PHYSICS

UNIT -1
ELECTROSTATICS

FORMULAE

(1) Electrostatic force between charges q_1 and q_2, $F = \vec{F}_{12} = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r_{21}^2}\hat{r}_{21}$

(2) Value of $k = \frac{1}{4\pi\varepsilon_o} = 9 \times 10^9\ Nm^2C^{-2}$

(3) Value of $\varepsilon = 8.854 \times 10^{-12}\ C^2N^{-1}m^{-2}$

(5) Total charge $q = n \times e$; Number of electrons × Charge of an electron

(6) Components of force F, $F_1 = F\cos\theta$; $F_2 = F\sin\theta$; $|F| = \sqrt{F_1^2 + F_2^2}$

(7) Relative permittivity or Dielectric constant $\varepsilon_r = \frac{\varepsilon}{\varepsilon_o}$

(8) Force between charges in medium $F_m = \frac{F_{air}}{\varepsilon_r}$

(9) Electrostatic field, $E = \frac{\text{force}}{\text{charge}} = \frac{F}{q} \Rightarrow F = qE$

(10) Electric field due to a point charge $E = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}\hat{r}$

(11) Electric dipole moment, $\vec{p} = q \times 2a\hat{i}$

(12) (i) Electric field due to a dipole at a point on the axial line, $\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3}$ $(r >> a)$

(ii) Electric field due to a dipole at a point on the equatorial line $E = \vec{E}_{tot} = \frac{-1}{4\pi\varepsilon_0}\frac{\vec{p}}{r^3}$ $(r >> a)$

(13) Magnitude of torque $\tau = \vec{p} \times \vec{E} = pE\sin\theta$ $(p = q\,2a)$

(14) Electric potential at a point due to a point charge, $V = \frac{1}{4\pi\varepsilon_o}\frac{q}{r}$

(15) Electric potential energy of dipole $U = -pE\cos\theta = -\vec{p}.\vec{E}$

(16) Electric potential at a point due to an electric dipole $V = \frac{p}{4\pi\varepsilon_0}\frac{\cos\theta}{r^2}$

(17) Electric flux $= \frac{q}{\varepsilon_0} \Rightarrow \phi_E = \vec{E}.\vec{A} = EA\cos\theta$

(18) Electric field due to infinite long straight charged wire, $E = \frac{\lambda}{2\pi\varepsilon_0 r}$

(19) Electric field due to plane sheet of charge $E = \frac{\sigma}{2\varepsilon_o} = \frac{q}{A}\frac{1}{2\varepsilon_o}$ Vector form, $\vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{n}$

(20) Electric field at a point between two parallel sheets of charge $E = \frac{\sigma}{\varepsilon_0}$

PUBLIC EXAM FREQUENTLY ASKED QUESTIONS

1 Mark

1. An air-core capacitor is charged by a battery. After disconnecting it from the battery, a dielectric slab is fully inserted in between its plates. Now, which of the following quantities remains constant? *[PTA-1]*

(a) Energy (b) Voltage
(c) Electric field (d) Charge

[Ans. (d) Charge]

2. The unit of permittivity is: *[PTA-2]*

(a) $C^2 N^{-1} m^{-2}$ (b) $N m^2 C^{-2}$
(c) $H m^{-1}$ (d) $N C^{-2} m^{-2}$

[Ans. (a) $C^2 N^{-1} m^{-2}$]

3. A coil of area of cross-section 0.5 m² with 10 turns is in a plane which is parallel to a uniform electric field of 100 N/C. The flux through the plane is: *[PTA-2]*

(a) 100 V.m (b) 500 V.m
(c) 20 V.m (d) zero

[Ans. (b) 500 V.m]

4. Dimension and unit of Electric flux is *[PTA-3; Aug-2021; FRT-'22]*

(a) $ML^3T^3A^{-2}$, Nm^2C^{-1}
(b) $ML^3T^{-3}A^{-1}$, Nm^2C^{-1}
(c) $ML^2T^{-1}A^{-2}$, Nm^2C^{-1}
(d) $ML^{-4}T^{-3}A^{-2}$, Nm^2C^{-1}

[Ans. (b) $ML^3T^{-3}A^{-1}$, Nm^2C^{-1}]

