IMPORTANT QUESTIONS WITH ANSWERS

Q # 1. What do you know about electrostatics?

Ans. The branch of Physics which deals with the charges at rest is called electrostatics.

Q # 2. State the coulomb's law.

Ans. Statement.

The electrostatic force between two point charges is directly proportional to the product of the magnitude of charges and inversely proportional to the square of distance between them.

If two point charges 'q_1' and 'q_2' are separated by a distance 'r', then the electrostatic force 'F' between them is expressed as:

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

where k is the constant of proportionality, which can be expressed as

$$k = \frac{1}{4\pi\,\varepsilon_0}$$

where ε_0 is the permittivity of free space and its value in SI unit is $8.85 \times 10^{-12}\ C^2N^{-1}\,m^{-2}$.

Q # 3. Write down the vector form of Coulomb's law.

Ans. The electrostatic force '**F**' between two point charges 'q_1' to 'q_2' is expressed as:

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

Here $\hat{\mathbf{r}}$ is the unit vector directed from 'q_1' to 'q_2'.

Q # 4. Show that Coulomb force is a mutual force

Ans. Coulomb's force is a mutual force, it means that if a charge 'q_1' exerts a force on charge 'q_2', then 'q_2' also exerts an equal and opposite force on 'q_1'. If charge 'q_1' exerts an electrostatic force '$\mathbf{F}_{12}$' due to charge 'q_2' and 'q_2' exerts electrical force '$\mathbf{F}_{21}$' on charge 'q_1' and, then

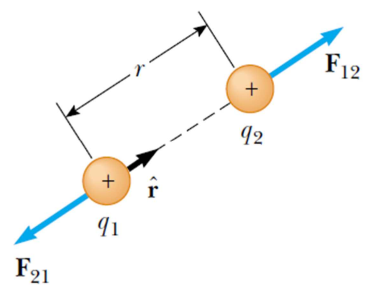
$$\mathbf{F}_{12} = -\mathbf{F}_{21}$$

Proof.

If $\hat{\mathbf{r}}_{12}$ represents the direction of force from charge 'q_1' to 'q_2' and $\hat{\mathbf{r}}_{21}$ is the unit vector which represent the direction of force from charge 'q_2' to 'q_1', then

$$\mathbf{F}_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{\mathbf{r}}_{21} \quad \text{----------------} \quad (1)$$

$$\mathbf{F}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{\mathbf{r}}_{12} \quad \text{----------------} \quad (2)$$



As $\hat{\mathbf{r}}_{21} = -\,\hat{\mathbf{r}}_{12}$, so the eq. (1) becomes

$$\mathbf{F}_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\left(-\,\hat{\mathbf{r}}_{12}\right)$$

$$\mathbf{F}_{21} = -\frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{\mathbf{r}}_{12}$$

By eq. (2)

$$\mathbf{F}_{21} = -\mathbf{F}_{12}$$

This expression shows that Coulomb force is a mutual force.

Q # 5. What is the effect of dielectric medium on electrical force, when it is placed between two point charges?

Ans. If the dielectric medium having relative permittivity 'ε_r' is placed between two point charges, then the electrical force will reduced by ε_r-times. The expression of coulomb's force between two point charges, when the dielectric medium is placed between them, is expressed as:

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

(*Definition*) Dielectric

An insulator, placed between two point charges, is referred as dielectric.

(*Definition*) Point Charges

The charges whose sizes are very small as compared to the distance between them are called point charges.

(*Definition*) Electric Field

The space or region around any charge, in which it exerts forces of attraction or repulsion on other charges, is called its electric field.

Q # 6. What do you know about 'Electric Field Intensity'? Also derive its expression.

Ans. The electrostatic force per unit test charge, at a specific point in the electric field, is called electric field intensity.

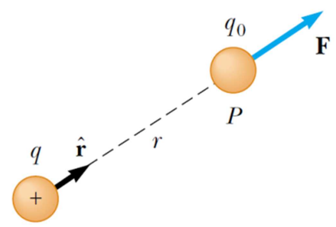
If '**F**' is the electrostatic force acting on a test charge 'q_0' at a point 'P', then electric field intensity '**E**' is expressed as

$$\mathbf{E} = \frac{\mathbf{F}}{q_0}$$

Electric field intensity is a vector quantity and its direction is same as the direction of the force.

