DAY NINETEEN

Electrostatics

Learning & Revision for the Day

- Electric Charge
- Coulomb's Law of Forces between Two Point Charges
- Superposition Principle
- Electric Field
- Continuous Charge Distribution
- Motion of A Charged Particle in An Electric Field
- Electric Dipole
- Electric Flux (ϕ_E)
- Gauss Law
- Electric Potential
- Electric Potential Energy
- Equipotential Surface
- Conductors and Insulators
- Electrical Capacitance
- Capacitor

If the charge in a body does not move, then the frictional electricity is known as static electricity. The branch of physics which deals with static electricity is called electrostatics.

Electric Charge

Electric charge is the property associated with matter due to which it produces and experiences electric and magnetic effects.

Conservation of Charge

We can neither create nor destroy electric charge. The charge can simply be transferred from one body to another. There are three modes of charge transfer:

(a) By friction (b) By conduction (c) By induction

Quantisation of Charge

Electric charge is quantised. The minimum unit of charge, which may reside independently is the electronic charge e having a value of 1.6×10^{-19} C, i.e. $Q = \pm ne$, where, n is any integer.

Important properties of charges are listed below

- Like charges repel while opposite charges attract each other.
- Charge is invariant i.e. charge does not change with change in velocity.
- According to theory of relativity, the mass, time and length change with a change in velocity but charge does not change.
- A charged body attracts a lighter neutral body.
- Electronic charge is additive, i.e. the total charge on a body is the algebraic sum of all the charges present in different parts of the body. For example, if a body has different charges as $+2q, +4q, -3q, -q$, then the total charge on the body is $+2q$.

Coulomb's Law of Forces between Two Point Charges

- If q_1 and q_2 be two stationary point charges in free space separated by a distance r, then the force of attraction / repulsion between them is

$$F = \frac{K|q_1||q_2|}{r^2} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{|q_1||q_2|}{r^2} \qquad \left[K = \frac{1}{4\pi\varepsilon_0}\right]$$

$$= \frac{9\times10^9 \times |q_1||q_2|}{r^2} \qquad [K = 9\times10^9 \text{ N-m}^2/\text{c}^2]$$

- If some dielectric medium is completely filled between the given charges, then the Coulomb's force between them becomes

$$F_m = \frac{1}{4\pi\varepsilon}\frac{q_1q_2}{r^2} = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1q_2}{r^2} \qquad \left[\because \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r \text{ or } k\right]$$

$$= \frac{1}{4\pi k\varepsilon_0}\cdot\frac{q_1q_2}{r^2}$$

Superposition Principle

It states that, the net force on any one charge is equal to the vector sum of the forces exerted on it by all other charges. If there are four charges q_1, q_2, q_3 and q_4, then the force on q_1 (say) due to q_2, q_3 and q_4 is given by $\mathbf{F}_1 = \mathbf{F}_{12} + \mathbf{F}_{13} + \mathbf{F}_{14}$, where $\mathbf{F}_{12}$ is the force on q_1 due to q_2, $\mathbf{F}_{13}$ that due to q_3 and $\mathbf{F}_{14}$ that due to q_4.

Electric Field

The space surrounding an electric charge q in which another charge q_0 experiences a force of attraction or repulsion, is called the electric field of charge q. The charge q is called the **source charge** and the charge q_0 is called the **test charge**. The test charge must be negligibly small so that it does not modify the electric field of the source charge.

Intensity (or Strength) of Electric Field (E)

The intensity of electric field at a point in an electric field is the ratio of the forces acting on the test charge placed at that point to the magnitude of the test charge.

$$\mathbf{E} = \frac{\mathbf{F}}{q_0}, \qquad \text{where } \mathbf{F} \text{ is the force acting on } q_0.$$

Electric field intensity ($\mathbf{E}$) is a vector quantity.

The direction of electric field is same as that of force acting on the positive test charge. Unit of E is NC^{-1} or Vm^{-1}.

Electric Field Lines

An electric field line in an electric field is a smooth curve, tangent to which, at any point, gives the direction of the electric field at that point.

Properties of electric field lines are given below

- Electric field lines come out of a positive charge and go into the negative charge.
- No two electric field lines intersect each other.
- Electric field lines are continuous but they never form a closed loop.
- Electric field lines cannot exist inside a conductor. Electric shielding is based on this property.

Continuous Charge Distribution

The continuous charge distribution may be one dimensional, two dimensional and three-dimensional.

1. **Linear charge density** (λ) If charge is distributed along a line, i.e. straight or curve is called linear charge distribution. The uniform charge distribution q over a length L of the straight rod.

   Then, the linear charge density, $\lambda = \frac{q}{L}$

   Its unit is coulomb metre^{-1} (Cm^{-1}).
2. **Surface charge density** (σ) If charge is distributed over a surface is called surface charge density, i.e. $\sigma = q/A$

   Its unit is coulomb m^{-2} (Cm^{-2})
3. **Volume charge density** (ρ) If charge is distributed over the volume of an object, is called volume charge density, *i.e.*, $p = \frac{q}{V}$. Its unit is coulomb metre^{-3} (Cm^{-3}).

1. Electric Field due to a Point Charge

- Electric field at a distance r from a point charge q is

$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2}$$

- If q_1 and q_2 are two like point charges, separated by a distance r, a neutral point between them is obtained at a point distant r_1 from q_1, such that $r_1 = \dfrac{r}{\left[1 + \sqrt{\dfrac{q_2}{q_1}}\right]}$
- If q_1 and q_2 are two charges of opposite nature separated by a distance r, a neutral point is obtained in the extended line joining them, at a distance r_1 from q_1, such that,

$$r_1 = \frac{r}{\left[\sqrt{\dfrac{q_2}{q_1}} - 1\right]}$$

2. Electric Field due to Infinitely Long Uniformly Charged Straight Wire

Electric field at a point situated at a normal distance r, from an infinitely long uniformly charged straight wire having a linear charge density λ, is

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

3. Electric Field due to a Charged Cylinder

- For a conducting charged cylinder of linear charge density λ and radius R, the electric field is given by

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}, \text{ for } r > R,$$

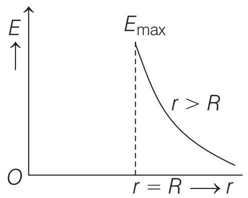
$$E = \frac{\lambda}{2\pi\varepsilon_0 R}, \text{ for } r = R$$

and $E = 0$, for $r < R$

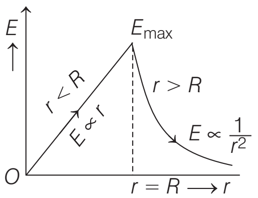
- For a non-conducting charged cylinder, for $r \le R$,

$$E = \frac{\lambda r}{2\pi\varepsilon_0 R^2}$$

and $$E = \frac{\lambda}{2\pi\varepsilon_0 r}, \text{ for } r > R$$



(a) Variation of electric field with distance for conducting cylinder



(b) Variation of electric field with distance for non-conducting cylinder

4. Electric Field due to a Uniformly Charged Infinite Plane Sheet

Electric field near a uniformly charged infinite plane sheet having surface charge density σ is given by

$$E = \frac{\sigma}{2\,\varepsilon_0}$$

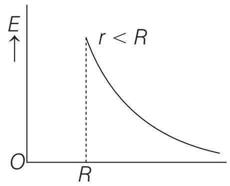
5. Electric Field due to a Uniformly Charged Thin Spherical Shell

For a charged conducting sphere/shell of radius R and total charge Q, the electric field is given by

Case I $E = 0$, for $r < R$

Case II $E = \dfrac{Q}{4\pi\varepsilon_0 R^2}$, for $r = R$

Case III $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$, for $r > R$



Variation of electric field with distance for uniformly charge spherical shell

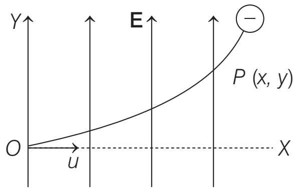
Motion of a Charged Particle in an Electric Field

Let a charged particle of mass m and charge q, enters the electric field along X-axis with speed u. The electric field E is along Y-axis is given by

$$F_y = qE$$

and force along X-axis remains zero, i.e.

$$F_x = 0$$



$\therefore$ Acceleration of the particle along Y-axis is given by

$$a_y = \frac{F_y}{m} = \frac{qE}{m}$$

The initial velocity is zero along Y-axis ($u_y = 0$).

$\therefore$ The deflection of charged particle along Y-axis after time t is given by $y = u_y t + \frac{1}{2} a_y t^2$

$$= \frac{qE}{2m} t^2$$

Along X-axis there is no acceleration, so the distance covered by particle in time t along X-axis is given by $x = ut$

Eliminating t, we have

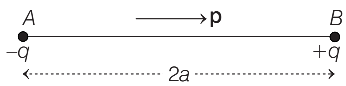
$$y = \left(\frac{qE}{2mu^2} x^2\right)$$

$$y \propto x^2$$

This shows that the path of charged particle in perpendicular field is a parabola.

Electric Dipole

An electric dipole consists of two equal and opposite charges separated by a small distance.



Electric Dipole

The dipole moment of a dipole is defined as the product of the magnitude of either charges and the distance between them. Therefore, dipole moment

$$\mathbf{p} = q(2\mathbf{a})$$

Electric Field due to a Dipole

- At a point distant r from the centre of a dipole, along its axial line $\mathbf{E} = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{2\mathbf{p}r}{(r^2 - a^2)^2}$

  [direction of **E** is the same as that of **p**]

  For a short dipole, $\mathbf{E} = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{2\mathbf{p}}{r^3}$ $[r >> a]$

- At a point distant r from the centre of a dipole, along its equatorial line

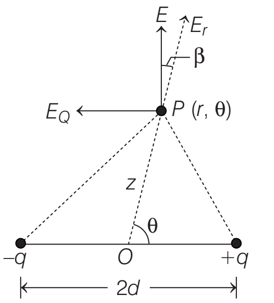
$$\mathbf{E} = -\frac{1}{4\pi\varepsilon_0} \cdot \frac{\mathbf{p}}{(r^2 + a^2)^{3/2}}$$

  [direction of **E** is opposite to that of **p**]

For a short dipole $\mathbf{E} = -\dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{\mathbf{p}}{r^3}$ $\quad [r >> a]$

- At a point distant r from the centre of a short dipole, along a line inclined at an angle θ with the dipole axis

$$E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{r^3} \sqrt{3\cos^2\theta + 1}$$



Electric Field at (r, θ) position

- $\mathbf{E}$ subtends an angle β from $\mathbf{r}$ such that

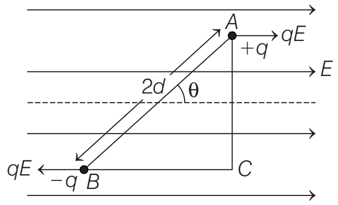
$$\tan\beta = \frac{1}{2}\tan\theta$$

Torque on a Dipole in a Uniform Electric Field

When a dipole is placed in an external electric field, making an angle θ with the direction of the uniform electric field E, it experiences a torque given by

$$\tau = qE \times AC$$
$$\tau = \mathbf{p} \times \mathbf{E}$$
$$\tau = pE \sin\theta$$

or $\quad qE \times 2\,d \sin\theta = (q \times 2\,d)\,E \sin\theta$



Rotation of Electric Dipole

Work Done in Rotating a Dipole

If an electric dipole initially kept in an uniform electric field $\mathbf{E}$, making an angle θ_1, is rotated so as to finally subtend an angle θ_2, then the work done for rotating the dipole is,

$$W = pE(\cos\theta_1 - \cos\theta_2)$$

Potential Energy of a Dipole

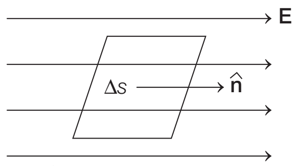
It is the amount of work done in rotating an electric dipole from a direction perpendicular to electric field to a particular direction.

Hence, $\quad U = -pE\cos\theta \qquad$ or $\; U = -\mathbf{p}\cdot\mathbf{E}$

Electric Flux (ϕ_E)

It is a measure of the flow of electric field through a surface. It can be defined as the total number of lines of electric field passes through a surface placed perpendicular to direction of field.

i.e. $\qquad \phi_E = \int EdS\cos\theta = \int \mathbf{E}\cdot d\mathbf{S} = \int \mathbf{E}\cdot\hat{\mathbf{n}}\,dS$



A surface placed perpendicular to electric field

Gauss Law

The total electric flux linked with a closed surface is equal to $\dfrac{1}{\varepsilon_0}$ times, the net charge enclosed by that surface. Thus,

$$\phi_E = \oint_S \mathbf{E}\cdot d\mathbf{S} = \frac{1}{\varepsilon_0}[Q_{\text{enclosed}}]$$

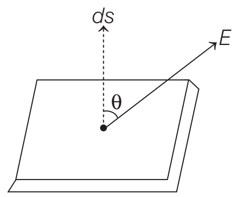


Illustration on Gauss Law

where, $Q_{\text{enclosed}} \sum_{i=1}^{i=n} qi$ is the algebraic sum of all the charges inside the closed surface.

Electric Potential

The amount of work done in bringing a unit positive charge, without any acceleration, from infinity to that point, along any arbitrary path.

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

Electric potential is a state function and does not depend on the path followed.