5. At infinity, the electrostatic potential is *[PTA-4]*

(a) infinity
(b) maximum
(c) minimum
(d) zero

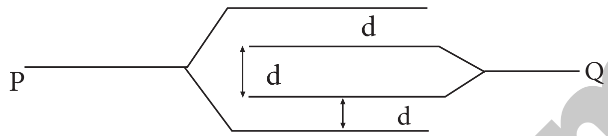
[Ans. (d) zero]

6. Five balls marked 1, 2, 3, 4 and 5 are suspended by separate threads. The pairs (1, 2) (2, 4) and (4, 1) show mutual attraction and the pairs (2,3) and (4, 5) show repulsion. The number of ball marked as 1 is *[PTA-5]*

(a) positive
(b) negative
(c) neutral
(d) can't determine

[Ans. (c) neutral]

7. The resultant capacitance of four plates, each is having an area A, arranged as shown above, will be (plate separation is d) *[PTA-5]*



(a) $\frac{A\varepsilon_0}{d}$ (b) $\frac{A\varepsilon_0}{2d}$
(c) $\frac{2A\varepsilon_0}{d}$ (d) $\frac{3A\varepsilon_0}{d}$

[Ans. (c) $\frac{2A\varepsilon_0}{d}$]

Hint: $C = C_1 + C_2 = 2C$

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

8. An electric dipole is placed at an angle 30° with an electric field intensity of 2×10^5 N C⁻¹. It experiences a torque equal to 4 N m. The charge on the dipole if the dipole length is 2 cm is *[PTA-6]*

(a) 8 mC (b) 2 mC
(c) 5 mC (d) 7 μC

[Ans. (b) 2 mC]

9. When a point charge of 6mC is moved between two points in an electric field, the work done is 1.8×10^{-5} J. The potential difference between the two points is *[Govt. MQP-2019]*

(a) 1.08 V (b) 1.08 μV
(c) 3 V (d) 30 V

[Ans. (c) 3 V]

Hint: $V = \frac{W}{q} = \frac{1.8\times10^{-5}}{6\times10^{-6}}$

$= 3$ V

10. Two point charges A and B having charges +Q and –Q respectively, are placed at certain distance, apart and force acting between them is F. If 25% charge of A is transformed to B, then force between the charges becomes. *[QY-2019]*

(a) $\frac{16}{9}$ F (b) $\frac{4}{3}$ F (c) F (d) $\frac{9}{16}$

[Ans. (d) $\frac{9}{16}$ F]

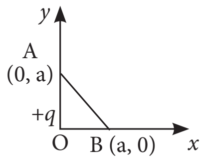
11. A cylinder of radius R and length L is placed in a uniform electric field E parallel to the cylinder axis. The total flux for the surface of the cylinder is given by *[QY-2019]*

(a) $2\pi R^2 E$ (b) $\frac{\pi}{E} R^2$

(c) $(\pi R^2 - \pi R)/E$ (d) Zero

[Ans. (d) Zero]

12. In the given diagram a point charge +q is placed at the origin O. Work done in taking another point charge –Q from point A to point B is : *[Mar-2020]*



(a) $\frac{qQ}{4\pi\varepsilon_0 a^2}\left(\frac{a}{\sqrt{2}}\right)$ (b) Zero

(c) $\left[\frac{-qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right]\sqrt{2a}$ (d) $\left[\frac{qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right]\sqrt{2a}$

[Ans. (b) Zero]

2 Marks

1. The electric field outside a conductor is perpendicular to its surface. Justify. *[PTA-1]*

Ans. (i) The electric field outside the conductor is perpendicular to the surface of the conductor and has a magnitude of $\frac{\sigma}{\varepsilon_0}$ where σ is the surface charge density at that point.

(ii) If the electric field has components parallel to the surface of the conductor, then free electrons on the surface of the conductor would experience acceleration.

(iii) This means that the conductor is not in equilibrium. Therefore at electrostatic equilibrium, the electric field must be perpendicular to the surface of the conductor.

2. State the law of conservation of electric charges. *[PTA-2]*

Ans. The total electric charge in the universe is constant and charge can neither be created nor be destroyed. In any physical process, the net change in charge will always be zero.

3. Define the physical quantity whose unit is Vm, and state whether it is scalar or vector. *[PTA-3]*

Ans. Unit of Electric flux is Vm or Nm^2C^{-1}
It is a scalar quantity.

4. Can two equipotential surfaces intersect? Give reason. *[PTA-5]*

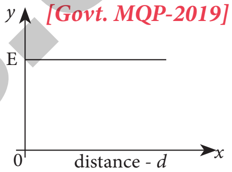
Ans. Since the electric field is normal to the equipotential surface and also the potential difference between any two points on the surface is nullified, the intersection is not possible.