Q # 7. Find out the expression of Electric Field Intensity due to Point Charge.

Ans. Consider a point charge 'q' as shown in the figure below



If '**F**' is the electrostatic force acting on a test charge 'q_0' at a point 'P', then electric field intensity '**E**' is expressed as:

$$\mathbf{E} = \frac{\mathbf{F}}{q_0} \quad \text{----------------} \quad (1)$$

By Coulomb's law, the electrostatic force '**F**' between point charges 'q' and 'q_0' is expressed as:

$$\mathbf{F} = \frac{1}{4\pi\,\varepsilon_0}\frac{qq_0}{r^2}\hat{\mathbf{r}}$$

Putting value of '**F**' in eq. (1), we get

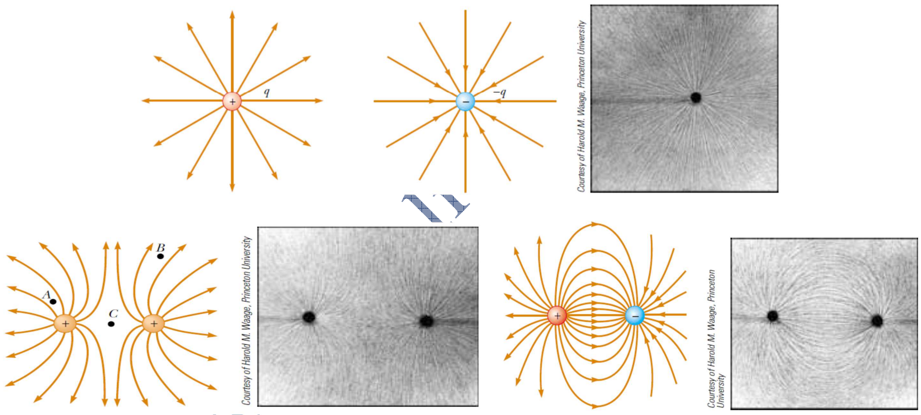
$$\mathbf{E} = \frac{\left(\frac{1}{4\pi\,\varepsilon_0}\frac{qq_0}{r^2}\hat{\mathbf{r}}\right)}{q_0} = \left(\frac{1}{q_0}\right)\left(\frac{1}{4\pi\,\varepsilon_0}\frac{qq_0}{r^2}\hat{\mathbf{r}}\right)$$

$$\mathbf{E} = \frac{1}{4\pi\,\varepsilon_0}\frac{q}{r^2}\hat{\mathbf{r}}$$

This is the expression of electric field intensity due to a point charge.

Q # 8. Write down the properties of electric lines of force.

- **i)** Electric field lines originate from positive charges and end on negative charges.
- **ii)** The tangent to a field line at any point gives the direction of the electric field intensity at that point.
- **iii)** The lines are closer where the field is strong, the lines are farther apart where the field is weak.
- **iv)** No two lines cross each other.



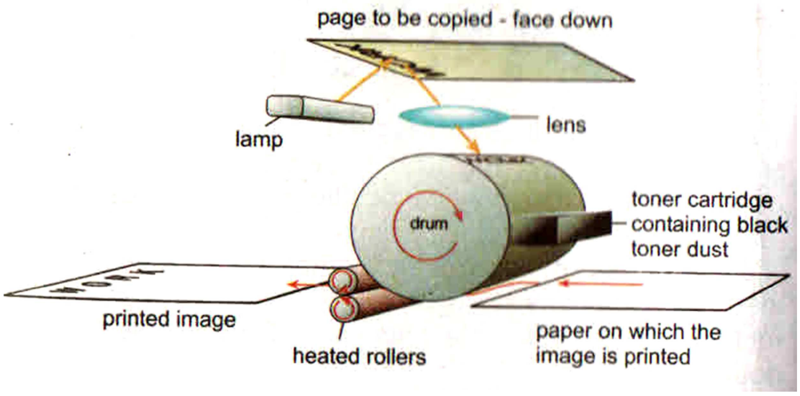
Q # 9. Write a note on following.

i) Xerography

The copying process is called xerography. The main component of photocopying machine is a drum which is an aluminum cylinder coated with layer of selenium.