1. Electric Potential Due to a Point Charge

Potential due to a point charge Q, at a distance r is given by $\qquad V = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{Q}{r}$

2. Electric Potential Due to a System of Charges

If a number of charges $q_1, q_2, q_3, \ldots$ are present in space, then the electric potential at any point will be

$$V = V_1 + V_2 + V_3 + \ldots$$
$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + \ldots\right]$$
$$= \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\left(\frac{q_i}{r_i}\right)$$

3. Electric Potential Due to an Electric Dipole

At any general point, $V = \frac{1}{4\pi\varepsilon_0} \frac{p\cos\theta}{r^2}$

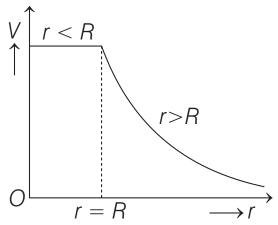
On the dipole axis, $\theta = 0°$ and $V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{r^2}$

On the equitorial axis $\theta = 90°$ and $V = 0$

4. Electric Potential due to Some Common Charge Distributions

Potential at a point distant r from an infinitely long wire having linear charge density λ, is

$$V = \frac{\lambda}{2\pi\varepsilon_0} \cdot \ln r$$



For a charged conducting sphere/shell having total charge Q and radius R, the potential at a point distant r from the centre of the sphere/shell is

(i) $V = \frac{Q}{4\pi\varepsilon_0 r}$, for $r > R$ (ii) $V = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r}$, for $r = R$

(iii) $V = \frac{Q}{4\pi\varepsilon_0 R}$, for $r \leq R$

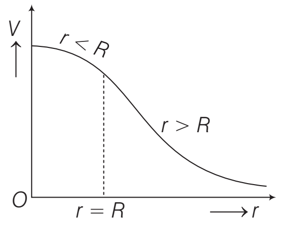
For a charged non-conducting (dielectric) sphere of radius R, the charge Q is uniformly distributed over the entire volume.

Hence, (i) $V = \frac{Q}{4\pi\varepsilon_0 r}$, for $r > R$ (ii) $V = \frac{Q}{4\pi\varepsilon_0 R}$, for $r = R$

and (iii) $V = \frac{Q}{4\pi\varepsilon_0}\left[\frac{3R^2 - r^2}{2R^3}\right]$, for $r < R$

At the centre of the sphere $(r = 0)$

$$V = \frac{3Q}{8\pi\varepsilon_0 R} = \frac{3}{2} V_s \qquad \left[V_s = \frac{Q}{4\pi\varepsilon_0 R}\right]$$



Electric Potential Energy

The electric energy of a system of charges is the work that has been done in bringing those charges from infinity to near each other to form the system. For two point charges q_1 and q_2 separated by distance r_{12}, the potential energy is given by $U = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r_{12}}$.

In general, for a system of n charges, the electric potential energy is given by

$$U = \frac{1}{2} \Sigma \frac{q_i q_j}{4\pi\varepsilon_0 r_{ij}}, \; i \neq j$$

$$\left[\frac{1}{2} \text{ is used as each term in summation will appear twice}\right]$$

Relation between E and V

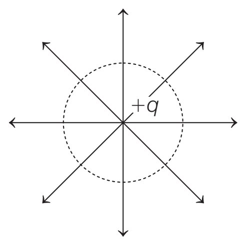
Because E is force per unit charge and V is work per unit charge. E and V are related in the same way as work and force.

Work done against the field to take a unit positive charge from infinity (reference point) to the given point $V_P = -\int_\infty^P \mathbf{E} \cdot d\mathbf{r}$ volt

where, the negative sign indicates that the work is done against the field.

Equipotential Surface

Equipotential surface is an imaginary surface joining the points of same potential in an electric field. So, we can say that the potential difference between any two points on an equipotential surface is zero.



An Equipotential Surface

The electric lines of force at each point of an equipotential surface are normal to the surface. Figure shows the electric lines of force due to point charge $+q$. The spherical surface will be the equipotential surface and the electrical lines of force emanating from the point charge will be radial and normal to the spherical surface.

Regarding equipotential surface, following points are worth noting

(i) Equipotential surface may be planar, solid etc. But equipotential surface can never be point size.

(ii) Equipotential surface is single valued. So, equipotential surfaces never cross each other.

(iii) Electric field is always perpendicular to equipotential surface.

(iv) Work done to move a point charge q between two points on equipotential surface is zero.

(v) The surface of a conductor in equilibrium is an equipotential surface.

Conductors and Insulators

Conductors are those materials through which electricity can pass through easily. e.g. metals like copper, silver, iron etc. **Insulators** are those materials through which electricity cannot pass through, e.g. rubber, ebonite, mica etc.

Dielectrics and Polarisation

Dielectrics are insulating materials which transmit electric effect without actually conducting electricity.

e.g. mica, glass, water etc.

When a dielectric is placed in an external electric field, so the molecules of dielectric gain a permanent electric dipole moment. This process is called polarisation.

Electrical Capacitance

Capacitance of a conductor is the amount of charge needed in order to raise the potential of the conductor by unity.

Mathematically, Capacitance $C = \dfrac{Q}{V}$

Sharing of Charges

- Let two charged conductors having charges Q_1 and Q_2 (or potentials V_1, V_2 and capacitances C_1, C_2 respectively). If these are joined together. In such case

  Common potential, $V = \dfrac{Q_1 + Q_2}{C_1 + C_2} = \dfrac{C_1V_1 + C_2V_2}{C_1 + C_2}$

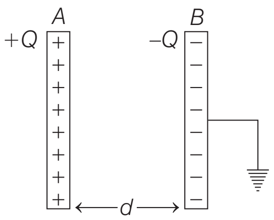
- During sharing of charges, there is some loss of electrostatic energy, which in turn reappears as heat or light. The loss of electrostatic energy

$$\Delta U = U_i - U_f = \frac{C_1C_2}{2(C_1 + C_2)}(V_1 - V_2)^2$$

- When charges are shared between any two bodies, their potential become equal. The charges acquired are in the ratio of their capacities.

Capacitor

A capacitor is a device which stores electrostatic energy. It consists of conductors of any shape and size carrying charges of equal magnitudes and opposite signs and separated by an insulating medium.



A Capacitor

There are two types of combination of capacitors:

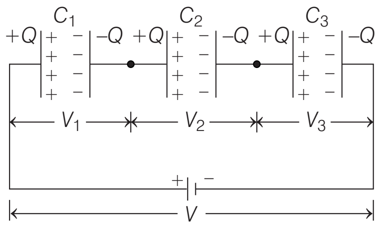
1. Series Grouping

In a series arrangement, $V = V_1 + V_2 + V_3 + \ldots$

and $\quad V_1 : V_2 : V_3 \ldots = \dfrac{1}{C_1} : \dfrac{1}{C_2} : \dfrac{1}{C_3} : \ldots$

The equivalent capacitance C_s is given by

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



Three Capacitor in Series

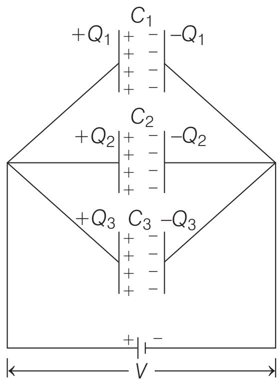
2. Parallel Grouping

In a parallel arrangement, $Q = Q_1 + Q_2 + Q_3 + \ldots$

and $\quad Q_1 : Q_2 : Q_3 \ldots = C_1 : C_2 : C_3 \ldots$

The equivalent capacitance is given by

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



Three Capacitor in Parallel

Capacitance of a Parallel Plate Capacitor

1. Capacitor without Dielectric Medium between the Plates

If the magnitude of charge on each plate of a parallel plate capacitor be Q and the overlapping area of plates be A, then

- Electric field between the plates, $E = \dfrac{\sigma}{\varepsilon_0} = \dfrac{Q}{\varepsilon_0 A}$
- Potential difference between the plates
  $V = E \cdot d = \dfrac{\sigma d}{\varepsilon_0} = \dfrac{Qd}{\varepsilon_0 A}$, where d = separation between the two plates.
- Capacitance, $C = \dfrac{Q}{V} = \dfrac{\varepsilon_0 A}{d}$

2. Capacitor with Dielectric Medium between the Plates

- If a dielectric medium of dielectric constant K is completely filled between the plates of a capacitor, then its capacitance becomes,

$$C' = \frac{K\varepsilon_0 A'}{d} = KC_0 \quad \left[\text{where, } C_0 = \frac{\varepsilon_0 A'}{d}\right]$$

- If a dielectric slab/sheet of thickness t (where, $t < d$) is introduced between the plates of the capacitor, then

$$C' = \frac{\varepsilon_0 A}{\left(d - t + \frac{t}{K}\right)}$$

- If a metallic slab/plate of thickness t (where, $t < d$), is inserted between the plates of capacitor, then

$$C' = \frac{K\varepsilon_0 A'}{d} = KC_0$$

- Magnitude of the attractive force between the plates of a parallel plate capacitor is given by

$$F = \frac{\sigma^2 A}{2\varepsilon_0} = \frac{Q^2}{2A\varepsilon_0} = \frac{CV^2}{2d}$$

- The energy density between the plates of a capacitor

$$u = \frac{U}{\text{Volume}} = \frac{1}{2}\varepsilon_0 E^2$$

Energy Stored in a Capacitor

If a capacitor of capacity C is charged to a potential V, the electrostatic energy stored in it is,

$$U = \frac{1}{2}CV^2 = \frac{1}{2}QV = \frac{1}{2}\frac{Q^2}{C}$$

Energy Loss During Parallel Combination

When capacitor of capacitance C_1 charge to potential V_1, whereas another of C_2 charge to potential of V_2, then after parallel combination.

$$\text{Loss in energy} = \frac{1}{2}\frac{C_1C_2}{C_1 + C_2}(V_1 - V_2)^2$$

DAY PRACTICE SESSION 1

FOUNDATION QUESTIONS EXERCISE

1 When a glass rod rubbed with silk is brought near the gold leaf electroscope, the leaves diverge. What is the charge on the leaves?

(a) Negative (b) Zero
(c) Positive (d) Either positive or negative

2 Identify the wrong statement in the following Coulomb's law correctly described the electric force that

(a) binds the electrons of an atom to its nucleus
(b) binds the protons and neutrons in the nucleus of an atom
(c) binds atoms together to form molecules
(d) binds atoms and molecules to form solids

3 The excess (equal in number) of electrons that must be placed on each of two small spheres spaced 3 cm apart, with force of repulsion between the spheres to be 10^{-19}N, is

(a) 25 (b) 225 (c) 625 (d) 1250

4 When air is replaced by a dielectric medium of constant K. The maximum force of attraction between two charges separated by a distance

(a) increases K^{-1} times (b) increases K times
(c) decreases K times (d) remains constant

5 Two identical coins having similar charges are placed 4.5 m apart on a table. Force of repulsion between them is $\frac{40}{9}$ N. The value of charge on each coin is

(a) 100 μC (b) 200 μC (c) 300 μC (d) 400 μC

6 A small uncharged metallic sphere is positioned exactly at a point midway between two equal and opposite point charges. If the sphere is slightly displaced towards the positive charge and released, then

(a) it will oscillate about its original position
(b) it will move further towards the positive charge
(c) its electric potential energy will decrease and kinetic energy will increase
(d) its total energy remains constant but it non-zero

7 A charge Q is divided into two parts of q and $-q$. If the coulomb repulsion between them when they are separated is to be maximum, the ratio of $\frac{Q}{q}$ should be

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

8 Two positive ions, each carrying a charge q, are separated by a distance d. If F is the force of repulsion between the ions, the number of electrons missing from each ion will be (e being the charge on an electron) ➔ CBSE AIPMT 2010

(a) $\dfrac{4\pi\varepsilon_0 Fd^2}{e^2}$ (b) $\sqrt{\dfrac{4\pi\varepsilon_0 Fe^2}{d^2}}$ (c) $\sqrt{\dfrac{4\pi\varepsilon_0 Fd^2}{e^2}}$ (d) $\dfrac{4\pi\varepsilon_0 Fd^2}{q^2}$

9 The electric field due to a charge at a distance of 3 m from it is 500 NC^{-1}. The magnitude of the charge is $[1/4\pi\varepsilon_0 = 9\times 10^9\ Nm^2C^{-2}]$

(a) 2.5 μC (b) 1.0 μC
(c) 2.0 μC (d) 0.5 μC

10 An electron is sent in electric field of intensity $9.1\times 10^6\ NC^{-1}$. The acceleration produced is (mass of electron $= 9.1\times 10^{-31}$ kg)

(a) 1.6 ms^{-2} (b) $1.6\times 10^{18}\ ms^{-2}$
(c) $3.2\times 10^{18}\ ms^{-2}$ (d) $0.8\times 10^{18}\ ms^{-2}$

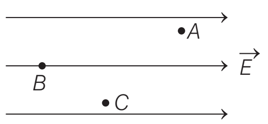
11 A charged particle of mass 0.003 g is held stationary in space by placing it in a downward direction of electric field of $6\times 10^4\ NC^{-1}$. Then, the magnitude of the charge is

(a) 5×10^{-4}C (b) 5×10^{-10}C (c) 18×10^{-6}C (d) -5×10^{-9}C

12 A point charge $+q$, is placed at a distance d from an isolated conducting plane. The field at a point P on the other side of the plane is

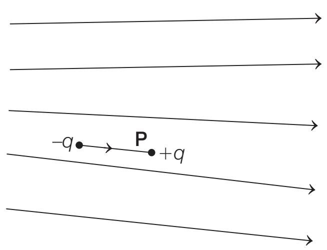
(a) directed perpendicular to the plane and away from the plane
(b) directed perpendicular to the plane but towards the plane
(c) directed radially away from the point charge
(d) directed radially towards the point charge

13 A, B and C are three points in a uniform electric field. The electric potential is ➔ NEET 2013



(a) maximum at A (b) maximum at B
(c) maximum at C
(d) same at all the three points A, B and C

14 Figure shows electric field lines in which an electric dipole p is placed as shown in figure. Which of the following statements is correct?