5. Define electric dipole. *[PTA-5; FRT-'22]*

Ans. Two equal and opposite charges separated by a very small vector distance.

6. Show graphically the variation of electric field E (*y*-axis) due to a charged infinite plane sheet with distance *d* (*x*-axis) from the plate. *[Govt. MQP-2019]*

Ans. It is independent of the distance. It is a straight line parallel to x-axis.



7. A parallel plate capacitor has square plates of side 5 cm and separated by a distance of 1mm, then calculate the capacitance of the capacitor. *[QY-2019]*

Ans. The capacitance of the capacitor is

$$C = \frac{\varepsilon_0 A}{d} = \frac{8.85\times10^{-12}\times25\times10^{-4}}{1\times10^{-3}}$$

$$= 221.2\times10^{-13}\ F$$

$$C = 22.12\times10^{-12}\ F = 22.12\ pF$$

8. Dielectric strength of air is $4\times10^6\ Vm^{-1}$. Suppose the radius of a hollow sphere in the Van de Graaff generator is R = 0.4 m, calculate the maximum potential difference created by this Van de Graaff generator. *[Aug-2021]*

Ans. The electric field on the surface of the sphere is given by (by Gauss law)

$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{R^2}$$

The potential on the surface of the hollow metallic sphere is given by

$$V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{R} = ER$$

Since $V_{max} = E_{max}R$

Here $E_{max} = 4\times10^6\ Vm^{-1}$. So the maximum potential difference created is given by

$$V_{max} = 4\times10^6\times0.4$$

$$= 1.6\times10^6\ V\ \text{(or) 1.6 million volt}$$

9. State : Gauss Law. *[FRT, July-'22]*

Ans. Gauss's law states that if a charge Q is enclosed by an arbitrary closed surface, then the total electric flux Φ_E through the closed surface is

$$\phi_E = \oint \vec{E}.d\vec{A} = \frac{Q_{encl}}{\varepsilon_0}$$

10. Calculate the electric flux through the rectangle of sides 5 cm and 10 cm kept in the region of a uniform electric field 100 NC^{-1}. The angle θ is 60°. What is the electric flux? *[FRT-'22]*

Sol. The electric flux through the rectangular area

$\theta = 60°$

$\Phi_E = \vec{E}.\vec{A} = EA\cos\theta$

$\Phi_E = 100 \times 5 \times 10 \times 10^{-4} \times \cos 60°$

$\Phi_E = 5000 \times 10^{-4} \times \frac{1}{2} = 2500 \times 10^{-4}$

$\Phi_E = 0.25\ Nm^2C^{-1}$

3 Marks

1. Four point charges +q, +q, −q and −q are to be arranged respectively at the four corners of a square PQRS of side r. Find the work needed to assemble this arrangement. *[PTA-1]*

Sol. The work done to arrange the charges in the corners of the square is independent of the way they are arranged. We can follow any order

(i) First, the charge $+q$ is brought to the corner P. This requires no work since no charge is already present, $W_P = 0$

(ii) Work required to bring the charge $-q$ to the corner Q = $(-q) \times$ potential at a point Q due to $+q$ located at a point P.

$$W_Q = -q \times \frac{1}{4\pi\varepsilon_0}\frac{q}{a} = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a}$$

(iii) Work required to bring the charge $+q$ to the corner R= $q \times$ potential at the point R due to charges at the point P and Q.

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

(iv) Work required to bring the fourth charge $-q$ at the position S = $q \times$ potential at the point S due the all the three charges at the point P, Q and R

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

2. Two capacitors of unknown capacitances are connected in series and parallel. If net capacitances in two combinations are 6 μF and 25 μF respectively, find their capacitances. *[PTA-2]*

Sol. $\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{C_1 + C_2}{C_1C_2}$

$\Rightarrow C_s = \frac{C_1C_2}{C_1 + C_2}$ But $C_p = C_1 + C_2$

Hence $C_s = \frac{C_1C_2}{C_P} \Rightarrow 6 = \frac{C_1C_2}{25}$

$\therefore C_1 C_2 = 25 \times 6 = 150$

$\Rightarrow C_2 = \frac{150}{C_1}$; $C_1 + C_2 = 25$

$\Rightarrow C_1 + \frac{150}{C_1} = 25 \Rightarrow C_1^2 + 150 = 25\,C_1$

(or)

