Electric Charges and Fields

Questions 1-10 are Case Study based questions and are compulsory. Attempt any 4 sub parts from each question. Each question carries 1 mark.

1

Syllabus

Electric Charges; Conservation of charge, Coulomb's law-force between two-point charges, forces between multiple charges; superposition principle and continuous charge distribution. Electric field, electric field due to a point charge, electric field lines, electric dipole, electric field due to a dipole, torque on a dipole in uniform electric field. Electric flux, statement of Gauss's theorem and its applications to find field due to infinitely long straight wire, uniformly charged infinite plane sheet

Coulomb's Law

Coulomb's law states that the electrostatic force of attraction or repulsion acting between two stationary point charges is given by

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

where F denotes the force between two charges q_1 and q_2 separated by a distance r in free space, ε_0 is a constant known as permittivity of free space. Free space is vacuum and may be taken to be air practically.

If free space is replaced by a medium, then ε_0 is replaced by $(\varepsilon_0 k)$ or $(\varepsilon_0 \varepsilon_r)$ where k is known as dielectric constant or relative permittivity.

(i) In coulomb's law, $F = k\dfrac{q_1 q_2}{r^2}$, then on which of the following factors does the proportionality constant k depends?
  (a) Electrostatic force acting between the two charges
  (b) Nature of the medium between the two charges
  (c) Magnitude of the two charges
  (d) Distance between the two charges.

(ii) Dimensional formula for the permittivity constant ε_0 of free space is
  (a) $[M L^{-3} T^4 A^2]$
  (b) $[M^{-1} L^3 T^2 A^2]$
  (c) $[M^{-1} L^{-3} T^4 A^2]$
  (d) $[M L^{-3} T^4 A^{-2}]$

(iii) The force of repulsion between two charges of 1 C each, kept 1 m apart in vaccum is
  (a) $\dfrac{1}{9 \times 10^9} N$
  (b) $9 \times 10^9 N$
  (c) $9 \times 10^7 N$
  (d) $\dfrac{1}{9 \times 10^{12}} N$

(iv) Two identical charges repel each other with a force equal to 10 mgwt when they are 0.6 m apart in air. $(g = 10 \text{ m s}^{-2})$. The value of each charge is

    (a) 2 mC   (b) 2×10^{-7} mC   (c) 2 nC   (d) 2 μC

(v) Coulomb's law for the force between electric charges most closely resembles with

    (a) law of conservation of energy   (b) Newton's law of gravitation

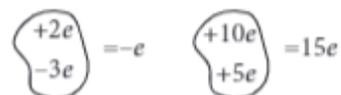   (c) Newton's 2nd law of motion   (d) law of conservation of charge

2

Quantization of Electric Charge

Smallest charge that can exist in nature is the charge of an electron. During friction it is only the transfer of electrons which makes the body charged. Hence net charge on any body is an integral multiple of charge of an electron $[1.6 \times 10^{-19} \text{ C}]$ *i.e.*

$$q = \pm ne$$
where $n = 1, 2, 3, 4, \ldots.$

$\left(\begin{array}{c}+2e\\-3e\end{array}\right) = -e$ $\left(\begin{array}{c}+10e\\+5e\end{array}\right) = 15e$

Hence no body can have a charge represented as $1.1e$, $2.7e$, $\frac{3}{5}e$, etc.

Recently, it has been discovered that elementary particles such as protons or neutrons are composed of more elemental units called quarks.

(i) Which of the following properties is not satisfied by an electric charge?

    (a) Total charge conservation.   (b) Quantization of charge.

    (c) Two types of charge.   (d) Circular line of force.

(ii) Which one of the following charges is possible?

    (a) 5.8×10^{-18} C   (b) 3.2×10^{-18} C

    (c) 4.5×10^{-19} C   (d) 8.6×10^{-19} C

(iii) If a charge on a body is 1 nC, then how many electrons are present on the body?

    (a) 6.25×10^{27} (b) 1.6×10^{19}

    (c) 6.25×10^{28} (d) 6.25×10^{9}

(iv) If a body gives out 10^9 electrons every second, how much time is required to get a total charge of 1 C from it?

    (a) 190.19 years   (b) 150.12 years   (c) 198.19 years   (d) 188.21 years

(v) A polythene piece rubbed with wool is found to have a negative charge of 3.2×10^{-7} C. Calculate the number of electrons transferred.

    (a) 2×10^{12} (b) 3×10^{12} (c) 2×10^{14} (d) 3×10^{14}

3

Electric Flux through a Cube

Net electric flux through a cube is the sum of fluxes through its six faces. Consider a cube as shown in figure, having sides of length $L = 10.0$ cm. The electric field is uniform, has a magnitude $E = 4.00 \times 10^3$ N C^{-1} and is parallel to the xy plane at an angle of 37° measured from the $+x$-axis towards the $+y$-axis.
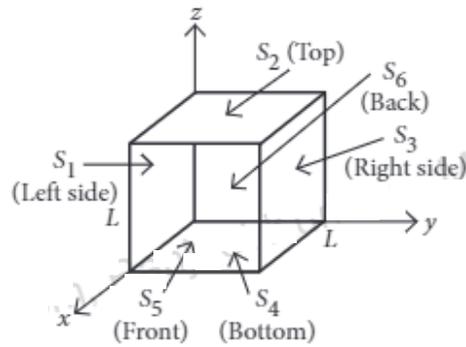
(i) Electric flux passing through surface S_6 is

    (a) $-24 \text{ N m}^2 \text{ C}^{-1}$
    (b) $24 \text{ N m}^2 \text{ C}^{-1}$
    (c) $32 \text{ N m}^2 \text{ C}^{-1}$
    (d) $-32 \text{ N m}^2 \text{ C}^{-1}$

