across C_1 is -



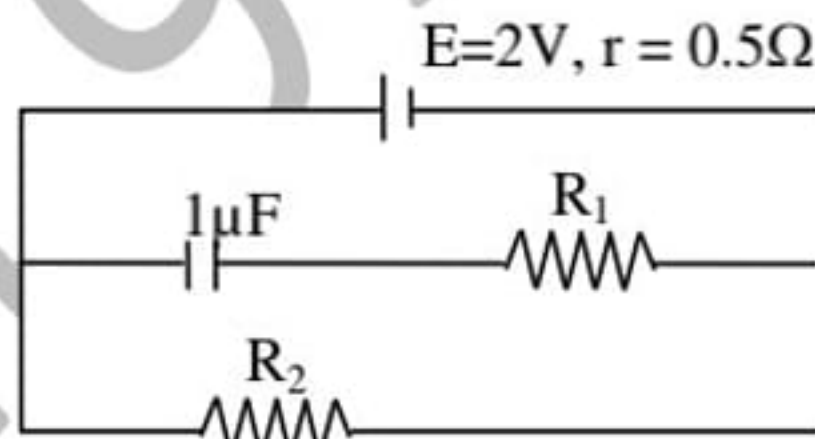
- (1) zero (2) 5V (3) 10V (4) 15V

Q.23 The potential difference between points (A) and (B) of the circuit is-



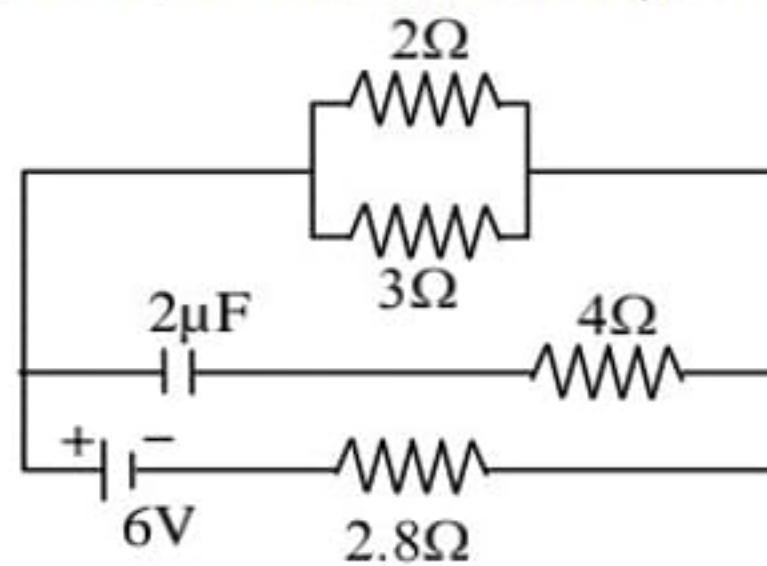
- (1) $(C_2 - C_1) E$ (2) $(C_4 - C_3) E$
 (3) $\frac{(C_2 C_3 - C_1 C_4) E}{(C_1 + C_2 + C_3 + C_4)}$ (4) $\frac{(C_2 C_3 - C_1 C_4) E}{(C_1 + C_2)(C_3 + C_4)}$

Q.24 A $1\mu F$ capacitor is connected in the circuit shown below. The e.m.f of the cell is 2 volts and internal resistance is 0.5 ohm. The resistors R_1 and R_2 have values 4 ohm and 1 ohm respectively. The charge on the capacitor must be-



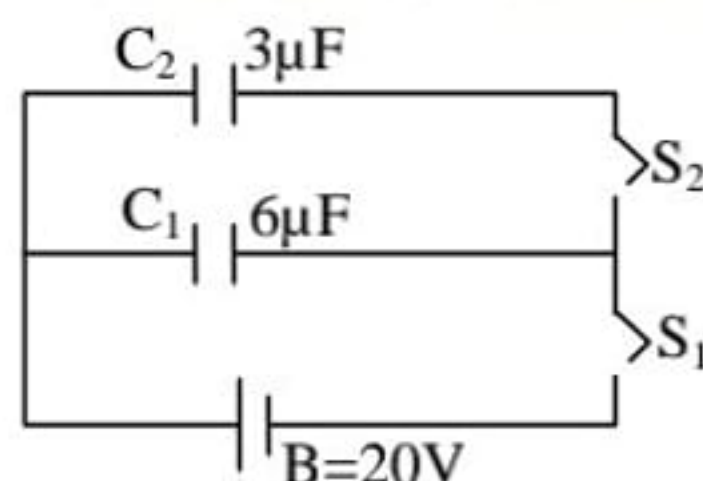
- (1) $2\mu C$ (2) $1\mu C$ (3) $1.33\mu C$ (4) zero

Q.25 In the figure shown, the capacity of the condenser C is $2\mu F$. The current in 2Ω resistor is-



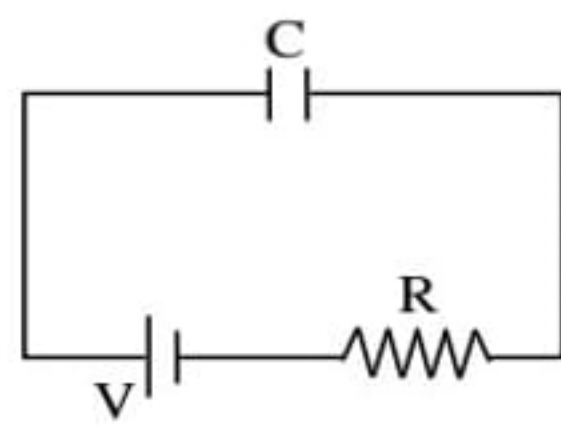
- (1) 9 A (2) 0.9 A (3) $\frac{1}{9}$ A (4) $\frac{1}{0.9}$ A

Q.26 In the circuit shown here $C_1 = 6\mu F$, $C_2 = 3\mu F$ and battery B = 20V. The Switch S_1 is first closed. It is then opened and afterwards S_2 is closed. What is the charge finally on C_2 ?



- (1) $120\mu\text{C}$ (2) $80\mu\text{C}$ (3) $40\mu\text{C}$ (4) $20\mu\text{C}$

Q.27 As in figure shown, if a capacitor C is charged by connecting it with resistance R, then energy is given by the battery will be -

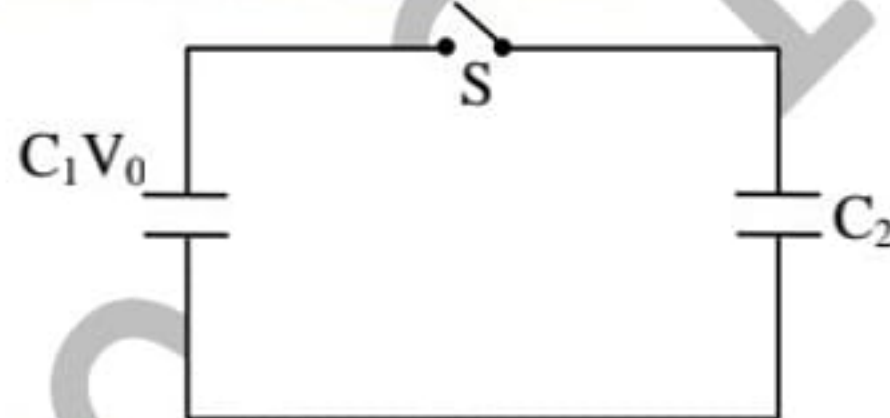


- (1) $\frac{1}{2}CV^2$ (2) More than $\frac{1}{2}CV^2$
 (3) Less than $\frac{1}{2}CV^2$ (4) Zero

Q.28 A parallel plate capacitor has plate area A and separation d. It is charged to a potential difference V_0 . The charging battery is disconnected and the plates are pulled apart to three times the initial separation. The work required to separate the plates is -

- (1) $\frac{3\varepsilon_0AV_0^2}{d}$ (2) $\frac{\varepsilon_0AV_0^2}{2d}$
 (3) $\frac{\varepsilon_0AV_0^2}{3d}$ (4) $\frac{\varepsilon_0AV_0^2}{d}$

Q.29 A capacitor of capacity C_1 is charged to the potential of V_0 . On disconnecting with the battery, it is connected with a capacitor of capacity C_2 as shown in the adjoining figure. The ratio of energies before and after the connection of switch S will be -



- (1) $(C_1 + C_2)/C_1$ (2) $C_1/(C_1 + C_2)$
 (3) C_1C_2 (4) C_1/C_2

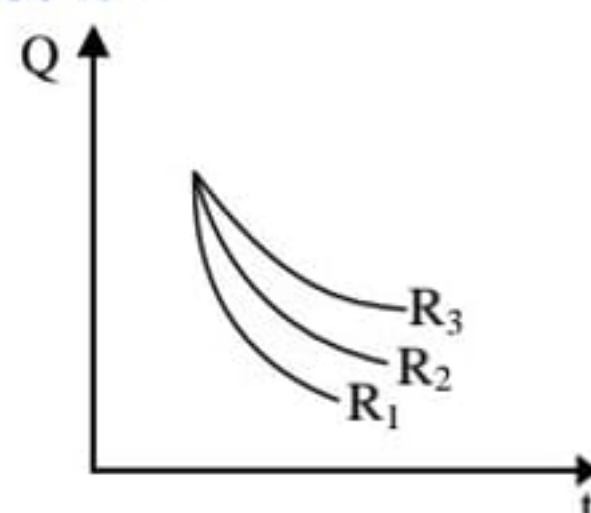
Q.30 Condenser A has a capacity of $15\mu\text{F}$ when it is filled with a medium of dielectric constant 15. Another condenser B has a capacity of $1\mu\text{F}$ with air between the plates. Both are charged separately by a battery of 100 V. After charging, both are connected in parallel without the battery and the dielectric medium being removed. The common potential now is -