(a) The dipole will not experience any force
(b) The dipole will experience a force towards right
(c) The dipole will experience a force towards left
(d) The dipole will experience a force upwards

15 An electric dipole has the magnitude of its charge as q and its dipole moment is p. It is placed in a uniform electric field E. If its dipole moment is along the direction the field, the force on it and its potential energy are respectively

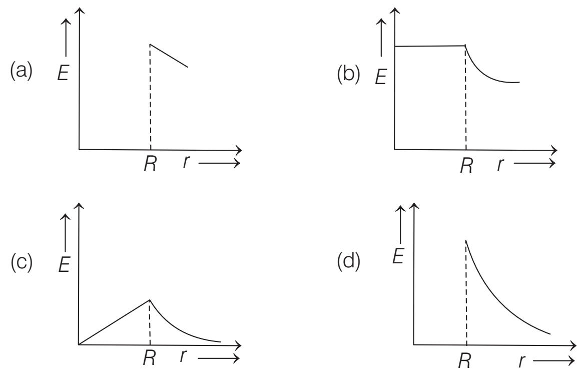
(a) $2qE$ and minimum (b) qE and pE
(c) zero and minimum (d) qE and maximum

16 The electric potential at a point (x, y, z) is given by $V = -x^2y - xz^3 + 4$. ➔ CBSE AIPMT 2009

The electric field $\mathbf{E}$ at that point is

(a) $\mathbf{E} = (2xy + z^3)\hat{\mathbf{i}} + x^2\hat{\mathbf{j}} + 3xz^2\hat{\mathbf{k}}$
(b) $\mathbf{E} = 2xy\hat{\mathbf{i}} + (x^2 + y^2)\hat{\mathbf{j}} + (3xz - y^2)\hat{\mathbf{k}}$
(c) $\mathbf{E} = z^3\hat{\mathbf{i}} + xyz\hat{\mathbf{j}} + z^2\hat{\mathbf{k}}$
(d) $\mathbf{E} = (2xy - z^3)\hat{\mathbf{i}} + xy^2\hat{\mathbf{j}} + 3z^2x\hat{\mathbf{k}}$

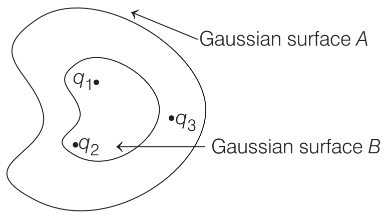
17 Which one of the following graphs represents the variation of electric field strength E with distance r from the centre of a uniformly charged non-conducting sphere?



18 An electric dipole of moment p is placed in an electric field of intensity E. The dipole acquires a position such that the axis of the dipole makes an angle θ with the direction of the field. Assuming that the potential energy of the dipole to be zero when $\theta = 90°$, the torque and the potential energy of the dipole will respectively be ➔ CBSE AIPMT 2012

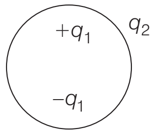
(a) $pE\sin\theta, -pE\cos\theta$ (b) $pE\sin\theta, -2pE\cos\theta$
(c) $pE\sin\theta, 2pE\cos\theta$ (d) $pE\cos\theta, -pE\sin\theta$

19 The electric flux for Gaussian surface A that enclose the charged particles in free space is (Given $q_1 = -14$ nC, $q_2 = 78.85$ nC, $q_3 = -56$ nC)



(a) $10^3\ Nm^2\ C^{-1}$ (b) $10^3\ CN^{-1}m^{-2}$
(c) $6.32\times 10^3\ Nm^2C^{-1}$ (d) zero

20 Consider the charge configuration and a spherical Gaussian surface as shown in figure. When calculating the flux of the electric field over the spherical surface, the electric field will be due to



(a) q_2 (b) only the positive charges
(c) all the charges (d) $+q_1$ and $-q_1$

21 If the electric flux entering and leaving an enclosed surface respectively is ϕ_1 and ϕ_2, the electric charge inside the surface will be

(a) $(\phi_1+\phi_2)\varepsilon_0$ (b) $(\phi_2-\phi_1)\varepsilon_0$
(c) zero (d) ϕ_2/ε_0

22 What is the total flux from the surface of cylinder of radius R and length L which is placed in a uniform electric field E parallel to cylinder axis?

(a) $2\pi R^2E$ (b) πR^2E
(c) $(\pi R+\pi R^2)/E$ (d) zero

23 A hemisphere surface of radius R is placed in uniform electric field of intensity E parallel to the axis of its circular plane. What will be the electric flux ϕ through the hemisphere surface?

(a) $2\pi RE$ (b) $2\pi R^2E$
(c) πR^2E (d) $(4/3)\pi R^3E$

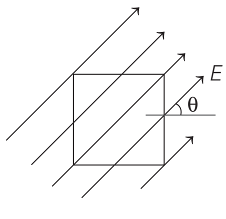
24 What is the total electric flux leaving a spherical surface of radius 1 cm and surrounding at electric dipole?

(a) q/ε_0 (b) zero (c) $2q/\varepsilon_0$ (d) $8\pi r^2q/\varepsilon_0$

25 A charge Q is enclosed by a gaussian spherical surface of radius R. If the radius is doubled, then the outward electric flux will ➜ CBSE AIPMT 2011

(a) be reduced to half (b) remain the same
(c) be doubled (d) increase four times

26 A square surface of side L metre in the plane of the paper is placed in a uniform electric field E (V/m) acting along the same place at an angle θ with the horizontal side of the square as shown in figure. The electric flux linked to the surface in unit of V-m, is ➜ CBSE AIPMT 2010



(a) EL^2 (b) $EL^2\cos\theta$ (c) $EL^2\sin\theta$ (d) 0

27 What is the flux through a cube of side a if a point charge of q is at one of its corner? ➜ CBSE AIPMT 2012

(a) $\dfrac{2q}{\varepsilon_0}$ (b) $\dfrac{q}{8\varepsilon_0}$
(c) $\dfrac{q}{\varepsilon_0}$ (d) $\dfrac{q}{2\varepsilon_0}6a^2$

28 There exists an electric field of 1 N/C along y-direction. The flux passing through the square of 1m placed in xy plane inside the electric field is

(a) 1 Nm^2/C (b) 10 Nm^2/C (c) 2 Nm^2/C (d) zero

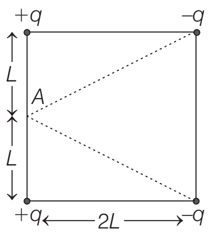
29 Four point charges $-Q$, $-q$, $2q$ and $2Q$ are placed, one at each corner of the square. The relation between Q and q for which the potential at the centre of the square is zero, is ➜ CBSE AIPMT 2012

(a) $Q=-q$ (b) $Q=-\dfrac{1}{q}$ (c) $Q=q$ (d) $Q=\dfrac{1}{q}$

30 A hollow metallic sphere of radius R is given a charge Q. Then, the potential at the centre is ➜ AFMC 2010

(a) zero (b) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{Q}{R}$ (c) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{2Q}{R}$ (d) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{Q}{2R}$

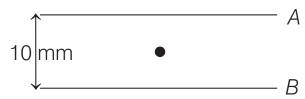
31 Four electric charges $+q$, $+q$, $-q$ and $-q$ are placed at the corners of a square of side $2L$ as see figure. The electric potential at point A, midway between the two charges $+q$ and $+q$, is ➜ CBSE AIPMT 2011



(a) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{2q}{L}\left(1+\dfrac{1}{\sqrt{5}}\right)$ (b) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{2q}{L}\left(1-\dfrac{1}{\sqrt{5}}\right)$

(c) zero (d) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{2q}{L}(1+\sqrt{5})$

32 The electric charge on drop B is 1.6×10^{-19} C and its mass is 1.6×10^{-14} kg. If the drop is in equilibrium, then the potential difference between the plates will be (where, density $d=10\times10^{-3}\ \text{kgm}^{-3}$)



(a) 5×10^5 V (b) 10^4 V (c) 2×10^4 V (d) 10^5 V

33 A conducting sphere of radius R is given a charge Q. The electric potential and the electric field at the centre of the sphere respectively are ➜ CBSE AIPMT 2014

(a) zero and $\dfrac{Q}{4\pi\varepsilon_0R^2}$ (b) $\dfrac{Q}{4\pi\varepsilon_0R}$ and zero

(c) $\dfrac{Q}{4\pi\varepsilon_0R}$ and $\dfrac{Q}{4\pi\varepsilon_0R^2}$ (d) Both are zero

34 Which of the following is not the property of equipotential surfaces?

(a) They do not cross each other
(b) They are concentric spheres for uniform electric field
(c) Rate of change of potential with distance on them is zero
(d) They can be imaginary spheres

35 The potential of a spherical conductor of radius 3 m is 6 V. The potential at its centre is

(a) zero (b) 2V (c) 6V (d) 18V

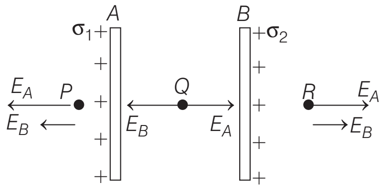
36 A parallel plate capacitor has an electric field of 10^5 Vm^{-1} between the plates. If the charge on the capacitor plates is $1\,\mu C$, the force on each capacitor plate is

(a) 0.5 N (b) 0.05 N
(c) 0.005 N (d) None of these

37 If a battery is disconnected from the capacitor and then a dielectric substance between two plates of condenser is introduced the capacity, potential and potential energy respectively

(a) increases, decreases, decreases
(b) decreases, increases, increases
(c) increases, increases, increases
(d) decreases, decreases, decreases

38 Two identical metal plates are given positive charge Q_1 and Q_2 such that $Q_2 < Q_1$. If they are now brought close to each other to form a parallel plate capacitor of capacitance C, the potential difference between them is



(a) $\frac{Q_1 + Q_2}{2C}$ (b) $\frac{Q_1 + Q_2}{C}$
(c) $\frac{Q_1 - Q_2}{C}$ (d) $\frac{Q_1 - Q_2}{2C}$

39 A 0.2 μF capacitor is charged to 600 V. After removing it from battery it is connected to another capacitor 1.0 μF in parallel. The voltage on the capacitor will become

(a) 300 V (b) 600 V
(c) 100 V (d) 120 V

40 A thin aluminium sheet is placed between the plates of a parallel plate capacitor. Its capacitance will

(a) increase (b) decrease
(c) remain same (d) become infinite

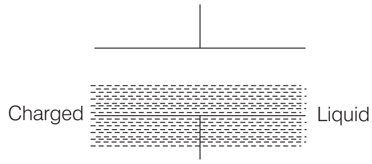
41 Work done in placing a charge of 8×10^{-18} C on a condenser of capacity 100 μF is

(a) 16×10^{-32} J (b) 31×10^{-26} J
(c) 4×10^{-10} J (d) 32×10^{-32} J

42 A number of condensers, each of the capacitance $1\mu F$ and each one of which gets punctured, if a potential difference just exceeding 500 V is applied, are provided. An arrangement suitable for giving capacitance of $2\,\mu F$ across which 3000 V may be applied requires at least.

(a) 6 component capacitors
(b) 12 component capacitors
(c) 72 component capacitors
(d) 2 component capacitors

43 A parallel plate capacitor is located horizontally such that one of the plates is submerged in a liquid while the other is above the liquid surface. When plates are charged, the level of liquid



(a) rises
(b) falls
(c) remains unchanged
(d) may rise or fall depending on the amount of charge

44 A parallel plate condenser has a uniform electric field $E\left(\frac{V}{m}\right)$ 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 (joule) stored in the condenser is

→ CBSE AIPMT 2011

(a) $\frac{1}{2}\varepsilon_0 E^2$ (b) $\varepsilon_0 EAd$
(c) $\frac{1}{2}\varepsilon_0 E^2 Ad$ (d) $E^2 \frac{Ad}{\varepsilon_0}$

45 Two capacitors of capacitances 3 μF and 6 μF are charged to a potential of 12 V 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

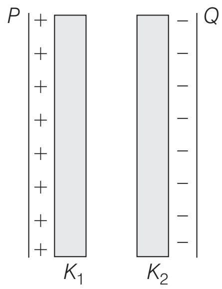
(a) 4 V (b) 6 V
(c) zero (d) 3 V

46 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

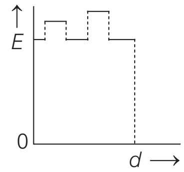
→ CBSE AIPMT 2009

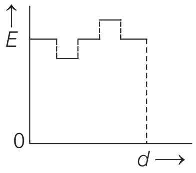
(a) $\frac{C}{3}, \frac{V}{3}$ (b) $3C, \frac{V}{3}$
(c) $\frac{C}{3}, 3V$ (d) $3C, 3V$

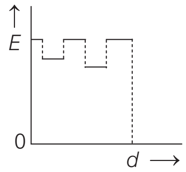
47 Two thin dielectric slabs of dielectric constants K_1 and K_2 $(K_1 < K_2)$ are inserted between plates of a parallel plate capacitor, as shown in the figure.

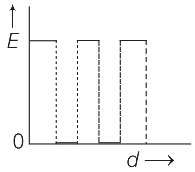


The variation of electric field E between the plates with distance d as measured from plate P is correctly shown by ➜ CBSE AIPMT 2014

(a) 

(b) 

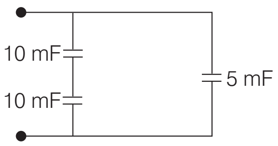
(c) 

(d) 

48 A capacitor having capacity of 2.0 μF is charged to 200 V and then the plates of the capacitor are connected to a resistance wire. The heat produced in joule will be

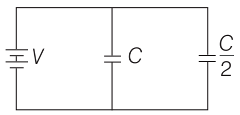
(a) 2×10^{-2} (b) 4×10^{-2}
(c) 4×10^{4} (d) 4×10^{10}

49 The equivalent capacitance of the following combination is



(a) 10 μF (b) 4 μF
(c) 25 μF (d) 15 μF

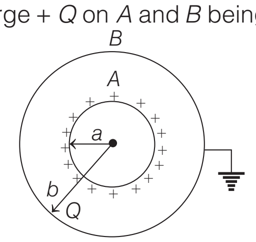
50 Two condensers, one of capacity C and the other of capacity $\frac{C}{2}$, are connected to a V volt battery, as shown in figure.