(ii) Electric flux passing through surface S_1 is

    (a) $-24 \text{ N m}^2 \text{ C}^{-1}$
    (b) $24 \text{ N m}^2 \text{ C}^{-1}$
    (c) $32 \text{ N m}^2 \text{ C}^{-1}$
    (d) $-32 \text{ N m}^2 \text{ C}^{-1}$

(iii) The surfaces that have zero flux are

    (a) S_1 and S_3
    (b) S_5 and S_6
    (c) S_2 and S_4
    (d) S_1 and S_2

(iv) The total net electric flux through all faces of the cube is

    (a) $8 \text{ N m}^2 \text{ C}^{-1}$
    (b) $-8 \text{ N m}^2 \text{ C}^{-1}$
    (c) $24 \text{ N m}^2 \text{ C}^{-1}$
    (d) zero

(v) The dimensional formula of surface integral $\oint \vec{E} \cdot d\vec{S}$ of an electric field is

    (a) $[\text{M L}^2 \text{ T}^{-2} \text{ A}^{-1}]$
    (b) $[\text{M L}^3 \text{ T}^{-3} \text{ A}^{-1}]$
    (c) $[\text{M}^{-1} \text{ L}^3 \text{ T}^{-3} \text{ A}]$
    (d) $[\text{M L}^{-3} \text{ T}^{-3} \text{ A}^{-1}]$

4

Motion of Charged Particle in Uniform Electric Field

When a charged particle is placed in an electric field, it experiences an electrical force. If this is the only force on the particle, it must be the net force. The net force will cause the particle to accelerate according to Newton's second law. So

$$\vec{F}_e = q\vec{E} = m\vec{a}$$
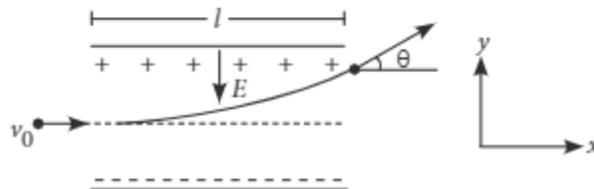
If $\vec{E}$ is uniform, then $\vec{a}$ is constant and $\vec{a} = q\vec{E}/m$. If the particle has a positive charge, its acceleration is in the direction of the field. If the particle has a negative charge, its acceleration is in the direction opposite to the electric field. Since the acceleration is constant, the kinematic equations can be used.

(i) An electron of mass m, charge e falls through a distance h metre in a uniform electric field E. Then time of fall,

    (a) $t = \sqrt{\dfrac{2hm}{eE}}$
    (b) $t = \dfrac{2hm}{eE}$
    (c) $t = \sqrt{\dfrac{2eE}{hm}}$
    (d) $t = \dfrac{2eE}{hm}$

(ii) An electron moving with a constant velocity v along X-axis enters a uniform electric field applied along Y-axis. Then the electron moves

(a) with uniform acceleration along Y-axis

(b) without any acceleration along Y-axis

(c) in a trajectory represented as $y = ax^2$

(d) in a trajectory represented as $y = ax$

(iii) Two equal and opposite charges of masses m_1 and m_2 are accelerated in an uniform electric field through the same distance. What is the ratio of their accelerations if their ratio of masses is $\dfrac{m_1}{m_2} = 0.5$?

(a) $\dfrac{a_1}{a_2} = 2$

(b) $\dfrac{a_1}{a_2} = 0.5$

(c) $\dfrac{a_1}{a_2} = 3$

(d) $\dfrac{a_1}{a_2} = 1$

(iv) A particle of mass m carrying charge q is kept at rest in a uniform electric field E and then released. The kinetic energy gained by the particle, when it moves through a distance y is

(a) $\dfrac{1}{2}qEy^2$

(b) qEy

(c) qEy^2

(d) qE^2y

(v) A charged particle is free to move in an electric field. It will travel

(a) always along a line of force

(b) along a line of force, if its initial velocity is zero

(c) along a line of force, if it has some initial velocity in the direction of an acute angle with the line of force

(d) none of these.

5

Millikan's Oil-drop Experiment

In 1909, Robert Millikan was the first to find the charge of an electron in his now-famous oil-drop experiment. In that experiment, tiny oil drops were sprayed into a uniform electric field between a horizontal pair of oppositely charged plates. The drops were observed with a magnifying eyepiece, and the electric field was adjusted so that the upward force on some negatively charged oil drops was just sufficient to balance the downward force of gravity. That is, when suspended, upward force qE just equaled Mg. Millikan accurately measured the charges on many oil drops and found the values to be whole number multiples of 1.6×10^{-19} C the charge of the electron. For this, he won the Nobel prize.
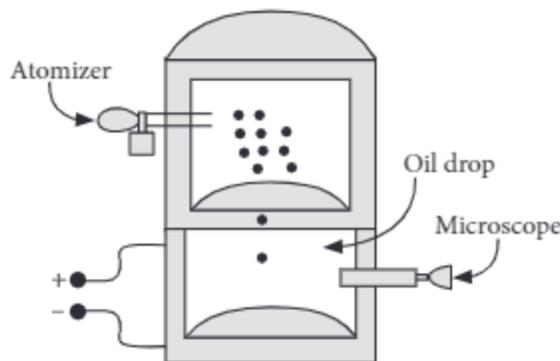

(i) If a drop of mass 1.08×10^{-14} kg remains stationary in an electric field of 1.68×10^5 N C^{-1}, then the charge of this drop is

(a) 6.40×10^{-19} C

(b) 3.2×10^{-19} C

(c) 1.6×10^{-19} C

(d) 4.8×10^{-19} C

(ii) Extra electrons on this particular oil drop (given the presently known charge of the electron) are

(a) 4

(b) 3

(c) 5

(d) 8

(iii) A negatively charged oil drop is prevented from falling under gravity by applying a vertical electric field 100 V m^{-1}. If the mass of the drop is 1.6×10^{-3} g, the number of electrons carried by the drop is ($g = 10$ m s^{-2})

(a) 10^{18} (b) 10^{15} (c) 10^{12} (d) 10^{9}

(iv) The important conclusion given by Millikan's experiment about the charge is

(a) charge is never quantized (b) charge has no definite value

(c) charge is quantized (d) charge on oil drop always increases.