- (1) 400 V (2) 800 V
 (3) 1200 V (4) 1600V

Q.31 A parallel plate capacitor is charged to a P.d. of 50 V. it is discharged through a resistance. After 1s, the P.d. between plates becomes 40 V. Then -

- (1) Fraction of stored energy after 1s is $16/25$
 (2) P.d. between the plates after 2 s will be 32 V
 (3) P.d. between the plates after 2 s. will be 20 V
 (4) Fraction of stored energy after 1 s. is $4/5$

Q.32 Three identical capacitors are given a charge Q each and they are then allowed to discharge through resistance R_1 , R_2 and R_3 . Their charges, as a function of time shown in the graph below. The smallest of the three resistance is -



- (1) R_3 (2) R_2

- (3) R_1 (4) Cannot be predicted

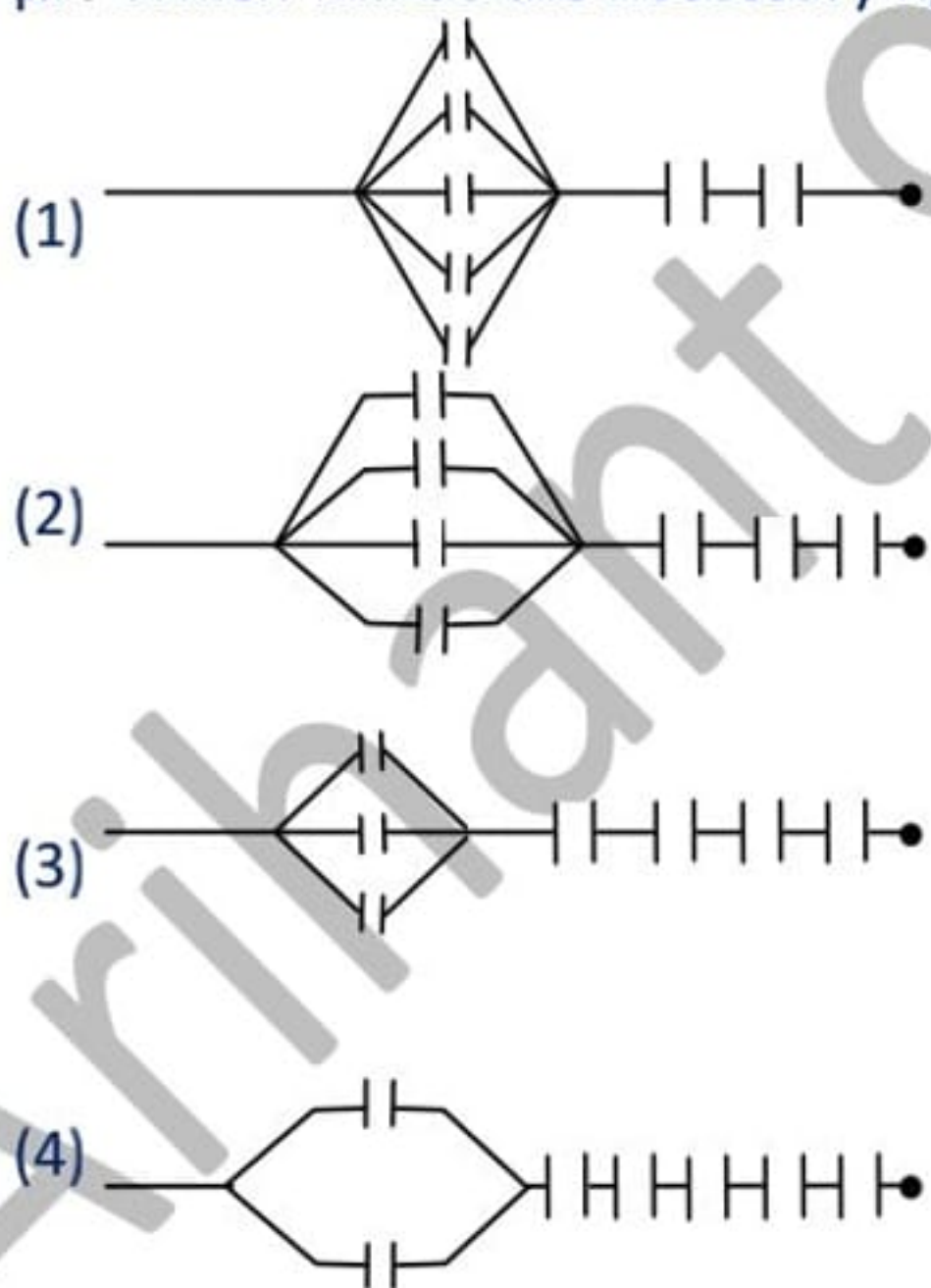
Q.33 A glass slab is put with in the plates of a charged parallel plate condenser. Which of the following quantities does not change?
 (1) energy of the condenser (2) capacity
 (3) intensity of electric field (4) charge

Q.34 A parallel plate capacitor is connected to a battery and inserted a dielectric plate between the place of plates then which quantity increase-
 (1) potential difference (2) electric field
 (3) stored energy (4) e.m.f. of battery

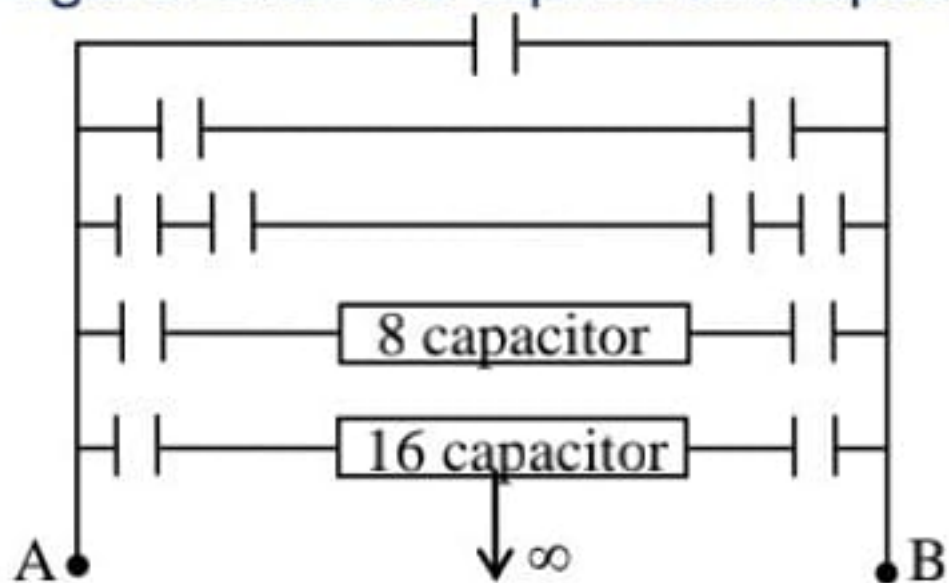
Q.35 A parallel plate capacitor is charged by a battery after charging the capacitor, battery is disconnected and decrease the distance between the plates then which of the following statement is correct-
 (1) electric field is not constant
 (2) potential difference is increased
 (3) decrease the capacitance
 (4) decrease the stored energy

Q.36 A parallel plate capacitor has rectangular plates of 400 cm^2 and are separated by a distance of 2 mm with air as medium. What charge will appear on the plates. If a 200 volt potential difference is applied across the condenser.?
 (1) $3.54 \times 10^{-6} \text{ C}$ (2) $3.54 \times 10^{-8} \text{ C}$
 (3) $3.54 \times 10^{-10} \text{ C}$ (4) $1770.8 \times 10^{-13} \text{ C}$

Q.37 Seven capacitors each of capacitance $2 \mu\text{F}$ are to be so connected to have total capacity $\frac{10}{11} \mu\text{F}$. Which will be the necessary figure as shown-



Q.38 An infinite number of identical capacitors each of capacitance $1 \mu\text{F}$ are connected as in adjoining figure. Then the equivalent capacitance between A and B is-



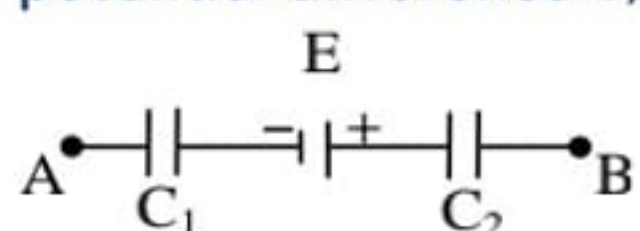
- (1) $1 \mu\text{F}$ (2) $2 \mu\text{F}$ (3) $\frac{1}{2} \mu\text{F}$ (4) ∞

- Q.39** An air capacitor, a capacitor with a dielectric and a capacitor with a conducting slab (thickness one half the separation introducing between the plates of parallel plate air capacitor in both case) has capacity C_1 , C_2 and C_3 respectively then-
- (1) $C_1 > C_2 > C_3$ (2) $C_2 > C_3 > C_1$
 (3) $C_3 > C_2 > C_1$ (4) $C_3 > C_1 > C_2$

- Q.40** Two spheres of radii 1 cm and 2 cm have been charged with 1.5×10^{-8} and 0.3×10^{-7} coulomb of positive charge. When they are connected with a wire, charge-
- (1) will flow from the first to the second
 (2) will flow from the second to the first
 (3) will not flow at all
 (4) may flow either from first to second, or from the second to first, depending upon the length of the connecting wire

- Q.41** A number of capacitors, each of capacitance $1\mu\text{F}$ and each one of which gets punctured if a potential difference just exceeding 500 volt is applied are provided. Then an arrangement suitable for giving a capacitor of capacitance $3\mu\text{F}$ across which 2000 volt may be applied requires at least -
- (1) 4 component capacitors
 (2) 12 component capacitors
 (3) 48 component capacitors
 (4) 16 component capacitors