The work done in charging fully both the condensers is

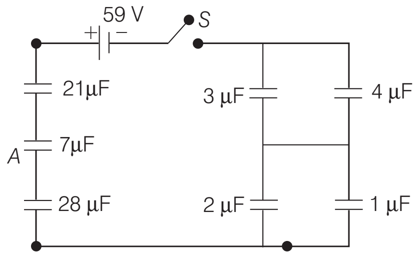
(a) $2CV^2$ (b) $\frac{1}{4}CV^2$
(c) $\frac{3}{4}CV^2$ (d) $\frac{1}{2}CV^2$

51 What will be the equivalent capacitance of the system as shown in the figure, where two spherical conductors A and B of radii a and b $(b > a)$ are placed concentrically in air with a charge $+Q$ on A and B being earthed?



(a) $4\pi\varepsilon_0\left(\frac{ab}{b-a}\right)$ (b) $4\pi\varepsilon_0(a+b)$
(c) $4\pi\varepsilon_0 b$ (d) $4\pi\varepsilon_0\left(\frac{b^2}{b-a}\right)$

52 The following figure shows seven capacitors, a switch S and a source of emf connected together. Initially S is open and all capacitors are uncharged.



What will be the potential difference in volts across the plates of the capacitor A, if S is closed afterwards and a steady state is attained?

(a) 12 (b) 15
(c) 17 (d) 19

53 A capacitor of capacitance C has charge Q and stored energy is W. If the charge is increased to $2Q$, the stored energy will be

(a) $\frac{W}{4}$ (b) $\frac{W}{2}$
(c) $2W$ (d) $4W$

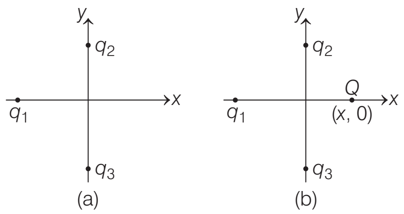
54 Two capacitors of 10 μF and 20 μF are connected in series with a 30 V battery. The charge on the capacitors will be respectively

(a) 100 μC, 100 μC (b) 200 μC, 100 μC
(c) 200 μC, 200 μC (d) 100 μC, 200 μC

DAY PRACTICE SESSION 2

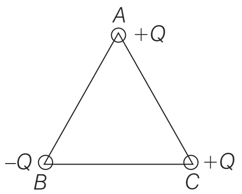
PROGRESSIVE QUESTIONS EXERCISE

1 In figure, two positive charges q_2 and q_3 fixed along the y-axis, exert a net electric force in the $+x$ direction on a charge q_1 fixed along the x-axis. If a positive charge Q is added at $(x, 0)$, the force on q_1



(a) shall increase along the positive x-axis
(b) shall decrease along the positive x-axis
(c) shall point along the negative x-axis
(d) shall increase but the direction changes, because of the intersection of Q with q_2 and q_3

2. Three charges are placed at the vertices of an equilateral triangle of side a as shown in the figure. The force experienced by the charge placed at the vertex A in a direction normal to BC is

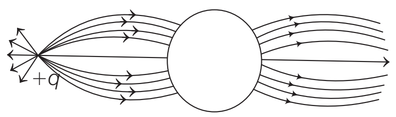


(a) $Q^2/(4\pi\varepsilon_0 a^2)$ (b) $-Q^2/(4\pi\varepsilon_0 a^2)$
(c) zero (d) $Q^2/(2\pi\varepsilon_0 a^2)$

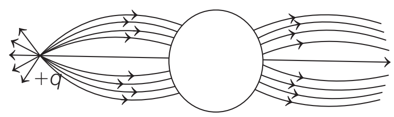
3 The ratio of electrostatic and gravitational forces acting between electron and proton separated by a distance 5×10^{-11}m, will be (Charge of electron = 1.6×10^{-19} C, mass of electron = 9.1×10^{-31}kg, mass of proton = 1.6×10^{-27}kg, $G = 6.7\times 10^{-11}$N-m^2 kg^{-2})

(a) 2.36×10^{39} (b) 2.36×10^{40}
(c) 2.34×10^{4} (d) 2.34×10^{42}

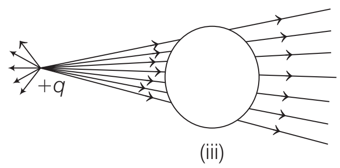
4 A point positive charge is brought near an isolated conducting sphere, in figure shown. The electric field is best given by



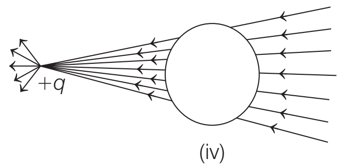
(i)



(ii)



(iii)



(iv)

(a) Fig. (i) (b) Fig. (ii)
(c) Fig. (iii) (d) Fig. (iv)

5 A hollow cylinder has a charge q coulomb within it. If ϕ is the electric flux in unit of V-m associated with the curved surface B, the flux linked with the plane surface A in unit of V-m will be

(a) $\frac{1}{2}\left(\frac{q}{\varepsilon_0} - \phi\right)$ (b) $\frac{q}{2\varepsilon_0}$

(c) $\frac{\phi}{3}$ (d) $\frac{q}{\varepsilon_0} - \phi$

6 Two infinitely long parallel conducting plates having surface charge densities $+\sigma$ and $-\sigma$ respectively, are separated by a small distance. The medium between the plates is vacuum. If ε_0 is the dielectric permittivity of vacuum, then the electric field in the region between the plates is

(a) zero (b) $\sigma/2\varepsilon_0$ Vm^{-1}
(c) σ/ε_0 Vm^{-1} (d) $2\sigma/\varepsilon_0$ Vm^{-1}

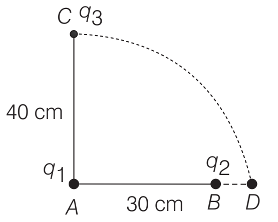
7 When n identical mercury droplets charged to the same potential V coalescence to form a single bigger drop. The potential of the new drop will be

(a) $\frac{V}{n}$ (b) nV (c) nV^2 (d) $n^{2/3}V$

8 Charges $+q$ and $-q$ are placed at points A and B respectively which are a distance $2L$ apart, C is the mid-point between A and B. The work done in moving a charge $+Q$ along the semi-circle CRD is

(a) $\frac{qQ}{4\pi\varepsilon_0 L}$ (b) $\frac{qQ}{2\pi\varepsilon_0 L}$
(c) $\frac{qQ}{6\pi\varepsilon_0 L}$ (d) $-\frac{qQ}{6\pi\varepsilon_0 L}$

9 Two charges q_1 and q_2 are placed 30 cm apart, as shown in the figure. A third charge q_3 is moved along the arc of a circle of radius 40 cm from C to D. The change in the potential energy of the system is $\frac{q_3}{4\pi\varepsilon_0}k$, where k is



(a) $8q_2$ (b) $8q_1$
(c) $6q_2$ (d) $6q_1$

10 The electrostatic potential inside a charged spherical ball is given by $V = ar^2 + b$, where r is the distance from the centre and a, b are constants. Then, the charge density inside the ball is

(a) $-3a\varepsilon_0 r$ (b) $-6a\varepsilon_0$
(c) $+3a\varepsilon_0 r$ (d) zero

11 Three point charges $+q, -2q$ and $+q$ are placed at points $(x=0, y=a, z=0)$, $(x=0, y=0, z=0)$ and $(x=a, y=0, z=0)$, respectively. The magnitude and direction of the electric dipole moment vector of this charge assembly are

(a) $\sqrt{2}aq$ along $+y$-direction
(b) $\sqrt{2}aq$ along the line joining points $(x=0, y=0, z=0)$ and $(x=a, y=a, z=0)$
(c) qa along the line joining points $(x=0, y=0, z=0)$ and $(x=a, y=a, z=0)$
(d) $\sqrt{2}aq$ along $+x$-direction

12 27 small drops each having charge q and radius r coalesce to form big drop. How many times charge and capacitance will become?

(a) 3, 27 (b) 27, 3
(c) 27, 27 (d) 3, 3

13 A parallel plate capacitor of value 1.77 μF is to be designed using a dielectric material (dielectric constant = 200), breakdown strength of $3\times 10^6\,\text{Vm}^{-1}$. In order to make such a capacitor which can withstand a potential difference of 20 V across the plates, the separation between the plates d and area A of the plates respectively are

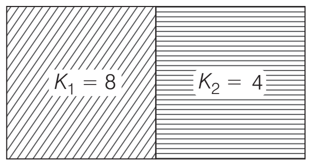
(a) 6.6×10^{-6} m ; $10^3\,\text{m}^2$ (b) 6.6×10^{-5} m ; $10^4\,\text{m}^2$
(c) 6.6×10^{-4} m ; $10^5\,\text{m}^2$ (d) 6.6×10^{-6} m ; $10^2\,\text{m}^2$

14 A parallel plate air capacitor of capacitance C is connected to a cell of emf V and then disconnected from it. A dielectric slab of dielectric constant K, which can just fill the air gap of the capacitor, is now inserted in it. Which of the following statements is incorrect?

➜ CBSE AIPMT 2015

(a) The energy stored in the capacitor decreases K times.
(b) The charge in energy stored is $\frac{1}{2}CV^2\left(\frac{1}{K}-1\right)$
(c) The charge on the capacitor is not conserved
(d) The potential difference between the plates decreases K times.

15 A capacitor having capacitance 1 μF with air, is filled with two dielectrics as shown in figure. How many times capacitance will increase?



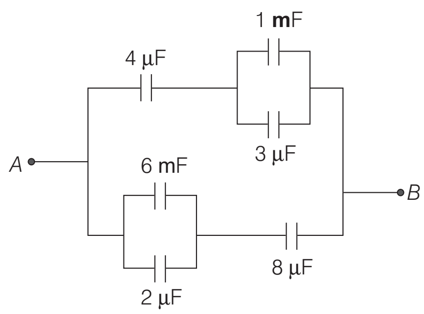
(a) 12 (b) 6
(c) 8/3 (d) 3

16 A series combination of n_1 capacitors, each of value C_1, is charged by a source of potential difference $4V$. When another parallel combination of n_2 capacitors, each of value C_2, is charged by a source of potential difference V, it has the same (total) energy stored in it, as the first combination has. The value of C_2, in terms of C_1, is then

➜ CBSE AIPMT 2010

(a) $\frac{2C_1}{n_1 n_2}$ (b) $16\frac{n_2}{n_1}C_1$ (c) $2\frac{n_2}{n_1}C_1$ (d) $\frac{16C_1}{n_1 n_2}$

17 The equivalent capacitance between A and B for the combination of capacitors shown in figure, where all capacitances are in microfarad is



(a) 6.0 μF (b) 4.0 μF (c) 2.0 μF (d) 3.0 μF

18 Charge Q is divided into two parts which are then kept some distance apart. The force between them will be maximum, if the two parts are having the charge (where e = electronic charge)

(a) $\frac{Q}{2}$ each (b) $\frac{Q}{4}$ and $\frac{3Q}{4}$

(c) $\frac{Q}{3}$ and $\frac{2Q}{3}$ (d) e and $(Q - e)$

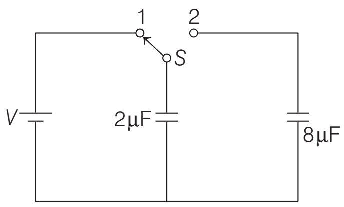
19 A capacitor is charged by a battery. The battery is removed and another identical uncharged capacitor is connected in parallel. The total electrostatic energy of resulting system ➔ NEET 2017

(a) increases by a factor of 4
(b) decreases by a factor of 2
(c) remains the same
(d) increases by a factor of 2

20 Suppose the charge of a proton and an electron differ slightly. One of them is $-e$ and the other is $(e + \Delta e)$. If the net of electrostatic force and gravitational force between two hydrogen atoms placed at a distance d (much greater than atomic size) apart is zero, then Δe is of the order (Given mass of hydrogen, $m_h = 1.67 \times 10^{-27}$ kg) ➔ NEET 2017

(a) 10^{-20} C (b) 10^{-23} C (c) 10^{-37} C (d) 10^{-47} C

21 A capacitor of 2μF is charged as shown in the figure. When the switch S is turned to position 2, the percentage of its stored energy dissipated is ➔ NEET 2016

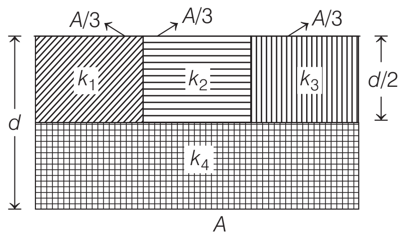


(a) 20% (b) 75% (c) 80% (d) 0%

22 An electric dipole is placed at an angle of 30° with an electric field intensity 2×10^5 N/C. It experiences a torque equal to 4 Nm. The charge on the dipole, if the dipole length is 2 cm, is ➔ NEET 2016

(a) 8 mC (b) 2 mC (c) 5 mC (d) 7 μC

23 A parallel-plate capacitor of area A, plate separation d and capacitance C is filled with four dielectric materials having dielectric constants k_1, k_2, k_3 and k_4 as shown in the figure below. If a single dielectric material is to be used to have the same capacitance C in this capacitor, then its dielectric constant k is given by ➔ NEET 2016



(a) $k = k_1 + k_2 + k_3 + 3k_4$ (b) $k = \frac{2}{3}(k_1 + k_2 + k_3) + 2k_4$

(c) $\frac{2}{k} = \frac{3}{k_1 + k_2 + k_3} + \frac{1}{k_4}$ (d) None of these

24 The electric field in a certain region is acting radially outward and is given by $E = Ar$. A charge contained in a sphere of radius 'a' centred at the origin of the field' will be given by ➔ CBSE AIPMT 2015