(v) If in Millikan's oil drop experiment, charges on drops are found to be $8\mu C$, $12\mu C$, $20\mu C$, then quanta of charge is

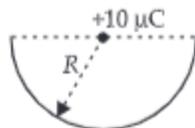(a) $8\mu C$ (b) $20\mu C$ (c) $12\mu C$ (d) $4\mu C$

6

Guass's Law and Its Significance

Gauss's law and Coulomb's law, although expressed in different forms, are equivalent ways of describing the relation between charge and electric field in static conditions. Gauss's law is $\varepsilon_0 \phi = q_{encl}$, when q_{encl} is the net charge inside an imaginary closed surface called Gaussian surface. $\phi = \oint \vec{E} \cdot d\vec{A}$ gives the electric flux through the Gaussian surface. The two equations hold only when the net charge is in vacuum or air.

Gaussian
spherical surfaces
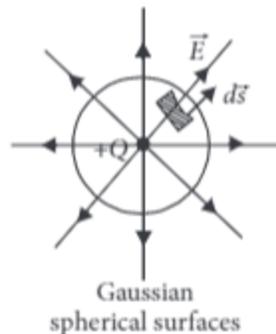
(i) If there is only one type of charge in the universe, then ($\vec{E} \rightarrow$ Electric field, $d\vec{s} \rightarrow$ Area vector)

(a) $\oint \vec{E} \cdot d\vec{s} \neq 0$ on any surface

(b) $\oint \vec{E} \cdot d\vec{s}$ could not be defined

(c) $\oint \vec{E} \cdot d\vec{s} = \infty$ if charge is inside

(d) $\oint \vec{E} \cdot d\vec{s} = 0$ if charge is outside, $\oint \vec{E} \cdot d\vec{s} = \dfrac{q}{\varepsilon_0}$ if charge is inside

(ii) What is the nature of Gaussian surface involved in Gauss law of electrostatic ?

(a) Magnetic (b) Scalar (c) Vector (d) Electrical

(iii) A charge $10\ \mu C$ is placed at the centre of a hemisphere of radius $R = 10$ cm as shown. The electric flux through the hemisphere (in MKS units) is


+10 μC

R

(a) 20×10^5 (b) 10×10^5 (c) 6×10^5 (d) 2×10^5

(iv) The electric flux through a closed surface area S enclosing charge Q is ϕ. If the surface area is doubled, then the flux is

   (a) 2ϕ (b) $\phi/2$ (c) $\phi/4$ (d) ϕ

(v) A Gaussian surface encloses a dipole. The electric flux through this surface is

   (a) $\dfrac{q}{\varepsilon_0}$ (b) $\dfrac{2q}{\varepsilon_0}$ (c) $\dfrac{q}{2\varepsilon_0}$ (d) zero

7

Relation between Strength of Electric Field and Density of Lines of Force

Electric field strength is proportional to the density of lines of force *i.e.*, electric field strength at a point is proportional to the number of lines of force cutting a unit area element placed normal to the field at that point. As illustrated in the given figure, the electric field at P is stronger that at Q.

(i) Electric lines of force about a positive point charge are

   (a) radially outwards   (b) circular clockwise

   (c) radially inwards   (d) parallel straight lines.

(ii) Which of the following is false for electric lines of force?

   (a) They always start from positive charges and terminate on negative charges.

   (b) They are always perpendicular to the surface of a charged conductor.

   (c) They always form closed loops.

   (d) They are parallel and equally spaced in a region of uniform electric field.

(iii) Which one of the following pattern of electric line of force in not possible in filed due to stationary charges ?

   (a)   (b)   (c)   (d)

(iv) Electric lines of force are curved

   (a) in the field of a single positive or negative charge   (b) in the field of two equal and opposite charges

   (c) in the field of two like charges   (d) both (b) and (c).

(v) The figure below shows the electric field lines due to two positive charges. The magnitudes E_A, E_B and E_C of the electric fields at points A, B and C respectively are related as

   (a) $E_A > E_B > E_C$ (b) $E_B > E_A > E_C$ (c) $E_A = E_B > E_C$ (d) $E_A > E_B = E_C$

## Torque on a Dipole in a Uniform Electric Field

When electric dipole is placed in uniform electric field, its two charges experience equal and opposite forces, which cancel each other and hence net force on electric dipole in uniform electric field is zero. However these forces are not collinear, so they give rise to some torque on the dipole. Since net force on electric dipole in uniform electric field is zero. so no work is done in moving the electric dipole in uniform electric field. However some work is done in rotating the dipole against the torque acting on it.
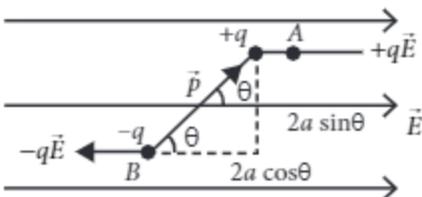