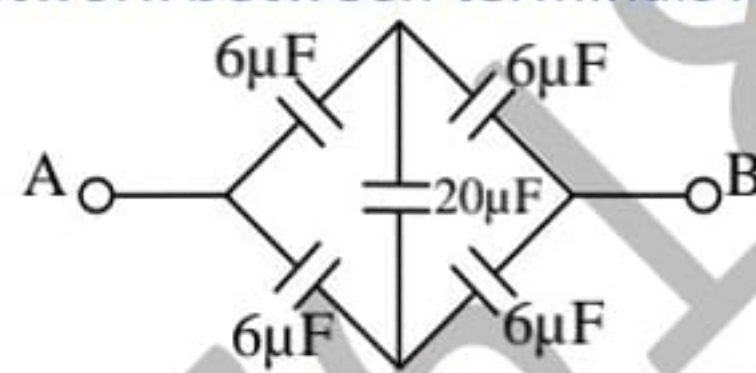
- Q.42** A circuit has a section AB as shown in the figure with $E = 10\text{V}$, $C_1 = 1.0\mu\text{F}$, $C_2 = 2.0\mu\text{F}$ and the potential difference $V_A - V_B = 5\text{V}$. The voltage across C_1 is-



- (1) zero (2) 5V (3) 10V (4) 15V

IMPORTANT PRACTICE QUESTION SERIES FOR IIT-JEE EXAM - 3

Q.1 The effective capacity of the network between terminals A and B is-



- (1) $6 \mu\text{F}$ (2) $20 \mu\text{F}$ (3) $3 \mu\text{F}$ (4) $10 \mu\text{F}$

Q.2 The energy and capacity of a charged parallel plate capacitor are U and C respectively. Now a dielectric slab of $\epsilon_r = 6$ is inserted in it then energy and capacity becomes (Assuming charge on plates remains constant)

- (1) $6U, 6C$ (2) U, C (3) $\frac{U}{6}, 6C$ (4) $U, 6C$

Q.3 A capacitor is charged with a battery and energy stored is U . After disconnecting battery another capacitor of same capacity is connected in parallel with it. Then energy stored in each capacitor is-

- (1) $U/2$ (2) $U/4$ (3) $4U$ (4) $2U$

Q.4 Energy per unit volume for a capacitor having area A and separation d kept at potential difference V is given by-

- (1) $\frac{1}{2} \epsilon_0 \frac{V^2}{d^2}$ (2) $\frac{1}{2 \epsilon_0} \frac{V^2}{d^2}$ (3) $\frac{1}{2} CV^2$ (4) $\frac{Q^2}{2C}$

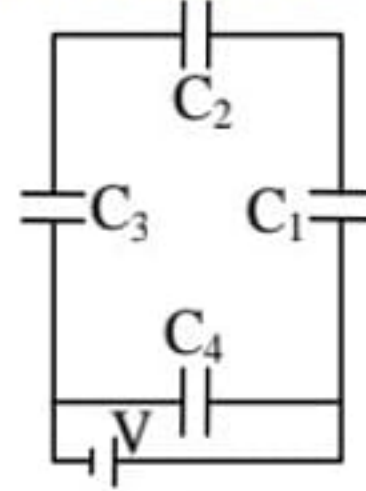
Q.5 A capacitor of capacity C_1 charged upto V and then connected to an uncharged capacitor of capacity C_2 . Then final potential difference across each will be-

- (1) $\frac{C_2 V}{C_1 + C_2}$ (2) $\frac{C_1 V}{C_1 + C_2}$ (3) $\left(1 + \frac{C_2}{C_1}\right) \cdot V$ (4) $\left(1 - \frac{C_2}{C_1}\right) \cdot V$

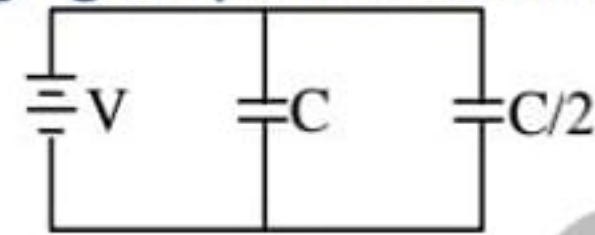
Q.6 Three capacitors each of capacity $4 \mu\text{F}$ are to be connected in such a way that the effective capacitance of $6 \mu\text{F}$. This can be done by-

- (1) connecting all of them in series
 (2) connecting them in parallel
 (3) connecting two in series and one in parallel
 (4) connecting two in parallel and one in series

- Q.7** A network of four capacitors of capacity equal to $C_1 = C$, $C_2 = 2C$, $C_3 = 3C$ and $C_4 = 4C$ are connected to a battery as shown in the figure. The ratio of the charges on C_2 and C_4 is-



- (1) $\frac{7}{4}$ (2) $\frac{22}{3}$ (3) $\frac{3}{22}$ (4) $\frac{4}{7}$
- Q.8** A parallel plate air capacitor is charged to a potential difference of V volts. After disconnecting the charging battery the distance between the plates of the capacitor is increased using an insulating handle. As a result the potential difference between the plates-
- (1) Decreases (2) Does not change (3) Becomes zero (4) Increases
- Q.9** Two condensers, one of capacity C and the other of capacity $\frac{C}{2}$, are connected to a V -volt battery, as shown. The work done in charging fully both the condensers is-

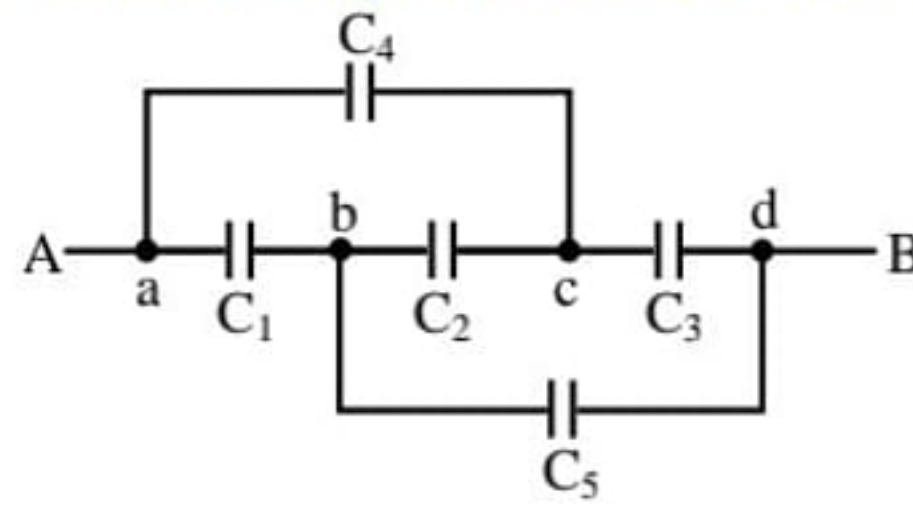


- (1) $\frac{1}{2} CV^2$ (2) $2 CV^2$ (3) $\frac{1}{4} CV^2$ (4) $\frac{3}{4} CV^2$
- Q.10** If the distance between the plates of a parallel plate condenser is halved and the dielectric is doubled, then its capacity will-
- (1) remain the same (2) increase by 2 times (3) increase by 4 times (4) increase by 6 times
- Q.11** What is the area of the plate of a $3F$ parallel plate capacitor, if the separation between the plates is 5 mm ?
- (1) $1.694 \times 10^9 \text{ m}^2$ (2) $4.569 \times 10^9 \text{ m}^2$ (3) $9.281 \times 10^9 \text{ m}^2$ (4) $12.918 \times 10^9 \text{ m}^2$
- Q.12** The dimensions of RC is equal to-
- (1) time (2) inverse time (3) square of inverse time (4) square of time
- Q.13** Minimum number of $8\mu F$ and 250 V capacitors used to make a combination of $16 \mu F$ and 1000 V are -
- (1) 32 (2) 16 (3) 8 (4) 4
- Q.14** Three capacitors of capacitance $3\mu F$, $10\mu F$ and $15\mu F$ are connected in series to a voltage source of 100 V . The charge on $15\mu F$ is-
- (1) $50 \mu C$ (2) $160 \mu C$
(3) $200 \mu C$ (4) $280 \mu C$
- Q.15** Two materials of dielectric constant k_1 and k_2 are filled between two parallel plates of a capacitor as shown in figure. The capacity of the capacitor is-

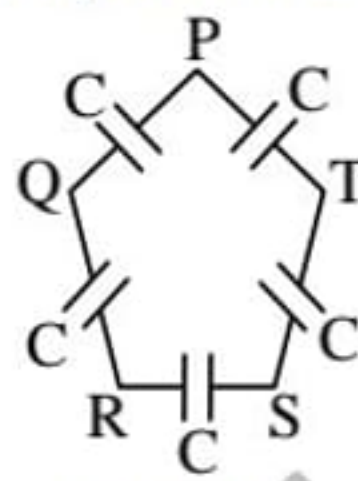


- (1) $\frac{A \epsilon_0 (k_1 + k_2)}{2d}$ (2) $\frac{2A \epsilon_0}{d} \left(\frac{k_1 k_2}{k_1 + k_2} \right)$
(3) $\frac{A \epsilon_0}{d} \left(\frac{k_1 k_2}{k_1 + k_2} \right)$ (4) $\frac{A \epsilon_0}{2d} \left(\frac{k_1 + k_2}{k_1 k_2} \right)$
- Q.16** A conducting sphere of radius 10 cm is charged with $10 \mu C$. Another uncharged sphere of radius 20 cm is allowed to touch it for some time. After that if the spheres are separated, then surface density of charged on the spheres will be in the ratio of-
- (1) $1 : 4$ (2) $1 : 3$ (3) $2 : 1$ (4) $1 : 1$