Aluminum is a good conductor but selenium is a photoconductor. The positive charge is spread over the selenium. The charge will remain on the surface of drum as long as it remains in dark. When light falls on the drum, the electrons from aluminum pass through the conducting selenium and neutralize the positive charge.

The light from lamp transfers an image of the page to the drum. The dark areas retain their positive charge, but light area becomes conducting, lose their positive charge and become neutral. The drum collects negatively charged dry ink from toner where it sticks to the positive charged areas. The ink from the drum is transferred on to a sheet of paper on which the document is to be copied. Heated pressure rollers then melt the ink on to the paper to produce the permanent print of the document.

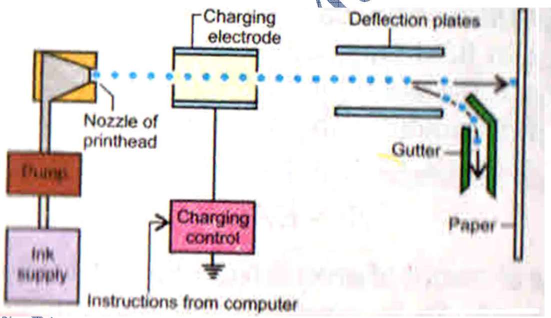


ii) Inkjet Printer

The inkjet printer uses electric charge in its working. The ink is forced out of a small nozzle and breaks up into extremely small droplets. During their flight, the droplets pass thorough two electrical components, which are the "charging electrode" and "deflecting plates"

The charging electrodes are used to charge the ink droplets that are not needed on the paper. The charged ink droplets are deflected in to the gutter (closed surface) by the deflecting plates.

The uncharged ink droplets pass through deflecting plates and strike the paper. When the print head moves over the paper which is to be inked, the charging control turns off the charging electrodes.



Q # 10. What do you know about electric flux? Describe its different cases.

Ans. The number of the field lines passing through a certain area is known as electric flux.

OR

The dot product of electric field intensity and vector area element is called electric flux. It is a scalar quantity and it is denoted by a Greek letter Φ_e. Mathematically, it can be expressed as

$$\Phi_e = \mathbf{E.A} \quad \text{-------------------} \ \mathbf{(1)}$$

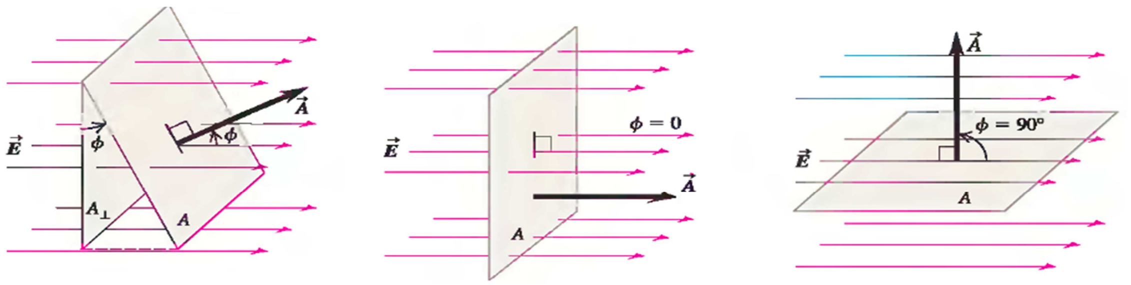
Where **E** = Electric Field Intensity

A = Vector Area

Eq. (1) can be written as

$$\Phi_e = EA\cos\theta$$

$\because \theta$ is the angle between **E** and **A.**



Case 1. If the vector area **A** is taken parallel to the field lines **E** then the electric flux will be

$$\Phi_e = EA\cos 0 \quad = EA \qquad\qquad (\text{Since } \cos 0° = 1)$$

Thus the electric flux through an area element will be maximum, when the **E** is parallel to **A**.

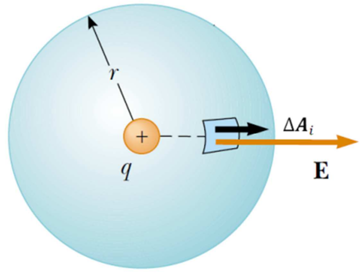
Case 2. If the vector area **A** is taken perpendicular to the field lines **E** then the electric flux passing through the body is given by

$$\Phi_e = EA\cos 90° = 0 \qquad\qquad (\text{Since } \cos 90 = 0)$$

Thus the electric flux through an area element will be zero, when the **E** and **A** are perpendicular to each other.