(i) The dipole moment of a dipole in a uniform external field $\vec{E}$ is $\vec{P}$. Then the torque $\vec{\tau}$ acting on the dipole is

    (a) $\vec{\tau} = \vec{P} \times \vec{E}$
    (b) $\vec{\tau} = \vec{P} \cdot \vec{E}$
    (c) $\vec{\tau} = 2(\vec{P} + \vec{E})$
    (d) $\vec{\tau} = (\vec{P} + \vec{E})$

(ii) An electric dipole consists of two opposite charges, each of magnitude 1.0 μC separated by a distance of 2.0 cm. The dipole is placed in an external field of 10^5 N C^{-1}. The maximum torque on the dipole is

    (a) 0.2×10^{-3} Nm
    (b) 1×10^{-3} Nm
    (c) 2×10^{-3} Nm
    (d) 4×10^{-3} Nm

(iii) Torque on a dipole in uniform electric field is minimum when θ is equal to

    (a) 0°
    (b) 90°
    (c) 180°
    (d) Both (a) and (c)

(iv) When an electric dipole is held at an angle in a uniform electric field, the net force F and torque τ on the dipole are

    (a) $F = 0, \tau = 0$
    (b) $F \neq 0, \tau \neq 0$
    (c) $F = 0, \tau \neq 0$
    (d) $F \neq 0, \tau = 0$

(v) 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 θ = 90°, the torque and the potential energy of the dipole will respectively be

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

Continuous Charge Distribution

In practice, we deal with charges much greater in magnitude than the charge on an electron, so we can ignore the quantum nature of charges and imagine that the charge is spread in a region in a continuous manner. Such a charge distribution is known as continuous charge distribution. There are three types of continuous charge distribution : (i) Line charge distribution (ii) Surface charge distribution (iii) Volume charge distribution as shown in figure.

Line charge $\Delta Q = \lambda \Delta l$ Surface charge $\Delta Q = \sigma \Delta S$ Volume charge $\Delta Q = \rho \Delta V$
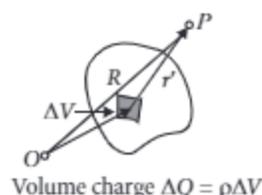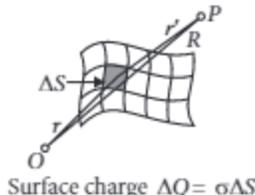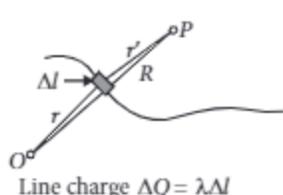
(i) **Statement 1 :** Gauss's law can't be used to calculate electric field near an electric dipole.
Statement 2 : Electric dipole don't have symmetrical charge distribution.
(a) Statement 1 and statement 2 are true
(b) Statement 1 is false but statement 2 is true.
(c) Statement 1 is true but statement 2 is false.
(d) Both statements are false.

(ii) An electric charge of 8.85×10^{-13} C is placed at the centre of a sphere of radius 1 m. The electric flux through the sphere is
(a) $0.2 \text{ N C}^{-1} \text{ m}^2$
(b) $0.1 \text{ N C}^{-1} \text{ m}^2$
(c) $0.3 \text{ N C}^{-1} \text{ m}^2$
(d) $0.01 \text{ N C}^{-1} \text{ m}^2$

(iii) The electric field within the nucleus is generally observed to be linearly dependent on r. So,
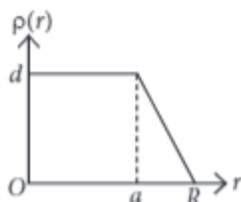
(a) $a = 0$
(b) $a = \dfrac{R}{2}$
(c) $a = R$
(d) $a = \dfrac{2R}{3}$

(iv) What charge would be required to electrify a sphere of radius 25 cm so as to get a surface charge density of $\dfrac{3}{\pi} \text{ C m}^{-2}$?
(a) 0.75 C
(b) 7.5 C
(c) 75 C
(d) zero

(v) The SI unit of linear charge density is
(a) C m
(b) C m^{-1}
(c) C m^{-2}
(d) C m^{-3}

10

Parallel Sheet of Charge

Surface charge density is defined as charge per unit surface area of surface charge distribution. i.e., $\sigma = \dfrac{dq}{dS}$. Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs having magnitude of $17.0 \times 10^{-22} \text{ C m}^{-2}$ as shown. The intensity of electric field at a point is $E = \dfrac{\sigma}{\varepsilon_0}$, where ε_0 = permittivity of free space.
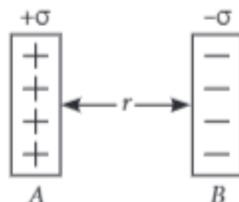
(i) E in the outer region of the first plate is
(a) 17×10^{-22} N/C
(b) 1.5×10^{-25} N/C
(c) 1.9×10^{-10} N/C
(d) zero

(ii) E in the outer region of the second plate is
(a) 17×10^{-22} N/C
(b) 1.5×10^{-15} N/C
(c) 1.9×10^{-10} N/C
(d) zero

(iii) E between the plates is
(a) 17×10^{-22} N/C
(b) 1.5×10^{-15} N/C
(c) 1.9×10^{-10} N/C
(d) zero

(iv) The ratio of E from right side of B at distances 2 cm and 4 cm, respectively is

(a) $1:2$ (b) $2:1$ (c) $1:1$ (d) $1:\sqrt{2}$

(v) In order to estimate the electric field due to a thin finite plane metal plate, the Gaussian surface considered is

(a) spherical (b) cylindrical (c) straight line (d) none of these

ASSERTION & REASON

For question numbers 11-30, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false and R is also false

11. **Assertion (A)** : If there exists coulomb attraction between two bodies, both of them may not be charged.
    Reason (R): In coulomb attraction two bodies are oppositely charged.