- Q.17** In the given figure, the capacitors C_1, C_3, C_4, C_5 have a capacitance $4\mu\text{F}$ each. If the capacitor C_2 has a capacitance $10\mu\text{F}$, then effective capacitance between A and B will be-



- (1) $2\mu\text{F}$ (2) $4\mu\text{F}$ (3) $6\mu\text{F}$ (4) $8\mu\text{F}$
- Q.18** A $40\mu\text{F}$ capacitor in a defibrillator is charged to 3000 V . The energy stored in the capacitor is sent through the patient during a pulse of duration 2 ms . The power delivered to the patient is-
- (1) 45 kW (2) 90 Kw (3) 180 kW (4) 360 kW
- Q.19** Five capacitors, each of capacitance value C are connected as shown in the figure. The ratio of capacitance between P and R, and the capacitance between P and Q is-

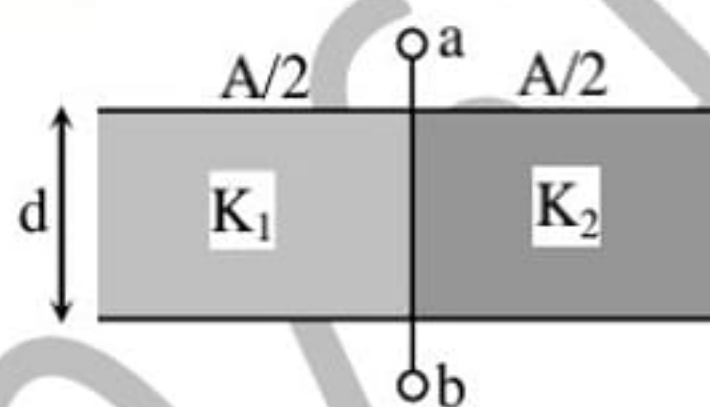


- (1) $3 : 1$ (2) $5 : 2$ (3) $2 : 3$ (4) $1 : 1$
- Q.20** Three capacitors each of capacitance C and of breakdown voltage V are joined in series. The capacitance and breakdown voltage of the combination will be-
- (1) $3C, 3V$ (2) $\frac{C}{3}, \frac{V}{3}$ (3) $3C, \frac{V}{3}$ (4) $\frac{C}{3}, 3V$
- Q.21** A parallel plate condenser has a uniform electric field E (V/m) in the space between the plates. If the distance between the plates is d (m) and area of each plate is A (m^2) the energy (joules) stored in the condenser is :
- (1) $\frac{1}{2} \epsilon_0 E^2 Ad$ (2) $E^2 Ad / \epsilon_0$ (3) $\frac{1}{2} \epsilon_0 E^2$ (4) $\epsilon_0 EAd$

IMPORTANT PRACTICE QUESTION SERIES FOR IIT-JEE EXAM - 4

- Q.1** Two capacitors of $1\mu\text{F}$ and $2\mu\text{F}$ are connected in series and this combination is charged upto a potential difference of 120V . What will be the potential difference across $1\mu\text{F}$ capacitor ?
 (1) 40V (2) 60V
 (3) 80V (4) 120V

- Q.2** The capacity of a parallel plate air capacitor is $10\mu\text{F}$. As shown in the figure this capacitor is divided into two equal parts, these parts are filled by media of dielectric constants $K_1 = 2$ and $K_2 = 4$, capacity of this arrangement will be -

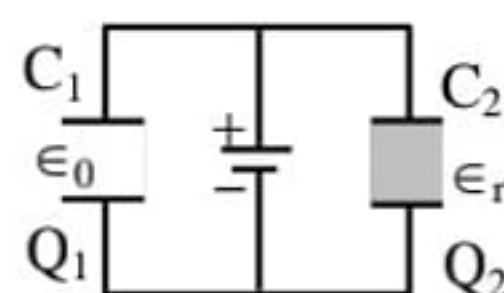


- (1) $20\mu\text{F}$ (2) $30\mu\text{F}$ (3) $10\mu\text{F}$ (4) $40\mu\text{F}$

- Q.3** Parallel combination of two capacitors, each of value $10\mu\text{F}$ is charged by 200V d.c. Total energy of the charges in joules will be -
 (1) 0.1 (2) 0.2 (3) 0.4 (4) 0.6

- Q.4** Three capacitors, each of value $1\mu\text{F}$ are such combined that the resultant capacity is $1.5\mu\text{F}$. Then
 (1) All three capacitors are connected in parallel.
 (2) All three capacitors are connected in series.
 (3) Third capacitor is in series with parallel combination of others two.
 (4) Third capacitor is in parallel with series combination of others two.

- Q.5** As shown in figure, two identical capacitors of values C_1 and C_2 are connected with a battery. Space between the plates of C_1 is filled with air and that of between plates of C_2 is filled with an insulator, then -



- (1) $Q_1 > Q_2$ (2) $Q_1 < Q_2$
 (3) $Q_1 = Q_2$ (4) None of the above

- Q.6** Charge and the energy stored of a capacitor of value C are respectively Q and W . If its charge is increased to $2Q$, then the stored energy will be -
 (1) $2W$ (2) $W/2$ (3) $4W$ (4) $W/4$

- Q.7** A capacitor of capacity C is charged to a potential V . Then it is taken out and connected in parallel with an uncharged identical capacitor. Then charge on each capacitor will be -
 (1) CV (2) $CV/2$ (3) $CV/8$ (4) $CV/4$

- Q.8** Two capacitors of value $0.3 \mu\text{F}$ and $0.6\mu\text{F}$ are connected in series with a source of 6 volt, then the ratio of energy stored in each capacitor will be -
 (1) $\frac{1}{2}$ (2) 2 (3) $\frac{1}{4}$ (4) 4
- Q.9** A parallel plate capacitor is connected with a battery whose potential is constant. If the plates capacitor are shifted apart then the intensity of electric field -
 (1) Decrease and charge on plates also decreases.
 (2) Remains constant but charge on plates decreases.
 (3) Remains constant but charge on plates increases.
 (4) Increase but charge on plates decreases.
- Q.10** Half of the space between parallel plate capacitor is filled with a medium of dielectric constant K parallel to the plates. If initially the capacity is C , then the new capacity will be -
 (1) $2KC/(1+K)$ (2) $C(K+1)/2$ (3) $CK/(1+K)$ (4) KC
- Q.11** The distance between the plates of a circular parallel capacitor of diameter 40 mm, whose capacity is equal to that of a metallic sphere of radius 1m will be -
 (1) 0.01 mm (2) 0.1 mm (3) 1.0 mm (4) 10 mm
- Q.12** When a slab of dielectric medium is placed between plates of a parallel plate capacitor high is connected with a battery, then the charge on plates in comparison with earlier charge -
 (1) Is less (2) Is same (3) Is more
 (4) Depends on the nature of the material inserted
- Q.13** Two identical parallel plate capacitors are connected in series and then joined with a battery of 100 V. A sheet of dielectric constant 4.0 is inserted between the plates of second capacitor. The potential difference across the capacitors will be respectively -
 (1) 50V, 50V (2) 80V, 20V (3) 20V, 80V (4) 75V, 25V
- Q.14** If a capacitor, with air as dielectric, is so charged that the potential difference across the plates becomes 100V. If now the space between plates is filled with a medium of dielectric constant 10, then the potential difference across the plates will be -
 (1) 1000 V (2) 100 V (3) 10 V (4) zero
- Q.15** A capacitor of value $4\mu\text{F}$ charged at 50V is connected with another capacitor of value $2\mu\text{F}$ charged at 100V, in such a way that plates of similar charges are connected together. Before joining and after joining the total energy in multiple 10^{-2} J will be -
 (1) 1.5 and 1.33 (2) 1.33 and 1.5 (3) 3.0 and 2.67 (4) 2.67 and 3.0
- Q.16** 64 small drops of water, whose charge and radius are same, are joined to make a big drop. The capacity of big drop is following times that of small drop -
 (1) 4 (2) 8 (3) 16 (4) 64
- Q.17** The radii of a spherical capacitor are 0.5 m and 0.6 m. If the empty space is completely filled by a medium of dielectric constant 6, then the capacity of the capacitor will be -
 (1) $3.3 \times 10^{-10}\text{F}$ (2) $2 \times 10^{-9}\text{F}$ (3) 2 F (4) 18 F
- Q.18** The distance between plates of a parallel plate capacitor is 'd'. Another thick metal plate of thickness $d/2$ and area same as that of plates is so plated between the plates, that it does not touch the plates. The capacity of the resultant capacitor -
 (1) remains same (2) becomes double
 (3) becomes half (4) becomes one fourth
- Q.19** When air is replaced by a dielectric medium from the space between the plates of a charged parallel plate capacitor, then the intensity of electric field -
 (1) Decreases (2) Remain same
 (3) Becomes zero (4) Increases

Q.20 In a parallel plate capacitor, sheets of thickness t_1 and t_2 with dielectric constant of K_1 and K_2 respectively are placed. Capacity of this condenser will be -

- (1) $\epsilon_0 A / \left\{ \frac{t_1}{K_1} + \frac{t_2}{K_2} \right\}$ (2) $\epsilon_0 A / \left\{ \frac{K_1}{t_1} + \frac{K_2}{t_2} \right\}$
 (3) $\epsilon_0 A / \left\{ \frac{t_1}{K_2} + \frac{t_2}{K_1} \right\}$ (4) $\epsilon_0 A / \left\{ \frac{K_2}{t_1} + \frac{K_1}{t_2} \right\}$

Q.21 When a capacitor of value $200\mu\text{F}$ charged to 200V is discharged separately through resistance of $2\ \Omega$ and $8\ \Omega$, then heat produced in joule will respectively be -