Q # 11. Find out the expression of the electric flux passing through a surface enclosing a charge.

Ans. Consider a closed surface in the form of a sphere of radius 'r' which has a point charge 'q' at its centre, as shown in the figure below:



We want to find out the value of electric flux through this close surface. For this, we divide the total surface area of the sphere into n small area elements $\Delta\mathbf{A}_1, \Delta\mathbf{A}_2, \ldots\ldots\ldots \Delta\mathbf{A}_n$. The electric intensities corresponding to the area elements $\Delta\mathbf{A}_1, \Delta\mathbf{A}_2, \ldots\ldots\ldots \Delta\mathbf{A}_n$ are $\mathbf{E_1}, \mathbf{E_2}, \ldots\ldots\ldots \mathbf{E_n}$ respectively. Total flux passing through a closed surface of sphere is

$$\Phi_e = \mathbf{E_1}.\Delta\mathbf{A}_1 + \mathbf{E_2}.\Delta\mathbf{A}_2 + \ldots\ldots\ldots + \mathbf{E_n}.\Delta\mathbf{A}_n \text{ ------------------- } \mathbf{(1)}$$

The direction of electric field intensity and the vector area is same at each patch. Moreover, because of spherical symmetry, at the surface of sphere,

$$|\mathbf{E_1}| = |\mathbf{E_2}| = \ldots\ldots\ldots = |\mathbf{E_n}| = E = \frac{1}{4\pi\,\varepsilon_0}\frac{q}{r^2} \text{ ------------------- } \mathbf{(2)}$$

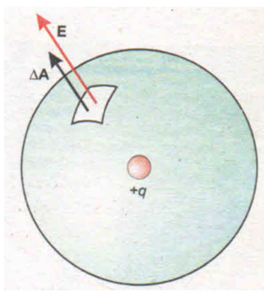
Equation (1) will become

$$\Phi_e = E\Delta A_1 + E\Delta A_2 + \ldots\ldots\ldots + E\Delta A_n$$

$$= E \times (\Delta A_1 + \Delta A_2 + \ldots\ldots\ldots + \Delta A_n)$$

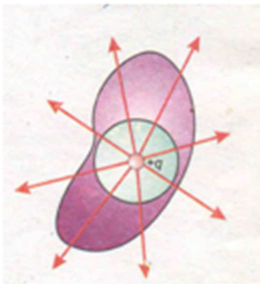
$$= E \times (\text{ Total spherical surface area})$$

$$= \frac{1}{4\pi\,\varepsilon_0}\frac{q}{r^2} \times 4\pi r^2$$



$$\Phi_e = \frac{q}{\varepsilon_0}$$

Q # 12. Describe the dependence of shape of close surface on electric flux passing through it.



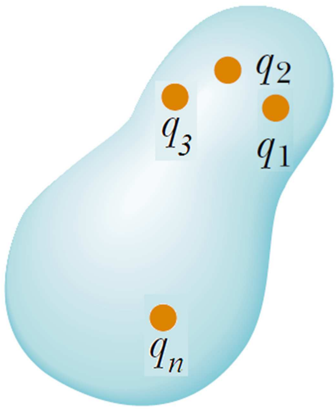
Ans. Consider an arbitrary shaped close surface enclosing a sphere which contain '$+q$' on its center, as shown in the figure below

It can be seen that the flux through arbitrary shaped close surface is same as that through the sphere. Hence the total flux through a close surface does not depend on the shape and geometry of closed surface.

Q # 13. State and explain the Gauss's law.

Statement. It states that the total electric flux through any closed surface is equal to the product of $\frac{1}{\varepsilon_0}$ times the total charge enclosed in it.