12. **Assertion (A)** : No two electric lines of force can intersect each other.
    Reason (R) : Tangent at any point of electric line of force gives the direction of electric field.

13. **Assertion (A)** : Electric force acting on a proton and an electron, moving in a uniform electric field is same, where as acceleration of electron is 1836 times that of a proton.
    Reason (R) : Electron is lighter than proton.

14. **Assertion (A)** : As force is a vector quantity, hence electric field intensity is also a vector quantity.
    Reason (R) : The unit of electric field intensity is newton per coulomb.

15. **Assertion (A)** : Sharper is the curvature of spot on a charged body lesser will be the surface charge density at that point
    Reason (R) : Electric field is non-zero inside a charged conductor.

16. **Assertion (A)** : The surface densities of two spherical conductors of different radii are equal. Then the electric field intensities near their surface are also equal.
    Reason (R) : Surface density is equal to charge per unit area.

17. **Assertion (A)** : Three equal charges are situated on a circle of radius r such that they form on equilateral triangle, then the electric field intensity at the centre is zero.
    Reason (R) : The force on unit positive charge at the centre, due to the three equal charges are represented by the three sides of a triangle taken in the same order. Therefore, electric field intensity at centre is zero.

18. **Assertion (A)** : The electric lines of forces diverges from a positive charge and converge at a negative charge.
    Reason (A) : A charged particle free to move in an electric field always move along an electric line of force.

19. **Assertion (A)** : Charging is due to transfer of electrons.
    Reason (R) : Mass of a body decreases slightly when it is negatively charged.

20. **Assertion (A)** : Range of Coulomb force is infinite.
    Reason (R) : Coulomb force acts between two charged particles.

21. **Assertion (A)** : A small metal ball is suspended in a uniform electric field with an insulated thread. If high energy X-ray beam falls on the ball, the ball will be deflected in the electric field.
    Reason (R) : X-rays emits photoelectron and metal becomes negatively charged.

22. **Assertion (A)** : If a point charge be rotated in a circle around a charge, the work done will be zero.
    Reason (R) : Work done is equal to dot product of force and distance.

23. **Assertion (A)** : A point charge is lying at the centre of a cube of each side . The electric flux emanating from each surface of the cube is $\dfrac{1}{6}^{th}$ of total flux.

Reason (R) : According to Gauss theorem, total electric flux through a closed surface enclosing a charge is equal to $1/\varepsilon_0$ times the magnitude of the charge enclosed.

24. **Assertion (A)** : A point charge is brought in an electric field. The field at a nearby point is increase, whatever be the nature of the charge.
Reason (R) : The electric field is independent of the nature of charge.

25. **Assertion (A)** : For charge to be in equilibrium, sum of the forces on charge due to rest of the two charges must be zero.
Reason (R) : A charge is lying at the centre of the line joining two similar charges each which are fixed. The system will be in equilibrium if that charge is one fourth of the similar charges.

26. **Assertion (A)** : If a conducting medium is placed between two charges, then electric force between them becomes zero.
Reason (R) : Reduction in a force due to introduced material is inversely proportional to its dielectric constant.

27. **Assertion (A)** : In electrostatics, electric lines of force can never be closed loops, as a line can never start and end on the same charge.
Reason (R) : The number of electric lines of force originating or terminating on a charge is proportional to the magnitude of charge.

28. **Assertion (A)** : If a point charge q is placed in front of an infinite grounded conducting plane surface, the point charge will experience a force.
Reason (R) : This force is due to the induced charge on the conducting surface which is at zero potential.

29. **Assertion (A)** : Charge is quantized.
Reason (R) : Charge which is less than 1 C is not possible.

30. **Assertion (A)** : The electric flux emanating out and entering a closed surface are 8×10^3 and 2×10^3 V m respectively. The charge enclosed by the surface is 0.053 µC.
Reason (R) : Gauss's theorem in electrostatics may be applied to verify.

HINTS & EXPLANATIONS

1. (i) **(b)**: The proportionality constant k depends on the nature of the medium between the two charges.

(ii) **(c)**: As, $[\varepsilon_0] = \dfrac{1}{4\pi F} \cdot \dfrac{q_1 q_2}{r^2} = \dfrac{[AT]^2}{[M\,L\,T^{-2}][L^2]}$

$$= [M^{-1}\,L^{-3}\,T^4 A^2]$$

(iii) **(b)**

(iv) **(d)**: $F = \dfrac{1}{4\pi\varepsilon_0} \dfrac{q_1 q_2}{d^2}$

$\therefore (10 \times 10^{-3}) \times 10 = \dfrac{(9 \times 10^9) \times q^2}{(0.6)^2}$

or $q^2 = \dfrac{10^{-1} \times 0.36}{9 \times 10^9} = 4 \times 10^{-12}$

or $q = 2 \times 10^{-6}\,C = 2\,\mu C$

(v) **(b)**

2. (i) **(d)**

(ii) **(b)**: From, $q = ne$, $n = \dfrac{q}{e} = \dfrac{3.2 \times 10^{-18}}{1.6 \times 10^{-19}} = 20$

As n is an integer, hence this value of charge is possible.