(a) $4\pi\varepsilon_0 Aa^2$ (b) $A\varepsilon_0 a^2$
(c) $4\pi\varepsilon_0 Aa^3$ (d) $\varepsilon_0 Aa^3$

25 If potential (in volts) in a region is expressed as $V(x, y, z) = 6xy - y + 2yz$, the electric field (in N/C) at point (1, 1, 0) is ➔ CBSE AIPMT 2015

(a) $-(3\hat{i} + 5\hat{j} + 3\hat{k})$ (b) $-(6\hat{i} + 5\hat{j} + 2\hat{k})$
(c) $-(2\hat{i} + 3\hat{j} + \hat{k})$ (d) $-(6\hat{i} + 9\hat{j} + \hat{k})$

26 A parallel plate air capacitor has capacity C, distance of separation between plates is d and potential difference V is applied between the plates. Force of attraction between the plates of the parallel plate air capacitor is ➔ CBSE AIPMT 2015

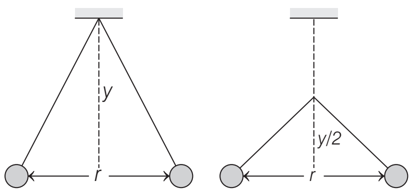
(a) $\frac{C^2V^2}{2d}$ (b) $\frac{CV^2}{2d}$

(c) $\frac{CV^2}{d}$ (d) $\frac{C^2V^2}{2d^2}$

27 In a region, the potential is represented by $V(x, y, z) = 6x - 8xy - 8y + 6yz$, where V is in volts and x, y, z are in metres. The electric force experienced by a charge of 2 C situated at point (1, 1, 1) is ➔ CBSE AIPMT 2014

(a) $6\sqrt{5}$ N (b) 30 N
(c) 24 N (d) $4\sqrt{35}$ N

28 Two pith balls carrying equal charges are suspended from a common point by strings of equal length, the equilibrium separation between them is r. Now, the strings are rigidly clamped at half the height. The equilibrium separation between the balls now becomes ➔ NEET 2013



(a) $\left(\frac{1}{\sqrt{2}}\right)^2$ (b) $\left(\frac{r}{\sqrt{2}}\right)$

(c) $\left(\frac{2r}{\sqrt{3}}\right)$ (d) $\left(\frac{2r}{3}\right)$

29 Two identical charged spheres suspended from a common point by two massless strings of lengths l, are initially at a distance d $(d << l)$ apart because of their mutual repulsion. The charges begin to leak from both the spheres at a constant rate. As a result, the spheres approach each other with a velocity v. Then, v varies as a function of the distance x between the sphere, as

➜ NEET 2016

(a) $v \propto x$ (b) $v \propto x^{-\frac{1}{2}}$ (c) $v \propto x^{-1}$ (d) $v \propto x^{\frac{1}{2}}$

30 An electron falls from rest through a vertical distance h in a uniform and vertically upward directed electric field E. The direction of electric field is now reversed, keeping its magnitude the same. A proton is allowed to fall from rest in it through the same vertical distance h. The time of fall of the electron,
in comparison to the time of fall of the proton is

(a) 10 times greater (b) 5 times greater
(c) smaller (d) equal

31 The electrostatic force between the metal plates of an isolated parallel plate capacitor C having a charge Q and area A, is ➜ NEET 2018

(a) proportional to the square root of the distance between the plates
(b) linearly proportional to the distance between the plates
(c) independent of the distance between the plates
(d) inversely proportional to the distance between the plates

32 A toy car with charge q moves on a frictionless horizontal plane surface under the influence of a uniform electric field $\mathbf{E}$. Due to the force $q\mathbf{E}$, its velocity increases from 0 to 6 m/s in one second duration. At that instant, the direction of the field is reversed. The car continues to move for two more seconds under the influence of this field. The average velocity and the average speed of the toy car between 0 to 3 seconds are respectively

(a) 1 m/s, 3.5 m/s
(b) 1 m/s, 3 m/s
(c) 2 m/s, 4 m/s
(d) 1.5 m/s, 3 m/s

ANSWERS

SESSION 1	**1** (c)	**2** (b)	**3** (c)	**4** (c)	**5** (a)	**6** (b)	**7** (a)	**8** (c)	**9** (d)	**10** (b)
	11 (b)	**12** (a)	**13** (b)	**14** (c)	**15** (c)	**16** (a)	**17** (c)	**18** (a)	**19** (a)	**20** (c)
	21 (b)	**22** (d)	**23** (c)	**24** (b)	**25** (b)	**26** (c)	**27** (b)	**28** (d)	**29** (a)	**30** (b)
	31 (b)	**32** (b)	**33** (b)	**34** (d)	**35** (c)	**36** (b)	**37** (c)	**38** (c)	**39** (c)	**40** (c)
	41 (d)	**42** (c)	**43** (a)	**44** (c)	**45** (a)	**46** (c)	**47** (c)	**48** (b)	**49** (a)	**50** (c)
	51 (a)	**52** (a)	**53** (d)	**54** (c)						
SESSION 2	**1** (a)	**2** (c)	**3** (a)	**4** (a)	**5** (a)	**6** (c)	**7** (d)	**8** (d)	**9** (a)	**10** (b)
	11 (b)	**12** (b)	**13** (a)	**14** (c)	**15** (b)	**16** (d)	**17** (a)	**18** (a)	**19** (d)	**20** (c)
	21 (c)	**22** (b)	**23** (d)	**24** (c)	**25** (b)	**26** (b)	**27** (d)	**28** (b)	**29** (b)	**30** (c)
	31 (c)	**32** (b)								

Hints and Explanations

1 The glass rod acquires positive charge on rubbing. When the rod is brought near the disc of the electroscope, the disc will acquire negative charge and there will be positive charge on the far end, i.e. on the leaves.

2 Coulomb's law is applicable for charge particles, it is not responsible to bind the protons and neutrons in the nucleus of an atom.

3 Coulomb's law is given by

$$F = k\frac{q_1 q_2}{r^2}$$

Substituting $q_1 = q_2 = ne$, we get

$$F = k\frac{(ne)(ne)}{r^2} = k\frac{n^2e^2}{r^2} \Rightarrow n^2 = \frac{Fr^2}{ke^2}$$

On putting

$F = 10^{-19}\text{N}, r = 3\text{cm} = 3\times10^{-2}\text{m}$,

$k = 9\times10^9\ \text{Nm}^2\text{C}^{-2}, e = 1.6\times10^{-19}\text{C}$,

we get $\quad n = 625$

4 Coulomb's force between them,

$$F = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1 q_2}{r^2} = \frac{q_1 q_2}{4\pi\varepsilon_0 kr^2} = \frac{F_0}{k}$$

5 Given, $F = \dfrac{40}{9}$ or $\dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r^2} = \dfrac{40}{9}$

or $\quad \dfrac{9\times10^9\times(q)^2}{(4.5)^2} = \dfrac{40}{9}$

[because $q_1 = q_2 = q$]

$\Rightarrow \quad q^2 = 10^{-8}$

$q = 10^{-4}\text{C} = 100\mu\text{C}$

6 Initially, the force on the sphere is equal due to both negative and positive charges.

$\therefore$ Net force $= 0$

On displacing the sphere towards the positive charge, force on sphere due to positive charge will be more than due to the negative charge, because it is nearer. So, sphere will move further to the positive charge.

7 Let distance between two charges is x. The force between them,

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q\,(Q-q)}{x^2}$$

x is constant, so for maximum force $q\,(Q-q)$ should be maximum.

$$\frac{d}{dq}[q\,(Q-q)] = 0$$

$$Q - 2q = 0 \Rightarrow \frac{Q}{q} = 2$$

8 From Coulomb's law, force of repulsion is

$$F = K\frac{qq}{d^2} \Rightarrow F = \frac{1}{4\pi\varepsilon_0}\frac{qq}{d^2}$$

where, $\quad q = ne$

$$\therefore\ F = \frac{1}{4\pi\varepsilon_0}\cdot\frac{n^2e^2}{d^2} \Rightarrow n = \sqrt{\frac{4\ \pi\varepsilon_0 Fd^2}{e^2}}$$

9 Electric field by the charges.

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\ 500 = 9\times10^9\times\frac{q}{(3)^2}$$

$\Rightarrow\ 500\times10^{-9} = q$

or $\quad q = 0.5\times10^{-6}$ C, $q = 0.5\mu$C

10 Electric field intensity is given by

$$E = \frac{F}{q} = \frac{F}{e} \qquad [\text{here}, q = e]$$

$\Rightarrow \quad F = eE$

or $\quad ma = eE \qquad$ [because, $F = ma$]

$\Rightarrow \quad a = \dfrac{eE}{m}$

Substituting

$e = 1.6\times10^{-19}$ C , $E = 9.1\times10^6\ \text{NC}^{-1}$,

and $\quad m = 9.1\times10^{-31}$kg, we get

$a = 1.6\times10^{18}\ \text{ms}^{-2}$

11 Weight of charged particle
= magnitude of force of electric field
i.e. $\quad mg = qE$

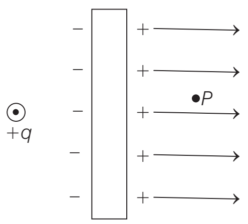
Given, $\quad m = 3\times10^{-6}$ kg

$g = 10\ \text{ms}^{-2}$ and $E = 6\times10^4\ \text{NC}^{-1}$

Substituting the values, we get

$q = 5\times10^{-10}$ C

12 When a point charge $+q$ is placed at a distance (d) from an isolated conducting plane, some negative charge develop on the surface of the plane towards the charge and an equal positive charge developes on opposite side of the plane. Hence, the field at a point P on the other side of the plane is directed perpendicular to the plane and away from the plane as shown in figure.



13 The electric field is maximum at B, because electric field is directed along decreasing potential. Hence, $V_B > V_C > V_A$.

14 In figure spacing between electric lines of force increases from left to right. Therefore, E on left is greater than E on right. Force on $+q$ charge of dipole is smaller and to the right. Force on $-q$ charge of dipole is bigger and to the left. Hence, the dipole will experience a net force towards the left.

15 Force on the charge q is $F_2 = qE$ along the direction of E and force on charge $-q$ is $F_1 = -qE$ in the direction opposite to E.

Since, forces on the dipole are equal and opposite, so net force on the electric dipole is zero.
Now, potential energy of the dipole.

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

where, θ is the angle between direction of electric field and direction of dipole moment.

$\therefore \quad \theta = 0°$

Hence, $\quad U = -\,pE\cos0° = -\,pE$ [minimum]

16 Potential gradient relates with electric field according to the following relation,

$E = \dfrac{-dV}{dr}$

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

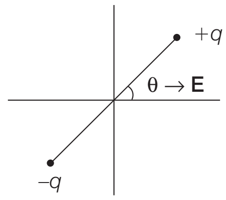
As $\ V = -\,x^2y - xz^3 + 4$

So, $\quad \mathbf{E} = -\dfrac{dV}{dx}\hat{\mathbf{i}} - \dfrac{dV}{dy}\hat{\mathbf{j}} - \dfrac{dV}{dz}\hat{\mathbf{k}}$

$$\mathbf{E} = (2xy + z^3)\hat{\mathbf{i}} + x^2\hat{\mathbf{j}} + 3xz^2\hat{\mathbf{k}}$$

17 At $\quad r \le R, E \propto r$ and at $r > R$, $E \propto \dfrac{1}{r^2}$

18 Here, torque, $\tau = pE\sin\theta$



Potential energy of the dipole,

$U = \int \tau\, d\theta$

$= \int_{\pi/2}^{\theta} pE\sin\theta d\theta = -\,pE\,[\cos\theta]_{\pi/2}^{\theta}$

$= -\,pE\cos\theta$

19 Electric flux $(\phi) = \dfrac{q}{\varepsilon_0}$

$$= \frac{(-14 + 78.85 - 56)\times10^9}{8.85\times10^{-12}}$$

$$= \frac{8.85\times10^{-9}}{8.85\times10^{-12}} = 10^3\ \text{Nm}^2\text{C}^{-1}$$

20 At any point over the spherical gaussian surface, net electric field is the vector sum of electric field due to $+q_1, -q_1$ and q_2. Hence, electric field will be due to all the charges.

21 For a closed surface outward flux is taken as positive and inward flux is taken as negative.

Net flux, $\phi = \dfrac{\text{Total charge enclosed}}{\varepsilon_0}$

$= \dfrac{1}{\varepsilon_0} \times Q$

$\therefore \quad Q = \varepsilon_0(\phi_2 - \phi_1)$

22 Electric field is perpendicular to area vector. Hence, the total flux,

$\phi = 0 \quad [\because \phi = E\, ds \cos\theta]$

23 The electric flux through any surface is equal to the product of electric field intensity at the surface and component of the surface perpendicular to electric field

$= E \times \pi R^2 = \pi R^2 E$

24 From Gauss' theorem,

$\phi = \dfrac{\text{Net charge enclosed by the surface}}{\varepsilon_0}$

The net charge due to a dipole is zero, hence $\phi = 0$

25 Total flux $(\phi_T) = \dfrac{\text{Net enclosed charge}}{\varepsilon_0}$

Hence, we can say the electric flux depends only on net enclosed charge by the surface.

26 Flux of electric field **E** through any area A is defined as $\phi = E\ A \cos\theta$. Now, angle between normal and field lines is $(90 - \theta)$.

So, $\phi = EA \cos(90 - \theta)$

$= EA \sin\theta$

$= EL^2 \sin\theta$

27 According to Gauss' law, the electric flux through a closed surface is equal to $\dfrac{1}{\varepsilon_0}$ times the net charge enclosed by the surface.