- (1) 4 and 16 (2) 16 and 4
 (3) 4 and 8 (4) 4 and 4

Q.22 A series combination of two capacitors of value $0.1\ \mu\text{F}$ and $1\ \mu\text{F}$ is connected with a source of voltage $500\ \text{V}$. The p.d. in volt across the capacitor of value $0.1\ \mu\text{F}$ will be -

- (1) 50 (2) 500
 (3) 45.5 (4) 454.5

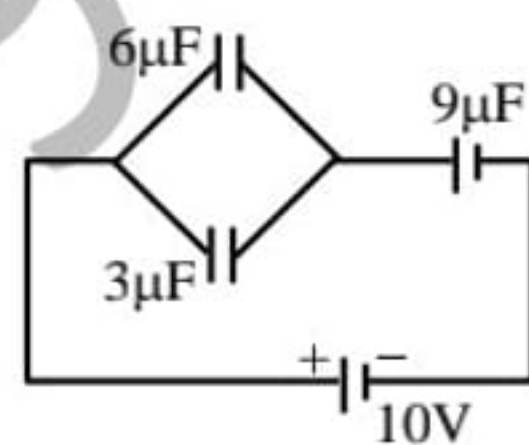
Q.23 The magnitude of storing capacity of a PPC does not depend on -

- (1) area of the plate
 (2) medium between the plates
 (3) distance between the plates
 (4) metal of the plate

Q.24 An uncharged capacitor is connected with a battery on charging the capacitor fully -

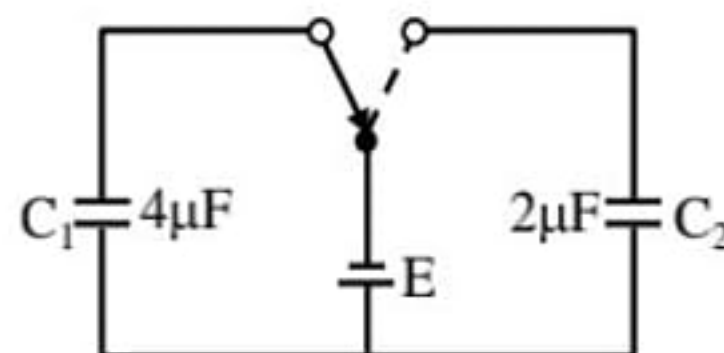
- (1) The total energy given is stored in capacitor.
 (2) Half of the energy given is stored in capacitor.
 (3) The energy stored depends only on capacity of capacitor.
 (4) The energy stored depends on the time taken to charge the capacitor.

Q.25 Three capacitors of value $6, 3$ and $9\ \mu\text{F}$ are joined according to the circuit and then the combination is connected with a battery of $10\ \text{V}$. The potential difference across the third capacitor plates will be -



- (1) 4 V (2) 5 V (3) 6 V (4) 2 V

Q.26 Two uncharged capacitors are charged with a battery of E volt. The ratio of charges produced on these capacitors Q_1/Q_2 will be -



- (1) 1 : 2 (2) 2 : 1 (3) 4 : 1 (4) 1 : 1

Q.27 A parallel plate capacitor is charged with a battery and afterwards the battery is removed. If now with the help of insulating handles, the distance between plates is increased, then -

- (1) charge on capacitor increases and capacity decreases.
 (2) potential difference between plates increases.
 (3) capacity of capacitor increases.
 (4) value of energy stored in capacitor decreases.

Q.28 Capacity of a capacitor is C and the potential given to it is V . Now if it is connected with a resistance $R\ \Omega$, then the energy across the resistance $R\ \Omega$ liberated as the form of heat will be

- (1) $1/2 CV^2$ (2) $1/2 CV$
 (3) $Q/2C$ (4) $QV^2 / 2$

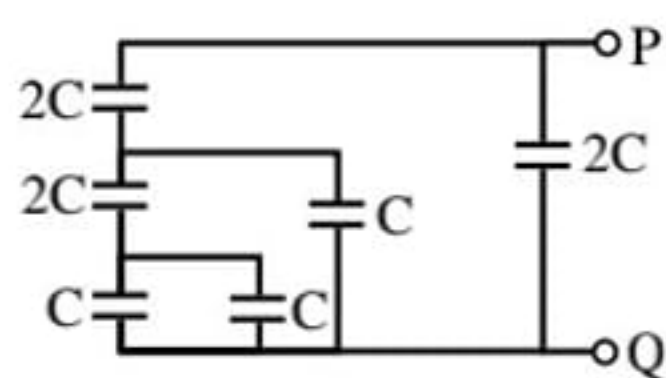
Q.29 A $3\mu\text{F}$ capacitor is charged to a potential of 300 V and $2\mu\text{F}$ capacitor is charged to 200 V. The capacitor are then connected in parallel with plates of opposite polarity joined together. What amount of charge will flow, when the plates are so connected ?

- (1) $1300\ \mu\text{C}$ (2) $800\ \mu\text{C}$
 (3) $600\ \mu\text{C}$ (4) $300\ \mu\text{C}$

Q.30 The value of capacitor formed by a thin metallic foil is $2\ \mu\text{F}$. The foil is attached to both sides of paper having a thickness of 0.015 mm. The dielectric constant of the paper is 2.5 and its breadth is 40 mm. The length of the foil used is-

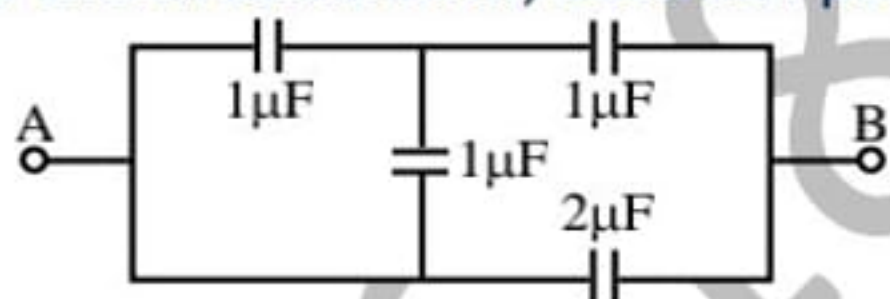
- (1) 0.34 m (2) 1.33 m
 (3) 13.4 mm (4) 33.9 m

Q.31 The value of equivalent capacitance of the combination shown in fig., between the points P and Q is -



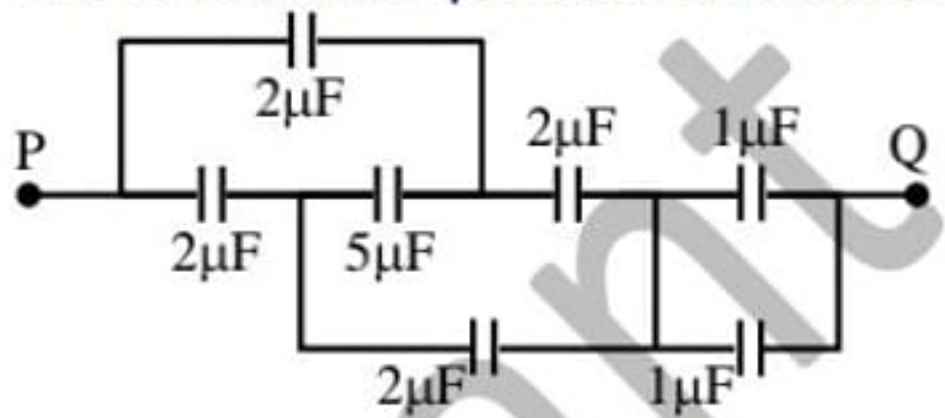
- (1) $3\ C$ (2) $2\ C$ (3) C (4) $C/3$

Q.32 The equivalent capacitance of the circuit shown, between points A and B will be -



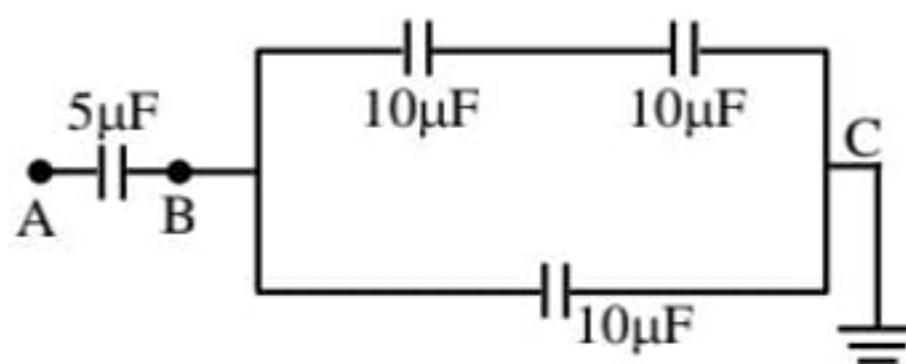
- (1) $\frac{2}{3}\ \mu\text{F}$ (2) $\frac{5}{3}\ \mu\text{F}$
 (3) $\frac{8}{3}\ \mu\text{F}$ (4) $\frac{7}{3}\ \mu\text{F}$

Q.33 The effective capacitance between the points P and Q of the arrangement shown in the fig. is -



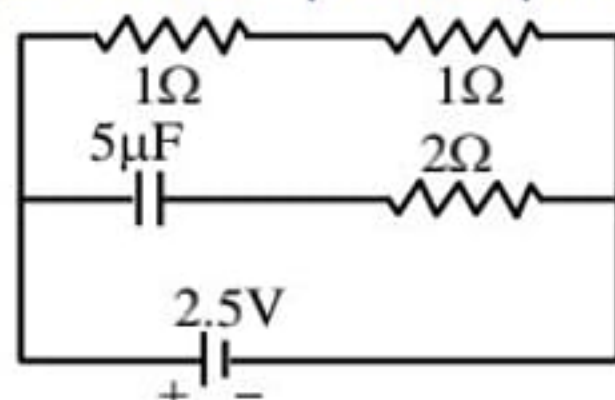
- (1) $(1/2)\ \mu\text{F}$ (2) $1\ \mu\text{F}$
 (3) $2\ \mu\text{F}$ (4) $1.33\ \mu\text{F}$