(iii) **(d)**: Charge on the body is $q = ne$
∴ No. of electrons present on the body is

$$n = \frac{q}{e} = \frac{1 \times 10^{-9} \text{C}}{1.6 \times 10^{-19} \text{C}} = 6.25 \times 10^9$$

(iv) (c) : Here, $n = 10^9$ electrons per second
Charge given per second,
$$q = ne = 10^9 \times 1.6 \times 10^{-19} \text{C}$$
$$q = 1.6 \times 10^{-10} \text{ C}$$
Total charge, $Q = 1$ C (given)
$$\therefore \quad \text{Time required} = \frac{Q}{q} = \frac{1}{1.6 \times 10^{-10}} \text{ s} = 6.25 \times 10^9 \text{s}$$
$$\therefore \quad \frac{6.25 \times 10^9}{3600 \times 24 \times 365} \text{ year} = 198.19 \text{ years.}$$

(v) (a) : As $q = ne$, $n = \dfrac{3.2 \times 10^{-7}}{1.6 \times 10^{-19}}$
$$\Rightarrow n = 2 \times 10^{12} \text{ electrons.}$$

3. **(i) (d) :** Electric flux, $\phi = \vec{E} \cdot \vec{A} = EA \cos\theta$,
where $\vec{A} = A\hat{n}$
For electric flux passing through S_6, $\hat{n}_{S_6} = -\hat{i}$ (Back)
$$\therefore \quad \phi_{S_6} = -(4 \times 10^3 \text{ N C}^{-1})(0.1 \text{ m})^2 \cos 37°$$
$$= -32 \text{ N m}^2 \text{ C}^{-1}$$

(ii) (a) : For electric flux passing through S_1,
$\hat{n}_{S_1} = -\hat{j}$ (Left)
$$\therefore \quad \phi_{S_1} = -(4 \times 10^3 \text{ N C}^{-1})(0.1 \text{ m})^2 \cos(90° - 37°)$$
$$= -24 \text{ N m}^2 \text{ C}^{-1}$$

(iii) (c) : Here, $\hat{n}_{S_2} = +\hat{k}$ (Top)
$$\therefore \quad \phi_{S_2} = -(4 \times 10^3 \text{ N C}^{-1})(0.1 \text{ m})^2 \cos 90° = 0$$
$\hat{n}_{S_3} = +\hat{j}$ (Right)
$\hat{n}_{S_4} = -\hat{k}$ (Bottom)
$$\therefore \quad \phi_{S_4} = (4 \times 10^3 \text{ N C}^{-1})(0.1 \text{ m})^2 \cos 90° = 0$$
And, $\hat{n}_{S_5} = +\hat{i}$ (Front)
$$\therefore \quad \phi_{S_5} = +(4 \times 10^3 \text{ N C}^{-1})(0.1 \text{ m})^2 \cos 37°$$
$$= 32 \text{ N m}^2 \text{ C}^{-1}$$
S_2 and S_4 surface have zero flux.

(iv) (d) : As the field is uniform, the total flux through the cube must be zero, i.e., any flux entering the cube must leave it.

(v) (b) : Surface integral $\oint \vec{E} \cdot d\vec{S}$ is the net electric flux over a closed surface S.
$$\therefore \quad [\phi_E] = [\text{M L}^3 \text{T}^{-3} \text{A}^{-1}]$$

4. **(i) (a) :** From Newton's law
$$\vec{F} = m\vec{a} \text{ or } qE = m\vec{a} \Rightarrow a = \frac{qE}{m} = \frac{eE}{m}$$

Using, $s = ut + \dfrac{1}{2}at^2$
$$\therefore \quad h = 0 + \frac{1}{2} \times \frac{eE}{m}t^2 \Rightarrow t = \sqrt{\frac{2hm}{eE}}$$

(ii) (c)

(iii) (b) : Force is same in magnitude for both.
$$\therefore \quad m_1 a_1 = m_2 a_2 ;$$
$$\frac{a_1}{a_2} = \frac{m_2}{m_1} = \frac{1}{0.5} = 2$$

(iv) (b) : Here, $u = 0$; $a = \dfrac{qE}{m}$; $s = y$
Using, $v^2 - u^2 = 2as \Rightarrow v^2 = 2\dfrac{qE}{m}y$
$$\therefore \quad \text{K.E.} = \frac{1}{2}mv^2 = qEy$$

(v) (b) : If charge particle is put at rest in electric field, then it will move along line of force.

5. **(i) (a) :** As, $qE = mg \Rightarrow q = \dfrac{1.08 \times 10^{-14} \times 9.8}{1.68 \times 10^5}$
$$= 6.4 \times 10^{-19} \text{ C}$$

(ii) (a) : $q = ne$ or $\Rightarrow n = \dfrac{6.4 \times 10^{-19}}{1.6 \times 10^{-19}} = 4$

(iii) (c) : For the drop to be stationary,
Force on the drop due to electric field = Weight of the drop

$$qE = mg$$
$$q = \frac{mg}{E} = \frac{1.6 \times 10^{-6} \times 10}{100} = 1.6 \times 10^{-7} \text{ C}$$
Number of electrons carried by the drop is
$$n = \frac{q}{e} = \frac{1.6 \times 10^{-7} \text{ C}}{1.6 \times 10^{-19} \text{ C}} = 10^{12}$$

(iv) (c)

(v) (d) : Millikan's experiment confirmed that the charges are quantized, i.e., charges are small integer multiples of the base value which is charge on electron. The charges on the drops are found to be multiple of 4. Hence, the quanta of charge is 4 µC.

6. **(i) (d) :** If there is only one type of charge in the universe then it will produce electric field somehow. Hence Gauss's law is valid.