$C_1^2 - 25\,C_1 + 150 = 0$

$C_1^2 - 10\,C_1 - 15\,C_1 + 150 = 0$

$C_1(C_1 - 10) - 15(C_1 - 10) = 0$

$(C_1-10)(C_1-15)$ or $C_1 = 10$ or 15

if $C_1 = 10\mu F$; $C_2 = 15\mu F$

$C_1 = 15\mu F$; $C_2 = 10\mu F$

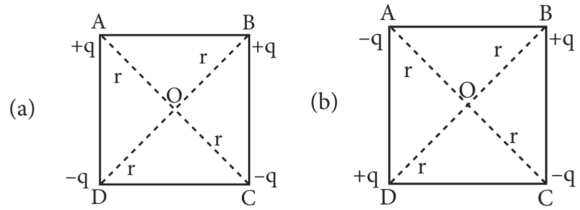
3. Calculate the force between electron and proton in Hydrogen atom.(e = 1.6 × 10^{-19} C and r$_0$ = 0.53Å) *[PTA-3]*

Sol. The proton and the electron attract each other. The magnitude of the electrostatic force between these two particles is given by

$$F_e = \frac{ke^2}{r^2} = \frac{9\times10^9 \times (1.6\times10^{-19})^2}{(5.3\times10^{-11})^2}$$

$$= \frac{9 \times 2.56}{28.09} \times 10^{-7} = 8.2 \times 10^{-8}\ N$$

4. Four point charges are placed at the four corners of a square in two ways (a) and (b) as shown in figure. Will the (i) electric potential and (ii) electric field, at the centre of the square be the same or different in the two configurations and why? *[PTA-5]*



Ans. (i) Electric field at the centre of fig (b) will be zero because same charges on the diagonally opposite corners of a square give zero electric field at the centre whereas it will be 'non zero' in fig (a).

(ii) Electric potential will be the same in case of fig(a) and (b) because there are two positive and two negative charges of same magnitude at equal distance from centres in both figures.

5. Define and derive an expression for the energy density in parallel plate capacitor. *[Govt. MQP-2018]*

Ans. The total work done to charge a capacitor is stored as electrostatic potential energy in the capacitor

Energy stored in the capacitor

$$U_E = \frac{1}{2}CV^2 \qquad ...(1)$$

This is rewritten as using $C = \frac{\varepsilon_0 A}{d}$ & $V = Ed$.

$$U_E = \frac{1}{2}\left(\frac{\varepsilon_0 A}{d}\right)(Ed)^2 = \frac{1}{2}\varepsilon_0 (Ad)E^2 \qquad ...(2)$$

where Ad = volume of the space between the capacitor plates. The energy stored per unit volume of space is defined as energy density

$u_E = \frac{U}{\text{Volume}}$ From equation (4),

We get $u_E = \frac{1}{2}\varepsilon_0 E^2$ ...(3)

The energy density depends only on the electric field and not on the size of the plates of the capacitor.

6. State the rules followed while drawing electric field lines for the representation of electric field. *[QY-2019]*

Ans. The following rules are followed while drawing electric field lines for charges.

(i) The electric field lines start from a positive charge and end at negative charges or at infinity.

(ii) The electric field vector at a point in space is tangential to the electric field line at that point.

(iii) The electric field lines are denser (more closer) in a region where the electric field has larger magnitude and less dense in a region where the electric field is of smaller magnitude.

(iv) No two electric field lines intersect each other. If two lines cross at a point, then there will be two different electric field vectors at the same point.

(v) The number of electric field lines that emanate from the positive charge or end at a negative charge is directly proportional to the magnitude of the charges.

7. What are the application of Capacitors? *[FRT-'22]*

Ans. Capacitors are used in various electronics circuits. A few of the applications.

(a) Flash capacitors are used in digital cameras for taking photographs.

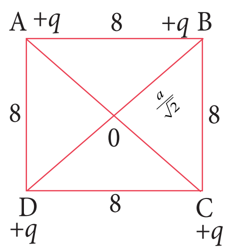
(b) During cardiac arrest, a device called heart defibrillator is used to give a sudden surge of a large amount of electrical energy to the patient's chest to retrieve the normal heart function.

(c) Capacitors are used in the ignition system of automobile engines to eliminate sparking

(d) Capacitors are used to reduce power fluctuations in power supplies and to increase the efficiency of power transmission.