Q.34 In the given circuit if point C is connected to the earth and a potential of + 2000 V is given to point A, the potential at B is -



- (1) 1500 V (2) 1000 V
 (3) 500 V (4) 400 V

Q.35 A capacitor of capacitance $5\ \mu\text{F}$ is connected as shown in the fig. The internal resistance of the cell is $0.5\ \Omega$. The amount of charge on the capacitor plate is -



- (1) $0\ \mu\text{C}$ (2) $5\ \mu\text{C}$

- (3) $10 \mu\text{C}$ (4) $25 \mu\text{C}$

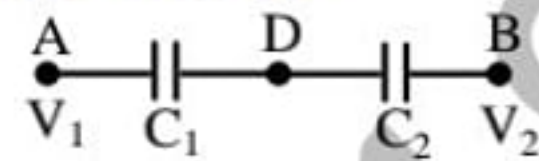
Q.36 Choose the incorrect statement from the following when two identical capacitors are charged individually to different potentials and connected parallel to each other after disconnecting them from the source-

- (1) Net charge equals the sum of initial charges
- (2) The net energy stored in the two capacitors is less than the sum of the initial individual energies.
- (3) The net potential difference across them is different from the sum of the individual initial potential difference.
- (4) The net potential difference across them equals the sum of the individual initial potential differences.

Q.37 The area of the plates of a parallel plate condenser is A and the distance between the plates is 10 mm . There are two dielectric sheets in it, one of dielectric constant 10 and thickness 6 mm and the other of dielectric constant 5 and thickness 4 mm . The capacity of the condenser is-

- (1) $\frac{12}{35} \epsilon_0 A$ (2) $\frac{2}{3} \epsilon_0 A$
- (3) $\frac{5000}{7} \epsilon_0 A$ (4) $1500 \epsilon_0 A$

Q.38 Two condensers C_1 and C_2 in a circuit are joined as shown in fig. The potential of point A is V_1 and that of B is V_2 . The potential of point D will be -

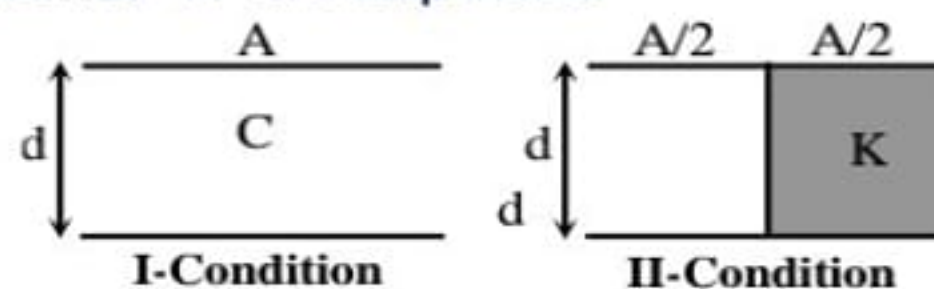


- (1) $\frac{1}{2} (V_1 + V_2)$ (2) $\frac{C_2 V_1 + C_1 V_2}{C_1 + C_2}$
- (3) $\frac{C_1 V_1 + C_2 V_2}{C_1 + C_2}$ (4) $\frac{C_2 V_1 - C_1 V_2}{C_1 + C_2}$

Q.39 An air capacitor of capacity $C = 10 \mu\text{F}$ is connected to a constant voltage battery of 12 V . Now the space between the plates is filled with a liquid of dielectric constant 5 . The additional charge that flows now from battery to the capacitor is -

- (1) $120 \mu\text{C}$ (2) $600 \mu\text{C}$
- (3) $480 \mu\text{C}$ (4) $24 \mu\text{C}$

Q.40 The capacitance of a parallel plate capacitor is C and distance between the plates is d . If the space between the plates is filled with a substance of dielectric constant K as shown in the fig. then what will be the new capacitance of the capacitor -



- (1) $\frac{C}{2} (1 + K)$ (2) $\frac{C}{2} (K)$
- (3) $\frac{C}{2}$ (4) $2 C$

Q.41 If there are three capacitors and a source which has an e.m.f. V then how the three capacitors should be connected across the source for the stored energy to be maximum -

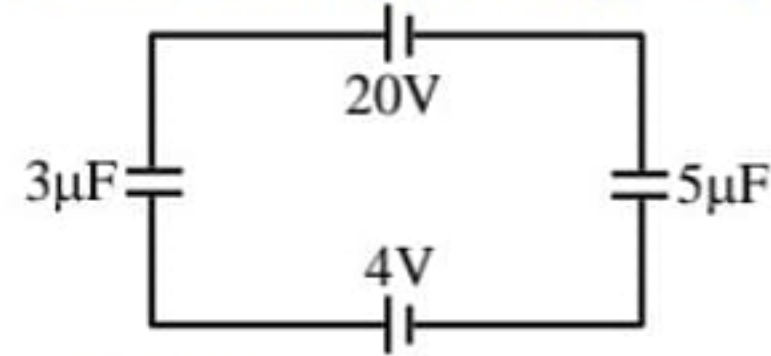
- (1) All the three capacitors should be connected in parallel
- (2) All the three capacitors should be connected in series
- (3) The stored energy will be same in all cases
- (4) Nothing can be said

Q.42 A capacitor is charged, now the battery is removed and a dielectric plate is entered, then choose the correct statement -

- (1) Charge increases, voltage decreases and electrostatic energy increases
- (2) Charge remains constant, voltage increases and electrostatic energy decreases
- (3) Charge remains constant and voltage and electrostatic energy both decrease

(4) None of these

Q.43 In the given circuit, the potential difference across $3\mu\text{F}$ capacitor will be -



(1) 16 V (2) 10 V (3) 6 V (4) 4 V

Q.44 A parallel plate capacitor has the space between its plates filled by two slabs of thickness $d/2$ each and dielectric constant K_1 and K_2 . d is the plate separation of the capacitor. The capacitance of the capacitor is -

- (1) $\frac{2\epsilon_0 A}{d} \left[\frac{K_1 + K_2}{K_1 K_2} \right]$ (2) $\frac{2\epsilon_0 A}{d} (K_1 + K_2)$
(3) $\frac{2\epsilon_0 A}{d} \left[\frac{K_1 K_2}{K_1 + K_2} \right]$ (4) $\frac{2\epsilon_0 d}{A} \left[\frac{K_1 + K_2}{K_1 K_2} \right]$

Q.45 A $10\mu\text{F}$ capacitor is charged to a potential difference of 50 V and is connected to another uncharged capacitor in parallel. Now the common potential difference becomes 20 volt. The capacitance of second capacitor is -

(1) $10\mu\text{F}$ (2) $20\mu\text{F}$ (3) $30\mu\text{F}$ (4) $15\mu\text{F}$

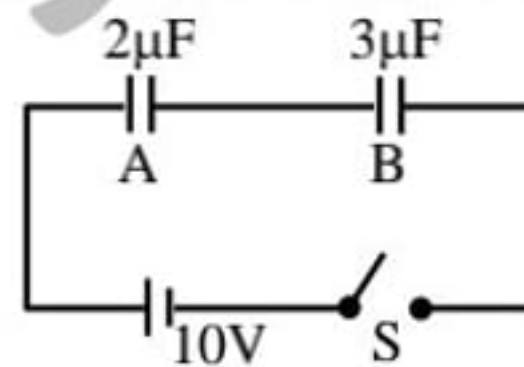
Q.46 The equivalent capacitance of three capacitors of capacitance C_1 , C_2 and C_3 are connected in parallel is 12 units and product $C_1 \cdot C_2 \cdot C_3 = 48$. When the capacitors C_1 and C_2 are connected in parallel, the equivalent capacitance is 6 units. Then the capacitance are -

(1) 2, 3, 7 (2) 1.5, 2.5, 8
(3) 1, 5, 6 (4) 2, 4, 6

Q.47 Two charged spheres having radii a and b are joined with a wire then the ratio of electric field E_a/E_b on their surface is -

(1) a/b (2) b/a (3) a^2/b^2 (4) b^2/a^2

Q.48 Two capacitors A and B are connected in series with a battery as shown in the figure when the switch S is closed and the two capacitors get charged fully, then -



- (1) The p.d. across the plates of A is 4 V and across the plates of B is 6V
(2) The p.d. across the plates of A is 6V and across the plates B is 4V
(3) The ratio of electrical energies stored in A and B is 2 : 3
(4) The ratio of charges on A and B is 3 : 2

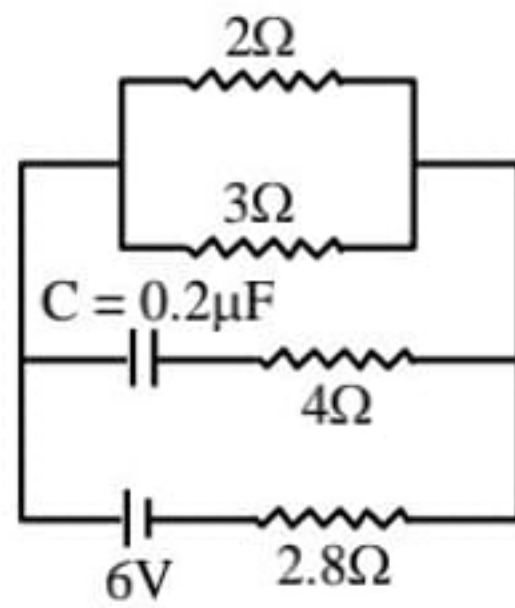
Q.49 In a capacitor of capacitance $20\mu\text{F}$ the distance between the plates is 2mm. If a dielectric slab of width 1 mm and dielectric constant 2 is inserted between the plates, then the new capacitance will be -