(ii) (c)

(iii) (c) : According to Gauss's theorem,

Electric flux through the sphere $= \dfrac{q}{\varepsilon_0}$

∴ Electric flux through the hemisphere $= \dfrac{1}{2}\dfrac{q}{\varepsilon_0}$

$= \dfrac{10\times10^{-6}}{2\times8.854\times10^{-12}} = 0.56\times10^6\ \text{N m}^2\,\text{C}^{-1}$

$\approx 0.6\times10^6\ \text{Nm}^2\,\text{C}^{-1} = 6\times10^5\ \text{N m}^2\,\text{C}^{-1}$

(iv) (d): As flux is the total number of lines passing through the surface, for a given charge, it is always the charge enclosed Q/ε_0. If area is doubled, the flux remains the same.

(v) (d): As net charge on a dipole is
$(-q + q) = 0$
Thus, when a gaussian surface encloses a dipole, as per Gauss's theorem, electric flux through the surface,

$$\oint \vec{E}\cdot d\vec{S} = \dfrac{q}{\varepsilon_0} = 0$$

7. (i) (a)

(ii) (c): Electric lines of force do not form any closed loops.

(iii) (c): Electric field lines can't be closed.

(iv) (d)

(v) (a)

8. (i) (a): As $\tau =$ either force × perpendicular distance between the two forces
$= qaE\sin\theta$ or $\tau = PE\sin\theta$
or $\tau = \vec{P}\times\vec{E}$ $(\because qa = P)$

(ii) (c): The maximum torque on the dipole in an external electric field is given by
$\tau = pE = q(2a)\times E$
Here, $q = 1\ \mu C = 10^{-6}\ \text{C}$, $2a = 2\ \text{cm} = 2\times10^{-2}\ \text{m}$,
$E = 10^5\ \text{N C}^{-1}$, $\tau = ?$
∴ $\tau = 10^{-6}\times2\times10^{-2}\times10^5 = 2\times10^{-3}\ \text{N m}$

(iii) (d): When θ is 0 or 180°, the τ is minimum, which means the dipole moment should be parallel to the direction of the uniform electric field.

(iv) (c): Net force is zero and torque acts on the dipole, trying to align p with E.

(v) (a): Torque, $\tau = pE\sin\theta$ and potential energy, $U = -pE\cos\theta$

9. (i) (a): Gauss's law is applicable for any closed surface. Gauss's law is most useful in situation where the charge distribution has spherical or cylindrical symmetry or is distributed uniformly over the plane. Whereas electric dipole is a system of two equal and opposite point charges separated by a very small and finite distance.
So both statements are correct.

(ii) (b): According to Gauss's law, the electric flux through the sphere is

$\phi = \dfrac{q_{in}}{\varepsilon_0} = \dfrac{8.85\times10^{-13}\,\text{C}}{8.85\times10^{-12}\ \text{C}^2\ \text{N}^{-1}\ \text{m}^{-2}} = 0.1\ \text{N C}^{-1}\ \text{m}^2$

(iii) (c): For uniformly volume charge density,
$E = \dfrac{\rho r}{3\varepsilon_0}$
$E \propto r$

(iv) (a): $r = 25\ \text{cm} = 0.25\ \text{m}$, $\sigma = \dfrac{3}{\pi}\ \text{C/m}^2$

As, $\sigma = \dfrac{q}{4\pi r^2}\ \Rightarrow q = 4\pi\times(0.25)^2\times\dfrac{3}{\pi}=0.75\ \text{C}$

(v) (b): The line charge density at a point on a line is the charge per unit length of the line at that point
$\lambda = \dfrac{dq}{dL}$
Thus, the SI unit for λ is $C\ m^{-1}$.

10. (i) (d): There are two plates A and B having surface charge densities,
$\sigma_A = 17.0\times10^{-22}\ \text{C/m}^2$

on A and $\sigma_B = -17.0\times10^{-22}\ \text{C/m}^2$ on B, respectively. According to Gauss' theorem, if the plates have same surface charge density but having opposite signs, then the electric field in region I is zero.
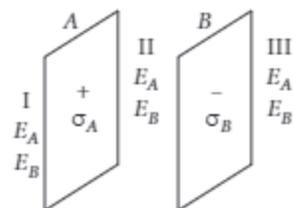
$E_I = E_A + E_B = \dfrac{\sigma}{2\varepsilon_0} + \left(-\dfrac{\sigma}{2\varepsilon_0}\right) = 0$

(ii) (d): The electric field in region III is also zero.

$E_{III} = E_A + E_B = \dfrac{\sigma}{2\varepsilon_0} + \left(-\dfrac{\sigma}{2\varepsilon_0}\right) = 0$

(iii) (c): In region II or between the plates, the electric field

$E_{II} = E_A - E_B = \dfrac{\sigma}{2\varepsilon_0} + \dfrac{\sigma}{2\varepsilon_0}$

$= \dfrac{\sigma(\sigma_A\ \text{or}\ \sigma_B)}{\varepsilon_0} = \dfrac{17.0\times10^{-22}}{8.85\times10^{-12}}$

$E = 1.9 \times 10^{-10} \text{ N C}^{-1}$

(iv) (c): Since, electric field due to an infinite-plane sheet of charge does not depend on the distance of observation point from the plane sheet of charge. So, for the given distances, the ratio of E will be $1 : 1$.

(v) (b): In order to estimate the electric field due to a thin finite plane metal plate, we take a cylindrical cross-sectional area A and length $2r$ as the gaussian surface.

11. (b): Coulomb attraction exists even when one body is charged, and the other is uncharged.

12. (a): If the two electric lines of force can intersect each other than at the point of intersection, we can draw two tangents to the two lines of force. This would mean two directions of electric field intensity at the point of intersection, which is not possible.