As the charge enclosed $= q/8$

So, electric flux $= \dfrac{q_{\text{enclosed}}}{\varepsilon_0}$

$\Rightarrow \quad \phi = \dfrac{q}{8\varepsilon_0}$

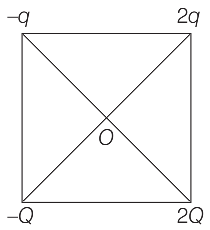
28 The flux passing through the square of 1m placed in xy plane inside the electric field is zero. Because surface area is parallel to the electric field.

So, $\quad \mathbf{E} \cdot d\mathbf{S} = 0$

$\Rightarrow \quad \int \mathbf{E} \cdot d\mathbf{S} = 0$

29 If potential at centre is zero, then

$V_1 + V_2 + V_3 + V_4 = 0$



$-\dfrac{kQ}{r} - \dfrac{kq}{r} + \dfrac{k2Q}{r} + \dfrac{k2q}{r} = 0$

$-Q - q + 2q + 2Q = 0$

$Q = -q$

30 Potential at the centre of a hollow metallic sphere

$V = \dfrac{1}{4\pi\varepsilon_0} \dfrac{Q}{R}$

31 Electric potential, $V = \dfrac{1}{4\pi\varepsilon_0} \dfrac{q}{r}$

Here, $\quad V = 2V_{+\text{ve}} + 2V_{-\text{ve}}$

$V = \dfrac{1}{4\ \pi\varepsilon_0}\left[\dfrac{2q}{L} - \dfrac{2q}{L\sqrt{5}}\right]$

$V = \dfrac{2q}{4\ \pi\varepsilon_0 L}\left(1 - \dfrac{1}{\sqrt{5}}\right)$

32 As $E = v/d$ and $mg = qE$.

So,

$V = \dfrac{mgd}{q} = \dfrac{1.6 \times 10^{-14} \times 9.8 \times 10 \times 10^{-3}}{1.6 \times 10^{-19}}$

$V = 10^4$ V

33 In a conducting sphere charge is present on the surface of the sphere. So, electric field inside will be zero and potential remains constant from centre to surface of sphere and is equal to $\dfrac{1}{4\pi\varepsilon_0} \dfrac{Q}{R}$.

34 Spherical equipotential surface exists only for point charges.

35 Electric potential inside a charged sphere is everywhere same as that on the surface.

36 Net charge on the parallel plate capacitor is 1μC

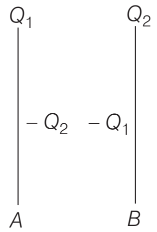
$\Rightarrow$ Charge on each plate of the capacitor, $q = 0.5\mu$C

Now, force is given by $F = qE$

Substituting $q = 0.5\mu\text{C} = 0.5 \times 10^{-6}$C and $E = 10^5 \text{Vm}^{-1}$, we get $F = 0.05$ N

37 If a battery is disconnected from the capacitor and then a dielectric substance between the two plates of condenser, so capacity, potential and potential energy are increased at saturated point and then it will decreases.

38 Let plate A and plate B be carrying charge Q_1 and Q_2, respectively.



When they are brought closer, they induce equal and opposite charge on each other, i.e. $-Q_2$ on plate A and $-Q_1$ on plate B.

Therefore, net charge on plate $A = Q_1 - Q_2$ and net charge on plate $B = -(Q_1 - Q_2)$. So, the charge on capacitor is given as

$Q_1 - Q_2$

Potential difference between the plates is $V = \dfrac{Q_1 - Q_2}{C}$

39 Charge on capacitor plates is given by

$q = CV$

Substituting $C = 0.2\,\mu$F and $V = 600$ V,

we get $\quad q = 120\,\mu$C $\quad$ ...(i)

When $0.2\,\mu$F capacitor is joined to $1.0\,\mu$F capacitor in parallel combination, then equivalent capacitance.

Now, voltage across the capacitor is given by $V' = \dfrac{q}{C'} = \dfrac{120\mu\text{C}}{1.2\mu\text{F}} = 100$ V

40 The combination shows two capacitors connected in series. Resultant capacitance is

$\dfrac{1}{C'} = \dfrac{1}{C_1} + \dfrac{1}{C_2}$

$C = \dfrac{K\varepsilon_0 A}{d}$, where A is area, d is the distance between the plates and K is dielectric constant $(= 1)$. Therefore,

$C_1 = \dfrac{\varepsilon_0 A}{d/2}, C_2 = \dfrac{\varepsilon_0 A}{d/2}$

$\therefore \quad \dfrac{1}{C'} = \dfrac{d/2}{\varepsilon_0 A} + \dfrac{d/2}{\varepsilon_0 A} \Rightarrow C' = \dfrac{\varepsilon_0 A}{d} = C$

Hence, on inserting aluminium sheet the capacitance remains the same.

41 Here, $q = 8 \times 10^{-18}$ C,

$C = 100\,\mu\text{F} = 10^{-4}$ F

$V = \dfrac{q}{C} = \dfrac{8 \times 10^{-18}}{10^{-4}} = 8 \times 10^{-14}$ V

Work done $= \dfrac{1}{2} qV$

$= \dfrac{1}{2} \times 8 \times 10^{-18} \times 8 \times 10^{-14}$

$= 32 \times 10^{-32}$ J

42 Minimum number of condensers in each row $= \frac{3000}{500} = 6$

If C_s is capacity of 6 condensers in a row,

$$\frac{1}{C_s} = \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} = 6$$

$$C_s = \frac{1}{6}\,\mu\text{F}$$

Let there be m such rows in parallel,

Total capacity $= m \times C_s$

$$2 = m \times \frac{1}{6}$$

$\therefore \quad m = 12$

Total number of capacitors $= 6 \times 12 = 72$

43 When plates of the capacitor are charged, then opposite charges are induced on water, so due to attractive force water level will rise.

44 The energy stored in the condenser

$$U = \frac{1}{2}CV^2 \Rightarrow U = \frac{1}{2}\left(\frac{A\varepsilon_0}{d}\right)(Ed)^2$$

$$\left[\because C = \frac{A\varepsilon_0}{d} \text{ and } V = Ed\right]$$

$$U = \frac{1}{2}\,\varepsilon_0 E^2 Ad$$

45 Common potential is given by

$$V = \frac{C_1V_1 - C_2V_2}{C_1 + C_2}$$

Substituting

$C_1 = 3\mu\text{F}, C_2 = 6\,\mu\text{F}, V_1 = V_2 = 12\,\text{V}$,

we get, potential difference, $V = 4\,\text{V}$

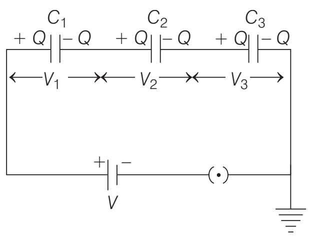
46 In series arrangement charge on each plate of all the capacitors have same magnitude. The potential difference is distributed inversely in the ratio of capacitors,

i.e. $\quad V = V_1 + V_2 + V_3$

$$[\because V_1 = V_2 = V_3 = V]$$

Here, $\quad V = 3V$

The equivalent capacitance C_s is given by

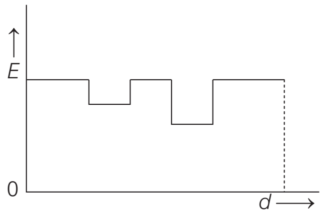


$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$[\because C_1 = C_2 = C_3 = C]$$

$$C_s = \frac{C}{3}$$

47 Graph (c) will be the right graph, the electric field inside the dielectrics will be less than the electric field outside the dielectrics. The electric field inside the dielectrics could not be zero.



As $K_2 > K_1$, the drop in electric field for K_2 dielectric must be more than K_1.

48 Heat produced in wire

= Energy stored in capacitor

$$= \frac{1}{2}CV^2 = \frac{1}{2} \times (2 \times 10^{-6})(200)^2$$

$$= 4 \times 10^{-2}\text{ J}$$

49 Both 10μF capacitances are in series.

Hence, equivalent capacitance can be calculated as, i.e.

$$\frac{1}{C_1} = \frac{1}{10} + \frac{1}{10} = \frac{1}{5} \Rightarrow C_1 = 5\mu\text{F}$$

Now, $C_1 = 5\,\mu$F and $C_2 = 5\,\mu$F, both are in parallel.

Hence, equivalent capacitance,

$$C = C_1 + C_2 = 5 + 5 = 10\,\mu\text{F}$$

50 The two condensers in the circuit are in parallel order, hence

$$C' = C + \frac{C}{2} = \frac{3C}{2}$$

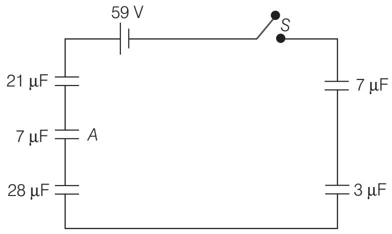
The work done in charging the equivalent capacitor is stored in the form of potential energy.

Hence, $\quad W = U = \frac{1}{2}C'V^2$

$$= \frac{1}{2}\left(\frac{3C}{2}\right)V^2 = \frac{3}{4}CV^2$$

51 If the outer sphere is earthed, then inside of outer sphere and outside of inner sphere constitute a spherical capacitor. So, the capacitance of the system is $C = 4\pi\varepsilon_0 \frac{ab}{b-a}$.

52 The equivalent circuit is



If q be the charge on each capacitor, then $\frac{q}{21} + \frac{q}{7} + \frac{q}{28} + \frac{q}{3} + \frac{q}{7} = 59$

or $\quad q = 84\mu\text{C}$

$\therefore$ Potential difference across A

$$= \frac{q}{7} = \frac{84}{7} = 12\,\text{V}$$

53 Stored energy, $W = \frac{Q^2}{2C}$

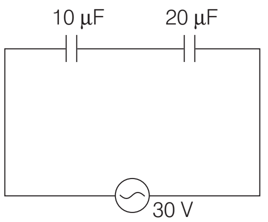
$$W_1 = \frac{(2Q)^2}{2C} = \frac{4Q^2}{2C} = 4W$$

54 The equivalent capacitance, for capacitors in series is

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$= \frac{1}{10} + \frac{1}{20}$$

$$\Rightarrow \quad C_s = \frac{20}{3}\,\mu\text{F}$$



Also, $\quad q = CV = \frac{20}{3} \times 30 = 200\,\mu\text{C}$

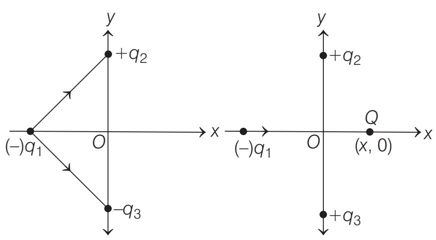
This charge on the two capacitors in series is same.

Hence, $q' = 200\,\mu\text{C}, q'' = 200\,\mu\text{C}$

SESSION 2

1 As q_2, q_3 are positive charges and net force on q_1 is along $+x$-direction, therefore q_1 must be negative as shown in figure.

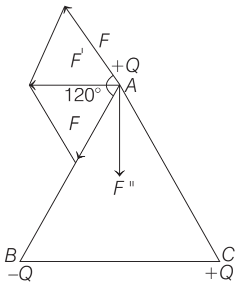
When a positive charge Q is added at $(x, 0)$, it will attract $(-q_1)$ along $+x$ direction, in figure. Therefore, force on q_1 will increase along the positive x-axis.



(a) (b)

2 Resultant force,

$$F' = \sqrt{F^2 + F^2 + 2FF\cos 120°} = F$$



Now, from figure

$$F = \sqrt{F'^2 + F''^2 + 2F'F''\cos 90^\circ}$$

Now, the force normal to BC at vertex A is

$$F'' = \sqrt{F^2 - F'^2} = 0 \qquad [\because F' = F]$$

3 Electrostatic force between electron and proton is given by

$$F_e = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

Substituting $\frac{1}{4\pi\varepsilon_0} = 9\times 10^9 \text{ Nm}^2\text{C}^{-2}$

$q_1 = 1.6\times 10^{-19}\text{C}$, $q_2 = 1.6\times 10^{-19}\text{C}$, $r = 5\times 10^{-11}$ m, we get

$$F_e = 9.22\times 10^{-8} \text{ N}$$

Now, gravitational force between electron and proton is given by

$$F_g = G\frac{M_1 M_2}{r^2}$$

Substituting $G = 6.67\times 10^{-11}$,

$M_1 = 9.1\times 10^{-31}$ kg,

$M_2 = 1.61\times 10^{-27}$ kg and

$r = 5\times 10^{-11}$, we get

$$F_g = 3.9\times 10^{-47} \text{ N}$$

So, the ratio of electrostatic and gravitational forces is given by

$$\frac{F_e}{F_g} = \frac{9.22\times 10^{-8}}{3.9\times 10^{-47}} = 2.36\times 10^{39}$$

4 When a point positive charge is brought near an isolated conducting sphere, there developes some negative charge on left side of the sphere and an equal positive charge on the right side of the sphere. Electric lines of force emitting from the point positive charge and normally on the left side of the sphere,the electric lines of force emanate normally from the right side.The electric field is best given by Fig (i).

5 Gauss' law states that the net electric flux through any closed surface is equal to the net charge inside the surface divided by ε_0.

i.e. $$\phi_{\text{total}} = \frac{q}{\varepsilon_0}$$

Let electric flux linked with surfaces A, B and C are ϕ_A, ϕ_B and ϕ_C, respectively.

i.e. $$\phi_{\text{total}} = \phi_A + \phi_B + \phi_C$$

$$[\because \phi_C = \phi_A]$$

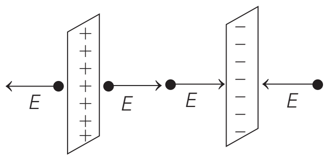
$$\therefore \quad 2\phi_A + \phi_B = \phi_{\text{total}} = \frac{q}{\varepsilon_0}$$

or $$\phi_A = \frac{1}{2}\left(\frac{q}{\varepsilon_0} - \phi_B\right)$$

$$[\because \phi_B = \phi]$$

Hence, $$\phi_A = \frac{1}{2}\left(\frac{q}{\varepsilon_0} - \phi\right)$$

6 Given that conducting plates have surface charge densities $+\sigma$ and $-\sigma$, respectively. Since, the sheet is large, the electric field E at energy point near the sheet will be perpendicular to the sheet.