(1) $22\mu\text{F}$ (2) $26.6\mu\text{F}$
(3) $52.2\mu\text{F}$ (4) $13\mu\text{F}$

Q.50 An automobile spring extends 0.2 m for 5000 N load. The ratio of potential energy stored in this spring when it has been compressed by 0.2 m to the potential energy stored in a $10\mu\text{F}$ capacitor at a potential difference of 10000 V will be

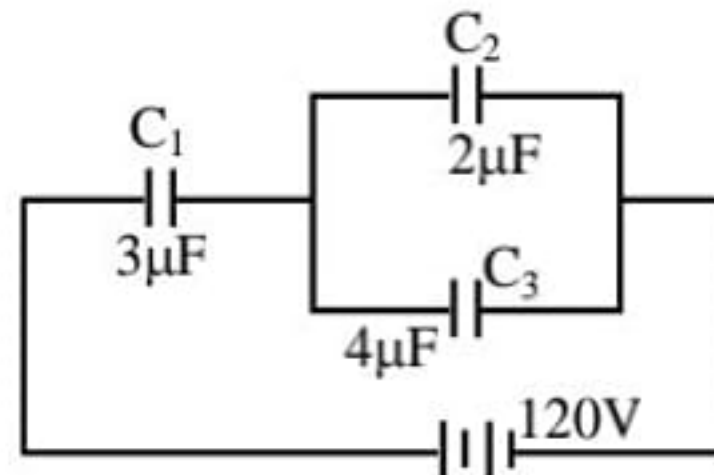
(1) $\frac{1}{4}$ (2) 1 (3) $\frac{1}{2}$ (4) 2

Q.51 In the given figure the steady state current is -



- (1) zero (2) 0.6 A (3) 0.9 A (4) 1.5 A

Q.52 The charge on capacitors shown in fig. and the potential difference across each will be respectively -

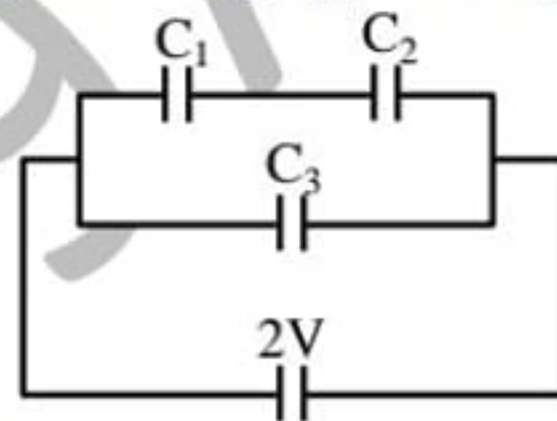


- (1) 240 μC , 80 μC , 160 μC and 80 V, 40 V, 40 V (2) 300 μC , 75 μC , 150 μC and 40 V, 80 V, 60 V
 (3) 220 μC , 70 μC , 140 μC and 60 V, 50 V, 40 V (4) none of these

Q.53 Three capacitor 2 μF , 3 μF and 6 μF are connected in series with 10 volt battery then charge on 3 μF capacitor is -

- (1) 5 μC (2) 10 μC
 (3) 11 μC (4) 15 μC

Q.54 Two capacitors $C_1 = 2\mu\text{F}$ and $C_2 = 6\mu\text{F}$ in series, are connected in parallel to a third capacitor $C_3 = 4\mu\text{F}$. This arrangement is then connected to a battery of e.m.f = 2V, as shown in the fig. How much energy is given by the battery in charging the capacitors -



- (1) $22 \times 10^{-6} \text{ J}$ (2) $11 \times 10^{-6} \text{ J}$
 (3) $\left(\frac{32}{3}\right) \times 10^{-6} \text{ J}$ (4) $\left(\frac{16}{3}\right) \times 10^{-6} \text{ J}$

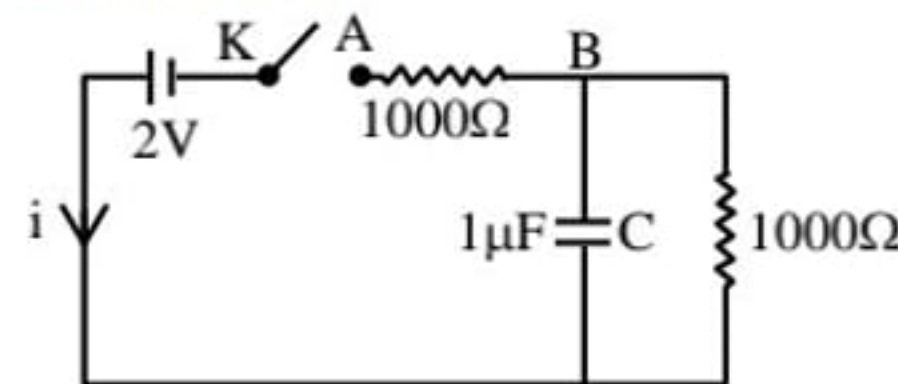
Q.55 A solid conducting sphere of radius R_1 is surrounded by another concentric hollow conducting sphere of radius R_2 . The capacitance of this assembly is proportional to -

- (1) $\frac{R_2 - R_1}{R_1 R_2}$ (2) $\frac{R_2 + R_1}{R_1 R_2}$
 (3) $\frac{R_1 R_2}{R_1 + R_2}$ (4) $\frac{R_1 R_2}{R_2 - R_1}$

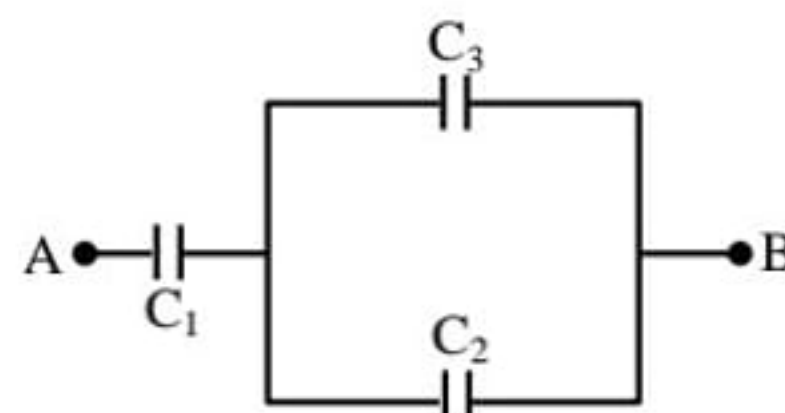
Q.56 Two conducting spheres of radii R_1 and R_2 are charged with charges Q_1 and Q_2 respectively. On bringing them in contact there is -

- (1) No change in the energy of the system
 (2) An increase in the energy of the system if $Q_1 R_2 \neq Q_2 R_1$
 (3) Always a decrease in energy of the system
 (4) A decrease in energy of the system if $Q_1 R_2 \neq Q_2 R_1$

- Q.57** When the key is pressed at time $t = 0$ then which of the following statement about the current i in the resistor AB of the given circuit is true -

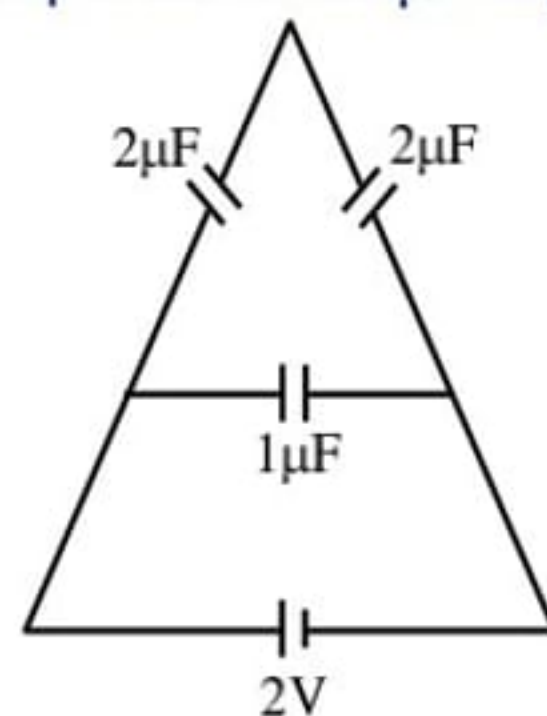


- (1) at $t = 0$, $i = 2\text{mA}$ and with time it goes to 1mA
 (2) i oscillates between 1mA and 2mA
 (3) $i = 2\text{mA}$ at all t
 (4) $i = 1\text{mA}$ at all t
- Q.58** Time constant of a series R–C circuit is -
 (1) $+RC$ (2) $-RC$
 (3) $\frac{R}{C}$ (4) $\frac{C}{R}$
- Q.59** Two capacitors of capacitances $3\mu\text{F}$ and $6\mu\text{F}$ are charged to a potential of 12V each. They are now connected to each other with the positive plate of each joined to the negative plate of the other. The potential difference across each will be -
 (1) 3V (2) Zero (3) 6V (4) 4V
- Q.60** A capacitor of $0.2\mu\text{F}$ capacitance is charged to 600V . On removing the battery, it is connected with a $1.0\mu\text{F}$ capacitor in the parallel then the potential of capacitor will become -
 (1) 300V (2) 600V
 (3) 100V (4) 120V
- Q.61** Mean electric energy density between the plates of a charged capacitor is -
 Here q = Charge on capacitor
 A = Area of the plate of the capacitor
 (1) $q^2/2\epsilon_0 A^2$ (2) $q/2\epsilon_0 A^2$
 (3) $q^2/2\epsilon_0 A$ (4) None of these
- Q.62** If potential difference across a capacitor is changed from 15V to 30V , work done is W . The work done when potential difference is changed from 30V to 60V , will be -
 (1) W (2) $4W$ (3) $3W$ (4) $2W$
- Q.63** The combination of capacitors with $C_1=3\mu\text{F}$, $C_2=4\mu\text{F}$ and $C_3=2\mu\text{F}$ is charged by connecting AB to a battery. Consider the following statements –
 (I) Energy stored in C_1 = Energy stored in C_2 + Energy stored in C_3
 (II) Charge on C_1 = Charge on C_2 + Charge on C_3
 (III) Potential drop across C_1 = Potential drop across C_2 = Potential drop across C_3
 Which of these are correct –