8. Charges of + $\frac{10}{3}\times 10^{-9}$ C are placed at each of the four corners of a square of side 8 cm. Find the potential at the intersection of the diagonals. *[QY-2019]*

Sol.:



$$l = \frac{a}{\sqrt{2}} = \frac{8}{\sqrt{2}} = 4\sqrt{2} \text{ cm}$$

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

Potential at the intersection of the diagonals

$$V = 4\times\frac{kq}{l}$$

$$= \frac{4\times 9\times 10^9\times\frac{10}{3}\times 10^{-9}}{4\sqrt{2}\times 10^{-2}}$$

$$= \frac{30\times 10^2}{\sqrt{2}} = \frac{3000}{\sqrt{2}}$$

$$= \frac{3000}{\sqrt{2}}\times\frac{\sqrt{2}}{\sqrt{2}} = 1500\sqrt{2} \text{ Volt}$$

9. A dipole is formed by two charges of 5 μC and –5 μC at a distance of 8 mm. Find the electric field at
a) a point 25 cm away from center of dipole along its axial line.
b) a point 20 cm away from center of dipole along its equatorial line. *[HY-2019]*

Sol.:

Given : q = 5 μC, E along axial line at 25 cm = ?, E along equatorial line at 20 cm = ?

a) E along axial line at 25 cm

∴ Dipole moment

$p = 2qd = 2 \times 5 \times 10^{-6} \times 8 \times 10^{-3} = 80\times10^{-9}$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3} = 9 \times 10^9 \times \frac{2\times80\times10^{-9}}{(25\times10^{-2})^3}$$

$= 0.09216 \times 10^6 = 9.2 \times 10^4\ NC^{-1}$

b) E along equatorial line at 20 cm

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3} = 9 \times 10^9 \times \frac{80\times10^{-9}}{(20\times10^{-2})^3}$$

$= 0.09 \times 10^6 = 9 \times 10^4\ NC^{-1}$

10. What are the differences between Coulomb force and gravitational force? *[QY; HY - 2019]*

Ans.

S. No	Coulomb	Gravitational
i)	It may be attractive or repulsive.	It is always attractive in nature.
ii)	It depends upon medium	It does not depend upon the medium
iii)	It is always greater in magnitude because of high value of K = 9×10^9 Nm^2 C^{-2}	It is lesser than coulomb force because value of G is 6.67×10^{-11} Nm^2 kg^{-2}
iv)	The force between the charges will not be same during motion or rest.	It is always same whether the two masses are rest or motion

11. Define 'electric dipole'. Give the expression for the magnitude of its electric dipole moment and the direction. *[PTA-5]*

Ans. (i) Two equal and opposite charges separated by a small distance constitute an electric dipole.

(ii) The magnitude of the electric dipole moment is equal to the product of magnitude of one of the charges and the distance between them.

$|\vec{p}| = 2qa$ and it is directed from $-q$ to $+q$

12. Define 'electrostatic potential'. *[PTA-6; Aug-2021]*

Ans. The electric potential at a point P is equal to the work done by an external force to bring a unit positive charge with constant velocity from infinity to the point P in the region of the external electric field $\vec{E}$.

13. What is Corona discharge? *[Mar-2020; May-2022]*

Ans. (i) The electric field near the edge is very high and it ionizes the surrounding air.

(ii) The positive ions are repelled at the sharp edge and negative ions are attracted towards the sharper edge.

(iv) This reduces the total charge of the conductor near the sharp edge. This is called action of points or corona discharge.

14. Derive an expression for the torque experienced by a dipole due to a uniform electric field. *[PTA-3]*

Ans. Electric dipole in uniform electric field :

(i) Consider an electric dipole of dipole moment $\vec{p}$ placed in a uniform electric field $\vec{E}$ whose field lines are equally spaced and point in the same direction. The charge $+q$ will experience a force $q\vec{E}$ in the direction of the field and charge $-q$ will experience a force $-q\vec{E}$ in a direction opposite to the field.

(ii) These two forces acting at different points will constitute a couple and the dipole experience a torque.

(iii) This torque tends to rotate the dipole. The total torque on the dipole about the point O.

$$\vec{\tau} = \vec{OA} \times \left|-q\vec{E}\right| + \vec{OB} \times q\vec{E}$$

Using right-hand corkscrew rule, it is found that total torque is perpendicular to the plane of the paper and is directed into it.