13. (a): As $F = qE$, and charge (q) on an electron and on a proton has the same magnitude, therefore force (F) on each is same. Now, acceleration $a = F/m$.

Mass of electron $= \dfrac{1}{1836}$ mass of a proton. Therefore, acceleration of electron is 1836 times that of a proton.

14. (b): The electric field intensity is equal to force experienced by unit positive test charge q_0 placed at that point *i.e.*

$\vec{E} = \dfrac{\vec{F}}{q_0}$ thus $\vec{E}$ is also a vector quality.

As, $E = \dfrac{F}{q} = \dfrac{\text{newton}}{\text{coulomb}}$.

15. (d): Surface of a charged conductor is always an equipotential surface, whatever may be its shape. Hence $\sigma R = $ constant, at every point on the surface of charged conductor *i.e.* at the sharpest point $(R \rightarrow 0)$ of the surface, charge density will be maximum. A uniformly charged conductor exerts no electrostatic force on a point charge located anywhere inside the conductor or electric field is zero.

16. (b): As $\sigma_1 = \sigma_2$ (Given)

$\therefore \quad \dfrac{q_1}{4\pi r_1^2} = \dfrac{q_2}{4\pi r_2^2}$, or, $\dfrac{q_1}{q_2} = \dfrac{r_1^2}{r_2^2}$
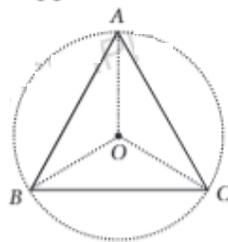
[Let r_1 and r_2 be two different radii]

Then the ratio of electric field intensities near the surface of spherical conductors,

$\dfrac{E_1}{E_2} = \dfrac{q_1}{4\pi \varepsilon_0 r_1^2} \times \dfrac{4\pi \varepsilon_0 r_2^2}{q_2} = \dfrac{q_1}{q_2} \times \dfrac{r_2^2}{r_1^2} = \dfrac{q_1}{q_2} \times \dfrac{q_2}{q_1} = 1$

i.e. $E_1 = E_2$

17. (a): Resultant of electric intensity at O due to B and C is equal and opposite to that due to A.

18. (c): If the charged particle is initially at rest in an electric field, it will move along the electric line of force. But when the initial velocity of charged particle makes some angle with the line of force then the resultant path is not along the line of force. Because electric line of force may not coincide with the line of velocity of the charge.

19. (c): A body becomes negatively charged only when some electrons are transferred to the body *i.e.* the body gains some electrons. Hence its mass increases slightly. Mass of a body decreases only when body gives some electrons to some other body.

20. (b): Coulomb's force or electric force given by Coulomb's law, is valid over nuclear distances $(\cong 10^{-15} \text{ m})$ as well as over very large distances.

From Coulomb's law, $F = \dfrac{k|q_1||q_2|}{r^2}$. This generally holds only for charged objects whose size are much smaller than the distance between them.

21. (c): When high energy X-ray beam falls on the ball, the metal will emit photoelectrons, thus leaving the positive charge on the ball. As a result of this, ball is deflected in the direction of electric field.

22. (a): Work done will be zero because in rotating the charge in a circle, force is along the radius and direction of motion is perpendicular to it.
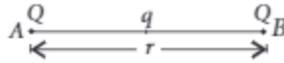
$\therefore$ Work done, $W = \vec{F}.\vec{S} = FS \cos\theta = FS \cos 90° = 0$

23. (b): The electric flux through the cube, $\phi = q/\varepsilon_0$. A cube has six faces of equal area. Therefore, electric flux through each face $= \dfrac{1}{6}\phi = \dfrac{1}{6}(q/\varepsilon_0)$.

24. (d): Electric field at the nearby point will be resultant of existing field and field due to the charge brought. It may increase or decrease if the charge is positive or negative depending on the position of the point with respect to the charge brought.

25. (c): According to Coulomb's law, $F = k\dfrac{Q_1 Q_2}{r^2}$.

The force on q due to A,

$$F_A = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Qq}{(r/2)^2} \text{ to the right}$$

$$A \overset{Q}{\bullet} \xleftarrow{\qquad} \overset{q}{\underset{r}{\xrightarrow{\hspace{2cm}}}} \overset{Q}{\bullet} B$$

Due to B,

$$F_B = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Qq}{(r/2)^2} \text{ to the left.}$$

$\therefore$ Their sum is zero whether q is $+\dfrac{Q}{4}$ or $-\dfrac{Q}{4}$ or any other value.

Therefore, it is not true that the third charge has to be $Q/4$ only. It can be any value.

26. (a): The dielectric constant of any material is

$$K = \frac{E_0}{E} = \frac{F_0/q}{F/q} = \frac{F_0}{F} \Rightarrow F = \frac{F_0}{K}, \text{ where } F_0 \text{ is force}$$

when conductor is not present between the charge. F is a force after introduction of conductor between charges. Since dielectric constant of a conducting medium is infinity therefore $F = 0$.

27. (b): Electrostatic field lines of force can never form any closed loop. Because electric field originate from positive charge and terminates on negative charge.

28. (a)

29. (c): The charge q on a body is given as $q = ne$ where n is any integer positive or negative.

The charge on the electron is $q = 1.6 \times 10^{-19}$ C which is less than 1 C.

30. (a): According to Gauss's theorem in electrostatics,

$$\phi = q/\varepsilon_0$$
$$q = \varepsilon_0 \phi = 8.85 \times 10^{-12} \, [8 \times 10^3 - 2 \times 10^3]$$
$$= 53.10 \times 10^{-9} \, C = 0.053 \, \mu C.$$