The resultant electric field is given by

$$E' = E + E = 2E$$

If σ is surface charge density, then electric field $E = \frac{\sigma}{2\varepsilon_0}$

$$\therefore E' = 2E = \frac{2\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0} \text{ Vm}^{-1}$$

7 Volume of n mercury droplets = Volume of bigger drop

$$\Rightarrow \quad n\times\frac{4}{3}\pi r^3 = \frac{4}{3}\pi R^3 \Rightarrow nr^3 = R^3$$

$$\Rightarrow \quad R = n^{1/3} r \qquad \ldots\text{(i)}$$

Now, charge on bigger drop = n (Charge on each mercury drop)

$$\Rightarrow \quad q' = nq \qquad \ldots\text{(ii)}$$

Therefore, potential of bigger drop becomes,

$$V' = \frac{1}{4\pi\varepsilon_0}\frac{q'}{R}$$

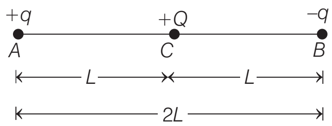
Using Eqs. (i) and (ii), we get

$$= \frac{1}{4\pi\varepsilon_0}\frac{nq}{n^{1/3} r}$$

$$\Rightarrow \quad V' = n^{2/3}\left(\frac{1}{4\pi\varepsilon_0}\frac{q}{r}\right) = n^{2/3} V$$

$$\left[\text{here}, V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}\right]$$

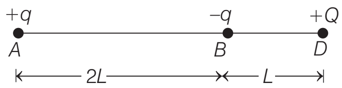
8 In first case, when charge $+Q$ is situated at C.



Electric potential energy of system

$$U_1 = \frac{1}{4\pi\varepsilon_0}\frac{(q)(-q)}{2L} + \frac{1}{4\pi\varepsilon_0}\frac{(-q)Q}{L} + \frac{1}{4\pi\varepsilon_0}\frac{qQ}{L}$$

In second case, when charge $+Q$ is moved from C to D



Electric potential energy of system in that case

$$U_2 = \frac{1}{4\pi\varepsilon_0}\frac{(q)(-q)}{2L} + \frac{1}{4\pi\varepsilon_0}\frac{qQ}{3L} + \frac{1}{4\pi\varepsilon_0}\frac{(-q)(Q)}{L}$$

$\therefore$ Work done $= \Delta U = U_2 - U_1$

$$= \left(-\frac{1}{4\pi\varepsilon_0}\frac{q^2}{2L} + \frac{1}{4\pi\varepsilon_0}\frac{qQ}{3L} - \frac{1}{4\pi\varepsilon_0}\frac{qQ}{L}\right) - \left(-\frac{1}{4\pi\varepsilon_0}\frac{q^2}{2L} - \frac{1}{4\pi\varepsilon_0}\frac{qQ}{L} + \frac{1}{4\pi\varepsilon_0}\frac{qQ}{L}\right)$$

$$= \frac{qQ}{4\pi\varepsilon_0}\frac{(1-3)}{3L} = -\frac{qQ}{6\pi\varepsilon_0 L}$$

9 When charge q_3 is at C, then its potential energy is

$$U_C = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_3}{0.4} + \frac{q_2 q_3}{0.5}\right)$$

When charge q_3 is at D, then

$$U_D = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_3}{0.4} + \frac{q_2 q_3}{0.1}\right)$$

Hence, change in potential energy

$$\Delta U = U_D - U_C = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_3}{0.1} + \frac{q_2 q_3}{0.5}\right)$$

But $\Delta U = \frac{q_3}{4\pi\varepsilon_0} k$

$$\therefore \quad \frac{q_3}{4\pi\varepsilon_0} k = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_2 q_3}{0.1} - \frac{q_2 q_3}{0.5}\right)$$

$$\Rightarrow \quad k = q_2(10 - 2) = 8q_2$$

10 $E = -\frac{dV}{dr} = -2ar$

From Gauss' theorem,

$E(4\pi r^2) = q/\varepsilon_0 \Rightarrow q = -8\pi\varepsilon_0 a r^3$

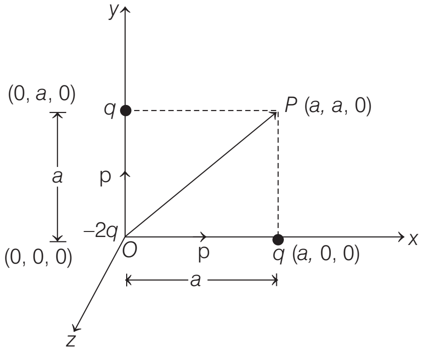
$$\rho = \frac{dq}{dv} = \frac{dq}{dr}\times\frac{dr}{dv}$$

$$= (-24\pi\varepsilon_0 a r^2)\times\frac{1}{4\pi r^2}$$

$$\Rightarrow \quad \rho = -6\varepsilon_0 a$$

11 Choose the three coordinate axes as x, y and z and plot the charges with the given coordinates as shown in figure.

O is the origin at which $-2q$ charge is placed. The system is equivalent to two dipoles along x and y-directions, respectively. The dipole moments of two dipoles are shown in figure.



The resultant dipole moment will be directed along OP, where $P \equiv (a, a, 0)$. The magnitude of resultant dipole moment is

$$P' = \sqrt{p^2 + p^2}$$
$$= \sqrt{(qa)^2 + (qa)^2} = \sqrt{2}qa$$

12 Let R and r be the radii of bigger and each smaller drop, respectively. In coalescence into a single drop, charge remains conserved. Hence, charge on bigger drop

$= 27 \times$ charge on smaller drop

i.e. $q' = 27q$

Now, before and after coalescing, volume remains same.

i.e. $\frac{4}{3}\pi R^3 = 27 \times \frac{4}{3}\pi r^3$

$\therefore \quad R = 3r$

Hence, capacitance of bigger drop

$$C' = 4\pi\varepsilon_0 R = 4\pi\varepsilon_0 (3r)$$
$$= 3(4\pi\varepsilon_0 r) = 3C$$

13 We know, the electric field is given by

$$E = \frac{V}{d} \text{ or } E_{\text{max}} = \frac{V}{d_{\text{min}}}$$

where, E_{max} = dielectric strength

Substituting $\quad V = 20\,\text{V}$

and $\quad E_{\text{max}} = 3 \times 10^6\,\text{V}$,

we get $\quad d_{\text{min}} = 6.6 \times 10^{-6}\,\text{m}$

We know that capacitance is given by

$$C = \frac{K\varepsilon_0 A}{d}$$
$$A = \frac{Cd}{K\varepsilon_0}$$

Substituting,

$C = 1.77\,\mu\text{F} = 1.77 \times 10^{-6}$ C,

$d = 6.6 \times 10^{-6}, K = 200$

$\varepsilon_0 = 8.85 \times 10^{-12}$, we get $A = 10^3\,\text{m}^2$

14 When a parallel plate air capacitor connected to a cell of emf V, then charge stored will be

$$q = CV \quad \Rightarrow \quad V = \frac{q}{C}$$

Also, energy stored is $U = \frac{1}{2}CV^2 = \frac{q^2}{2C}$

As the battery is disconnected from the capacitor the charge will not be destroyed, i.e. $q' = q$ with the introduction of dielectric in the gap of capacitor the new capacitance will be

$$C' = CK \quad \Rightarrow \quad V' = \frac{q}{C'} = \frac{q}{CK}$$

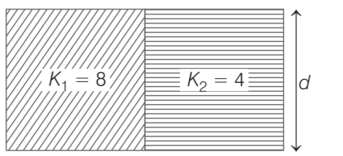
The new energy stored will be

$$U' = \frac{q^2}{2CK} \quad \Rightarrow \quad \Delta U = U' - U$$
$$= \frac{q^2}{2C}\left(\frac{1}{K} - 1\right) = \frac{1}{2}CV^2\left(\frac{1}{K} - 1\right)$$

Hence, option (c) is incorrect.

15 As shown in figure below, the two capacitors are connected in parallel. Initially, the capacitance of capacitor

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



After filling with dielectrics, we have two capacitors of capacitance.

$$C_1 = \frac{K_1\varepsilon_0(A/2)}{d} = \frac{8}{2}\frac{\varepsilon_0 A}{d} = \frac{4\varepsilon_0 A}{d} = 4C$$

and $\quad C_2 = \frac{K_2\varepsilon_0(A/2)}{d}$

$$= \frac{4}{2}\frac{\varepsilon_0 A}{d} = \frac{2\varepsilon_0 A}{d} = 2C$$

Hence, their equivalent capacitance,

$$C_{\text{eq}} = C_1 + C_2 = 4C + 2C = 6C$$

i.e. new capacitance will be six times of the original.

16 ***Case* I** When the capacitors are joined in series

$$U_{\text{Series}} = \frac{1}{2}\frac{C_1}{n_1}(4V)^2$$

***Case* II** When the capacitors are joined in parallel

$$U_{\text{Parallel}} = \frac{1}{2}(n_2 C_2)V^2$$

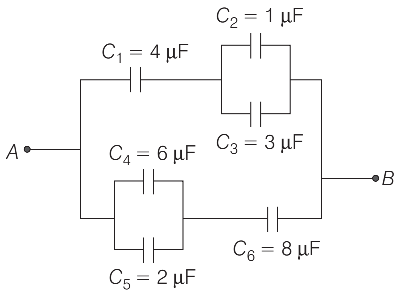
Given, $\quad U_{\text{Series}} = U_{\text{Parallel}}$

or $\quad \frac{1}{2}\frac{C_1}{n_1}(4V)^2 = \frac{1}{2}(n_2 C_2)V^2$

$\Rightarrow \quad C_2 = \frac{16C_1}{n_2 n_1}$

17 In given figure, C_2 and C_3 are in parallel.

$\therefore \quad C' = C_2 + C_3 = 4\,\mu\text{F}$



As C' and C_1 are in series,

$$\frac{1}{C''} = \frac{1}{C'} + \frac{1}{C_1} = \frac{1}{4} + \frac{1}{4}$$

$\Rightarrow \quad C'' = 2\,\mu\text{F}$

Similarly, C_4 and C_5 are in parallel

$$C''' = 6 + 2 = 8\,\mu\text{F}$$

C''' and C_6 are in series

$$\frac{1}{C''''} = \frac{1}{C'''} + \frac{1}{C_6} = \frac{1}{8} + \frac{1}{8}$$

$\Rightarrow \quad C'''' = 4\,\mu\text{F}$

Now, C'''' and C'' are in parallel

$\therefore \quad C = 4\,\mu\text{F} + 2\,\mu\text{F} = 6\,\mu\text{F}$

18. On differentiating force between two charges q and $\theta - q$ is

$F = k\frac{q(\theta - q)}{r^2}$ w.r.t. q, we get

$$\frac{dF}{dq} = \frac{d}{dq}\left[\frac{Kq}{r^2}(Q - q)\right]$$

or $\quad \frac{dF}{dq} = \frac{K}{r^2}\frac{d}{dq}[Qq - q^2]$

or $\quad \frac{dF}{dq} = \frac{K}{r^2}[Q - 2q] \quad \ldots\text{(i)}$

But we know that, when force is maximum, then $\frac{dF}{dq} = 0$

Then, from Eq. (i), we have

$$\frac{K}{r^2}[Q - 2q] = 0$$

or $\quad Q - 2q = 0$

or $\quad Q = 2q$

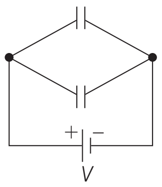
or $\quad q = \frac{Q}{2}$

So, the other part $= Q - \frac{Q}{2} = \frac{Q}{2}$

Hence, the each part have the same charge $\frac{Q}{2}$.

19 Energy stored in a system of capacitors

$$= \Sigma \frac{1}{2} CV^2$$



Also, potential drop remains same in parallel across both capacitors.
Initially stored energy,

$$U_1 = \frac{1}{2} CV^2$$

Finally, potential drop across each capacitor will be still V. So, finally stored energy,

$$U_2 = \frac{1}{2} CV^2 + \frac{1}{2} CV^2 = \frac{1}{2} (2C) V^2$$

$$= 2\left(\frac{1}{2} CV^2\right) = 2U_1$$

20 Net charge on one H-atom

$$q = -e + e + \Delta e = \Delta e$$

Net electrostatic repulsive force between two H-atoms

$$F_r = \frac{Kq^2}{d^2} = \frac{K(\Delta e)^2}{d^2}$$

Similarly, net gravitational attractive force between two H-atoms, $F_G = \frac{Gm_r^2}{d^2}$

It is given that,

$$F_r - F_G = 0$$

$$\Rightarrow \frac{K(\Delta e)^2}{d^2} - \frac{Gm_r^2}{d^2} = 0$$

$$\Rightarrow (\Delta e)^2 = \frac{Gm_r^2}{K}$$

$$(\Delta e)^2 = \frac{(6.67 \times 10^{-11})(1.67 \times 10^{-27})^2}{9 \times 10^9}$$

$$\Rightarrow \Delta e = 1.437 \times 10^{-37} \text{ C}$$

21 When the switch S is connected to point 1, then initial energy stored in the capacitor can be given as $= \frac{1}{2} (2\mu\text{F}) \times V^2$.