- (1) I and II (2) II only
 (3) I and III (4) III only
- Q.64** A capacitor is connected to 10V . The charge on plates is $40\mu\text{C}$. If medium between plates is air. The charge on plates will become $100\mu\text{C}$ if the space between the plates is filled with oil. The dielectric constant of oil is-
 (1) 2.5 (2) 4 (3) 6.25 (4) 10

- Q.65** The energy density of electric field is proportional to -
 (1) $\frac{1}{E^2}$ (2) E (3) $\frac{1}{E}$ (4) E^2
- Q.66** If the distance between plates of a capacitor having capacity C and charge Q is increased to double then work done will be -
 (1) $Q^2/4C$ (2) $Q^2/2C$ (3) Q^2/C (4) $2Q^2/C$
- Q.67** A slab of copper of thickness $d/2$ is introduced between the plates of a parallel plate capacitor where d is the separation between its two plates. If the capacitance of the capacitor without copper slab is C and with copper slab is C' then $\frac{C'}{C}$ is -
 (1) $\sqrt{2}$ (2) 2 (3) 1 (4) $\frac{1}{\sqrt{2}}$
- Q.68** Two capacitor each having a capacitance C and break down voltage V are joined in series. The effective capacitance and maximum working voltage of the combination is -
 (1) $2C, 2V$ (2) $\frac{C}{2}, \frac{V}{2}$ (3) $2C, V$ (4) $\frac{C}{2}, 2V$
- Q.69** The capacitance of a capacitor is 4×10^{-6} F and its voltage is 100 V. The energy required to discharge it completely -
 (1) 0.025 J (2) 0.05 J
 (3) 0.02 J (4) 0.04 J
- Q.70** Between the plates of parallel plate capacitors of capacity C two parallel plates of the same metal and area same as the plates of the original capacitor are placed. If the thickness of each plate is equal to $\frac{1}{5}$ th of the distance between the plates of the original capacitor then the capacity of the new capacitor is -
 (1) $\frac{5}{3}C$ (2) $\frac{3}{5}C$ (3) $\frac{3}{10}C$ (4) $\frac{10}{3}C$
- Q.71** The charge on any one of the $2\mu\text{F}$ capacitor and $1\mu\text{F}$ capacitor will be given respectively (in μC) as



- (1) 1,2 (2) 2,1 (3) 1,1 (4) 2,2

- Q.72** The electric field between the plates of a parallel plate capacitor when connected to a certain battery is E_0 . If the spaced between the plates of the capacitor is filled by introducing a material of dielectric constant K without disturbing the battery connections, the field between the plates shall be -
 (1) KE_0 (2) E_0
 (3) $\frac{E_0}{K}$ (4) None of the above
- Q.73** Two capacitor with capacity C_1 and C_2 , when connected in series, have a capacitance C_s and when connected in parallel have a capacitance C_p . Which of the following is true -

$$(1) C_s = C_1 + C_2 \quad (2) C_p = \frac{C_1 C_2}{C_1 + C_2}$$

$$(3) \frac{C_s}{C_p} = \frac{C_1}{C_2} \quad (4) C_s C_p = C_1 C_2$$

Q.74 A parallel plate capacitor C has a charge q and potential V between the plates. Work required to double the distance between the plates is -

$$(1) \frac{1}{2} CV^2 \quad (2) \frac{1}{4} CV^2$$

$$(3) \frac{1}{2} C \left(\frac{V}{2} \right)^2 \quad (4) CV^2$$

Q.75 Two metallic spheres of radii R_1 and R_2 are connected by a thin wire. If $+q_1$ and $+q_2$ are the charges on the two spheres then -

$$(1) \frac{q_1}{q_2} = \frac{R_1^2}{R_2^2} \quad (2) \frac{q_1}{q_2} = \frac{R_1}{R_2}$$

$$(3) \frac{q_1}{q_2} = \frac{R_1^3}{R_2^3} \quad (4) \frac{q_1}{q_2} = \frac{(R_1^2 - R_2^2)}{(R_1^2 + R_2^2)}$$

Q.76 Two same sphere having radii 10 cm and 20 cm. these have been given total charge $150 \mu\text{C}$ and connected by a wire. Their common potential will be -

$$(1) 9 \times 10^6 \text{ volt}$$

$$(2) 4.5 \times 10^6 \text{ volt}$$

$$(3) 1.8 \times 10^6 \text{ volt}$$

$$(4) 1.35 \times 10^9 \text{ volt}$$

IMPORTANT PRACTICE QUESTION SERIES FOR IIT-JEE EXAM - 5

These questions of two statements each, printed as Assertion and Reason. While answering these Questions you are required to choose any one of the following four responses.

- (A) If both Assertion & Reason are true & the Reason is a correct explanation of the Assertion.
(B) If both Assertion and Reason are true but Reason is not a correct explanation of the Assertion.
(C) If Assertion is true but the Reason is false.
(D) If Assertion & Reason both are false.

- Q.1** **Assertion:** Farad is too big a unit of capacity.
Reason: Capacity of earth- which is the largest sphere is in microfarad.
(1) A (2) B (3) C (4) D
- Q.2** **Assertion :** Capacity of a parallel plate condenser increases on introducing a conducting or insulating slab between the plates.
Reason : In both the cases, electric field intensity between the plates reduces.
(1) A (2) B (3) C (4) D
- Q.3** **Assertion :** When charges are shared between any two bodies, some charge is lost, and some loss of energy does occur.
Reason : Some energy disappears in the form of heat, sparking etc.
(1) A (2) B (3) C (4) D
- Q.4** **Assertion :** The whole charge of a body can be transferred to another body.
Reason : Charge can not be transferred partially.
(1) A (2) B (3) C (4) D
- Q.5** **Assertion :** In a series combination of capacitors, charge on each capacitor is same.
Reason : In such a combination, charge can move only along one route.
(1) A (2) B (3) C (4) D
- Q.6** **Assertion :** Increasing the charge on the plates of a capacitor means increasing the capacitance.
Reason : Because $Q = CV \Rightarrow Q \propto C$.
(1) A (2) B (3) C (4) D
- Q.7** **Assertion :** The capacitance of a capacitor depends on the shape, size and geometrical placing of the conductors and its medium between them.
Reason : When a charge q passes through a battery of emf E from the negative terminal to an positive terminal, an amount qE of work is done by the battery.
(1) A (2) B (3) C (4) D
- Q.8** **Assertion :** A dielectric slab is inserted between the plates of an isolated charged capacitor. The charge on the capacitor will remain the same.
Reason : Charge on a isolated system is conserved.
(1) A (2) B (3) C (4) D

IMPORTANT PRACTICE QUESTION SERIES FOR IIT-JEE EXAM - 1 (ANSWERS)

Q.No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans.	1	1	4	1	1	1	3	3	2	4	3	3	2	1	2	2	3	4	3	1
Q.No.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Ans.	1	3	4	4	3	3	2	3	2	2	2	2	1	4	2	2	1	3	4	4
Q.No.	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Ans.	3	3	2	3	1	1	2	4	1	1	1	1	2	3	4	3	1	3	3	2
Q.No.	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Ans.	4	3	4	2	4	3	3	3	1	2	4	1	3	1	1	4	4	3	1	3
Q.No.	81	82	83	84	85	86														
Ans.	1	1	2	3	2	3														

IMPORTANT PRACTICE QUESTION SERIES FOR IIT-JEE EXAM - 2 (ANSWERS)

Q.No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans.	2	1	1	2	3	1	1	1	1	2	3	2	1	4	3	2	3	3	3	1
Q.No.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Ans.	2	3	4	3	2	3	2	4	1	2	1,2	3	4	3	4	2	1	2	3	3
Q.No.	41	42																		
Ans.	3	3																		

IMPORTANT PRACTICE QUESTION SERIES FOR IIT-JEE EXAM - 3 (ANSWERS)

Ques.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ans.	1	3	2	1	2	3	3	4	4	3	1	1	1	3	1
Ques.	16	17	18	19	20	21									
Ans.	3	2	2	3	4	1									

IMPORTANT PRACTICE QUESTION SERIES FOR IIT-JEE EXAM - 4 (ANSWERS)

Q.No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans.	3	2	3	4	2	3	2	2	1	1	2	3	2	3	1	1	2	2	1	1
Q.No.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Ans.	4	4	4	2	2	2	2	1	3	4	1	3	2	3	3	4	3	3	3	1
Q.No.	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Ans.	1	3	2	3	4	4	2	2	2	2	4	1	2	1	4	4	1	1	4	3
Q.No.	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76				
Ans.	1	2	2	1	4	2	2	4	3	1	4	2	4	1	2	2				

IMPORTANT PRACTICE QUESTION SERIES FOR IIT-JEE EXAM - 5 (ANSWERS)

Ques.	1	2	3	4	5	6	7	8
Ans.	1	1	4	3	1	4	2	1