When the switch S is connected to point 2, energy dissipated on connection across 8 μF will be

$$= \frac{1}{2}\left(\frac{C_1 C_2}{C_1 + C_2}\right) \cdot V^2$$

$$= \frac{1}{2} \times \frac{2\mu\text{F} \times 8\,\mu\text{F}}{10\,\mu\text{F}} \times V^2$$

$$= \frac{1}{2} \times (1.6\,\mu\text{F}) \times V^2$$

Therefore, % loss of energy

$$= \frac{1.6}{2} \times 100 = 80\%$$

22 $\because$ Torque on an electric dipole in an electric field,

$$\tau = \mathbf{p} \times \mathbf{E} \Rightarrow |\tau| = pE \sin\theta$$

where, θ is angle between $\mathbf{E}$ and $\mathbf{p}$

$\Rightarrow 4 = p \times 2 \times 10^5 \times \sin 30$

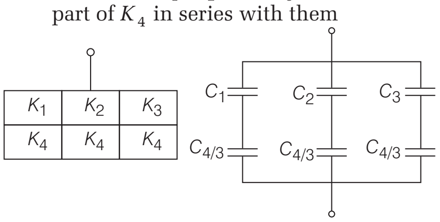
$\Rightarrow p = 4 \times 10^{-5}$ cm

$\therefore q\,2l = 4 \times 10^{-5}$ $\quad [\because p = q\,2l]$

where, $2l = 2 \text{ cm} = 2 \times 10^{-4}$ m

$$\therefore q = \frac{4 \times 10^{-5}}{2 \times 10^{-2}} \Rightarrow 2 \times 10^{-3} \text{ C} = 2 \text{ mC}$$

23 Given capacitor is equivalent to capacitors K_1, K_2 and K_3 in parallel and part of K_4 in series with them



$$\frac{1}{C_1} + \frac{3}{C_4} = \frac{3d}{2K_1\varepsilon_0 A} + \frac{3d}{2K_4\varepsilon_0 A}$$

$$= \frac{3d}{2\varepsilon_0 A}\left[\frac{1}{K_1} + \frac{1}{K_4}\right]$$

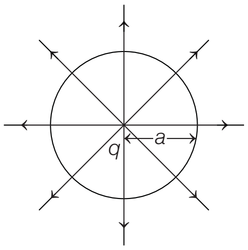
$$\Rightarrow C_{eq} = \frac{K\varepsilon_0 A}{d}$$

$$= \frac{2\varepsilon_0 A}{3d}\left[\frac{K_1K_4}{K_1 + K_4} + \frac{K_2K_4}{K_2 + K_4} + \frac{K_3K_4}{K_3 + K_4}\right]$$

$$K = \frac{2}{3}\left[\frac{K_1K_4}{K_1 + K_4} + \frac{K_2K_4}{K_2 + K_4} + \frac{K_3K_4}{K_3 + K_4}\right]$$

So, none of these option is correct.

24 Given, $\quad E = Ar$ $\quad$ ...(i)



Here, $r = a \Rightarrow E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{a^2}$

From Eq. (i), we get

$$\frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{a^2} = Aa \Rightarrow q = 4\pi\varepsilon_0 Aa^3$$

25 Given, potential in a region,

$$V = 6xy - y + 2yz$$

Electric field in a region,

$$E = -\frac{\partial V}{\partial x}\,\hat{\mathbf{i}} - \frac{\partial V}{\partial y}\,\hat{\mathbf{j}} - \frac{\partial V}{\partial z}\,\hat{\mathbf{k}}$$

$$\Rightarrow E = -6y\hat{\mathbf{i}} - (6x - 1)\hat{\mathbf{j}} - 2y\,\hat{\mathbf{k}}$$

At, (1, 1, 0), electric field can be expressed,

$$E = -(6 \times 1\,\hat{\mathbf{i}}) - (6 \times 1 - 1)\,\hat{\mathbf{j}} - 2 \times 1 \cdot \hat{\mathbf{k}}$$

$$= -(6\hat{\mathbf{i}} + 5\hat{\mathbf{j}} + 2\,\hat{\mathbf{k}}) \text{ N/C}$$

26 Force between plates of parallel capacitor,

$$F = q\,E = q\left[\frac{\sigma}{2\varepsilon_0}\right]$$

$\because$ Surface charge density $\sigma = \frac{q}{A}$

$$\therefore \quad F = q\left[\frac{q}{2A\varepsilon_0}\right] \Rightarrow F = \frac{q^2}{2A\varepsilon_0}$$

So, net charge across a capacitor, $q = CV$

$$F = \frac{C^2V^2}{2A\varepsilon_0} \qquad \left[C = \frac{A\varepsilon_0}{d}\right]$$

$$\Rightarrow F = \frac{\left(\frac{A\varepsilon_0}{d}\right) \times CV^2}{2\,A\,\varepsilon_0} = \frac{CV^2}{2\,d}$$

27 As we know that relation between potential difference and electric field $\mathbf{E}$ in a particular region is given by,

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

As $\quad V = 6x - 8xy - 8y + 6yz$

So, $\quad \mathbf{E} = -\frac{dV}{dr}$

$$= -[(6 - 8y)\hat{\mathbf{i}} + (-8x - 8 + 6z)\hat{\mathbf{j}} + 6y\hat{\mathbf{k}}]$$

The value of $\mathbf{E}$ at coordinate (1, 1, 1)

$$\mathbf{E} = -[-2\hat{\mathbf{i}} - 10\hat{\mathbf{j}} + 6\hat{\mathbf{k}}]$$

So, $\mathbf{E}_{net} = \sqrt{(-2)^2 + (-10)^2 + 6^2}$

$$= 2\sqrt{35} \text{ N/C}$$

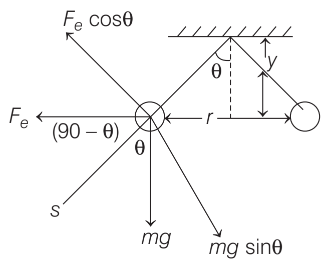
and force on charge q due to $\mathbf{E}_{net}$ is given by

$$F = q\,\mathbf{E}_{net} = 2 \times 2\sqrt{35} = 4\sqrt{35} \text{ N}$$

28 **Case I** $\quad F_e \cos\theta = mg \sin\theta$

$$\Rightarrow \frac{F_e}{mg} = \tan\theta$$

$$\Rightarrow mg = \frac{F_e}{\tan\theta} \qquad \text{...(i)}$$



Case II $\quad F_e{}' \cos\theta_1 = mg \sin\theta_1$

$$\Rightarrow \frac{F_e{}'}{mg} = \tan\theta_1$$

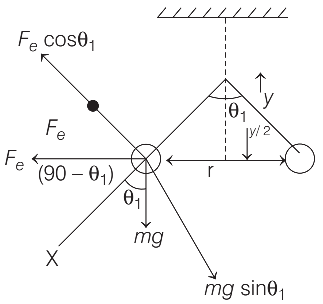
$$\Rightarrow mg = \frac{F_e{}'}{\tan\theta_1} \qquad \text{...(ii)}$$

From Eqs. (i) and (ii), we get

$$\frac{F_e}{\tan\theta} = \frac{F_e{}'}{\tan\theta_1} \Rightarrow \frac{F_e}{F_e{}'} = \frac{\tan\theta}{\tan\theta_1}$$

As, $\tan\theta = \frac{P\,(\text{perpendicular})}{b\,(\text{base})} = \frac{r}{2y}$

$$\tan\theta_1 = P/b = \frac{r}{2 \times y} \times 2 = \frac{r}{y}$$



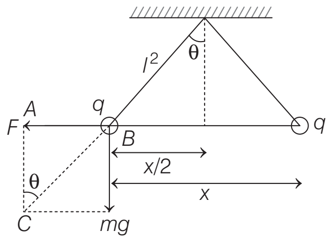
$$\frac{F_e}{F_e'} = \frac{r}{2y \times r} \times y \Rightarrow F_e' = 2F_e$$

So, $\frac{kq^2}{r'^2} = \frac{2kq^2}{r^2}$

$$\frac{1}{r'} = \frac{\sqrt{2}}{r}$$

$\therefore \quad r' = \frac{r}{\sqrt{2}}$

29 According to question, two identical charged spheres suspended from a common point by two massless strings of length L.



$\because$ In ΔABC

$$\tan\theta = \frac{F}{mg} \quad \text{or} \quad \frac{F}{mg} = \tan\theta \quad \ldots\text{(i)}$$

Since, the charges begins to leak from both the spheres at a con stant rate. As a result, the spheres approach each other with velocity v.

Therefore, Eq. (i) can be rewritten as

$$\frac{Kq^2}{x^2 mg} = \frac{x/2}{\sqrt{l^2 - \frac{x^2}{4}}}$$

$$\Rightarrow \frac{Kq^2}{x^2 mg} = \frac{x}{2l} \quad \text{or} \quad q^2 \propto x^3 \Rightarrow q \propto x^{3/2}$$

$$\Rightarrow \frac{dq}{dt} \propto \frac{d\,(x^{3/2})}{dx} \cdot \frac{dx}{dt}$$

$$\Rightarrow \frac{dq}{dt} \propto x^{1/2} \cdot v$$

$$\Rightarrow v \propto \frac{1}{x^{1/2}} \quad \text{or} \quad v \propto x^{-1/2}$$

30 Force on a charged particle in the presence of an electric field is given as

$$F = qE \quad \ldots\text{(i)}$$

where, q is the charge on the charged particle and E is the electric field.

From Newton's second law of motion, force on a particle with mass m is given as

$$F = ma \quad \ldots\text{(ii)}$$

where, a is the acceleration.

From Eqs. (i) and (ii), we get

$$F = ma = qE \Rightarrow a = \frac{qE}{m} \quad \ldots\text{(iii)}$$

Now, consider that a particle falls from rest through a vertical distance h. Therefore, $u = 0$ and the second equation of motion becomes

$$s = ut + \frac{1}{2}at^2$$

or $\quad h = 0 \times t + \frac{1}{2}at^2$

$$= \frac{1}{2} \times \frac{qE}{m}t^2 \quad \text{[from Eq. (iii)]}$$

$$\Rightarrow t^2 = \frac{2hm}{qE} \quad \text{or} \quad t = \sqrt{\frac{2hm}{qE}}$$

Since, the particles given in the question is electron and proton; and the quantity $\sqrt{\frac{2h}{qE}}$ (here, $q_p = q_e = e$) for both of them is constant. Thus, we can write

$$t = k\sqrt{m}$$

where, $\quad k = \sqrt{\frac{2h}{qE}}$

or $\quad t \propto \sqrt{m}$

As, mass of proton $(m_p) >>$ mass of electron (m_e).

Thus, the time of fall of an electrons would be smaller than the time of fall of a protons.

31 As we know that, the total work done in transferring a charge to a parallel plate capacitor is given as

$$W = \frac{Q^2}{2C} \quad \ldots\text{(i)}$$

where, C is the capacitance of the capacitor.

We can also wirte a relation for work done as,

$$W = F \cdot d \quad \ldots\text{(ii)}$$

where, F is the electrostatic force between the plates of capacitor and d is the distance between the plates.

From Eqs. (i) and (ii), we get

$$W = \frac{Q^2}{2C} = Fd \Rightarrow F = \frac{Q^2}{2Cd} \quad \ldots\text{(iii)}$$

As, the capacitance of a parallel plate is given as

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

Substituting the value of C in Eq. (iii), we get

$$F = \frac{Q^2 d}{2\varepsilon_0 Ad} = \frac{Q^2}{2\varepsilon_0 A}$$

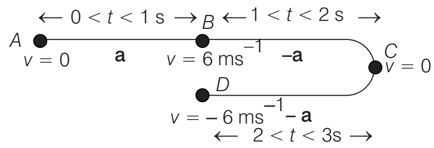
This means, electrostatic force is independent of the distance between the plates.

32 According to the question,

For the time duration $0 < t < 1\text{s}$, the velocity increase from 0 to 6 ms^{-1}

As the direction of field has been reversed for $1 < t < 2\text{s}$, the velocity firstly decreases from 6 ms^{-1} to 0.

Then, for $2 < t < 3\text{s}$; as the field strength is same; the magnitude of acceleration would be same, but velocity increases from 0 to − 6 ms^{-1}.



Acceleration of the car

$$|a| = \left|\frac{v-u}{t}\right| = \frac{6-0}{1} = 6\,\text{ms}^{-2}$$

The displacement of the particle is given as

$$s = ut + \frac{1}{2}at^2$$

For $t = 0$ to $t = 1\,\text{s}$

$$u = 0, a = +6\,\text{m/s}^2$$

$$\Rightarrow s_1 = 0 + \frac{1}{2} \times 6 \times (1)^2 = 3\,\text{m}$$

For $t = 1\,\text{s}$ to $t = 2\,\text{s}$

$$u = 6\,\text{ms}^{-1}, a = -6\,\text{ms}^{-2}$$

$$\Rightarrow s_2 = 6 \times 1 - \frac{1}{2} \times 6 \times (1)^2$$

$$= 6 - 3 = 3\,\text{m}$$

For $t = 2\,\text{s}$ to $t = 3\,\text{s}$

$$u = 0, a = -6\,\text{ms}^{-1}$$

$$\Rightarrow s_3 = 0 - \frac{1}{2} \times 6 \times (1)^2 = -3\,\text{m}$$

$\therefore$ Net displacement, $s = s_1 + s_2 + s_3$

$$= 3\,\text{m} + 3\,\text{m} - 3\,\text{m} = 3\,\text{m}$$

Hence, average velocity

$$= \frac{\text{Net displacement}}{\text{Total time}} = \frac{3}{3} = 1\,\text{ms}^{-1}$$

Total distance travelled, $d = 9\,\text{m}$

Hence, average speed

$$= \frac{\text{Total distance}}{\text{Total time}} = \frac{9}{3} = 3\,\text{ms}^{-1}$$