Explanation: Consider point charges $q_1, q_2, q_3, \dots\dots\dots q_n$ are spread in a closed surface S as shown in figure:



Electric flux due to charge $q_1 = \Phi_1 = \frac{q_1}{\varepsilon_0}$

Electric flux due to charge, $q_2 = \Phi_2 = \frac{q_2}{\varepsilon_0}$

Electric flux due to charge, $q_3 = \Phi_3 = \frac{q_3}{\varepsilon_0}$

$\vdots \quad \vdots \quad \vdots \quad \vdots$

$\vdots \quad \vdots \quad \vdots \quad \vdots$

Electric flux due to charge $q_n = \Phi_n = \frac{q_n}{\varepsilon_0}$

Total flux passing through the closed surface is

$$\Phi_e = \Phi_1 + \Phi_2 + \Phi_3 + \dots\dots\dots \Phi_n$$

$$\Phi_e = \frac{q_1}{\varepsilon_0} + \frac{q_2}{\varepsilon_0} + \frac{q_3}{\varepsilon_0} + \dots\dots\dots \frac{q_n}{\varepsilon_0}$$

$$\Phi_e = \frac{1}{\varepsilon_0} \times (q_1 + q_2 + q_3 + \dots\dots\dots + q_n)$$

$$\Phi_e = \frac{1}{\varepsilon_0} \times (\text{total charge enclosed by the closed surface})$$

$$\Phi_e = \frac{1}{\varepsilon_0} \times Q \quad \text{------------------- (1)}$$

Where $Q = q_1 + q_2 + q_3 + \dots\dots\dots + q_n$, is the total charge enclosed by the close surface. Equation (1) is the mathematical form of Gauss's law.

Q # 14. How the Gauss's law is applied to find out electric field intensity due symmetrical charge distribution.

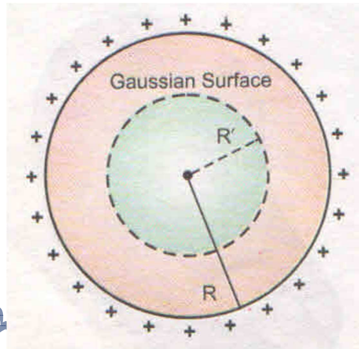
Ans. In order to find out electric field intensity due to different charge distributions, a Gaussian surface is considered which passes through the point at which the electric intensity is to be evaluated. Next the charge enclosed by the close surface is calculated and finally the electric intensity is computed by applying the Gauss's law.

Q # 15. Calculate the electric field intensity due to a hollow charged sphere.

Ans. Consider a hollow charged conducting sphere of radius 'R' is given a positive charge 'Q', as shown in the figure below:

We want to find out electric field intensity at point 'P' inside the hollow charged sphere. For this, we consider a spherical Gaussian surface which passes through the point P.

It can be seen that the charge enclosed by the Gaussian surface is zero. Then by applying the Gauss's law, we have



$$\Phi_e = \frac{q}{\varepsilon_0} = 0 \quad \text{------------------- } \mathbf{(1)}$$

Also

$$\Phi_e = \mathbf{E}.\mathbf{A} \quad \text{------------------- } \mathbf{(2)}$$

Comparing eq. (1) and (2), we get

$$\Phi_e = \mathbf{E}.\mathbf{A} = 0$$

As $\mathbf{A} \neq 0$,

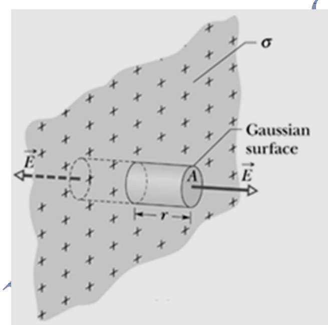
$$\text{Therefore } \mathbf{E} = 0$$

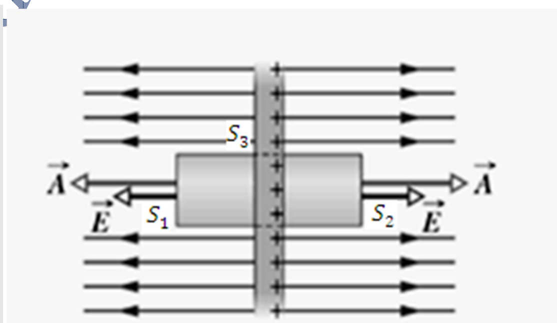
Thus the interior of a hollow charge sphere is a field free region.

Q # 16. Calculate the electric field intensity due to an infinite sheet of charge.

Ans. Consider an infinite sheet charges as shown in the figure below. Let the uniform surface charge density is 'σ'.

We want to find out electric field intensity at point 'P' due to this charge distribution. For this we consider a cylindrical Gaussian surface.



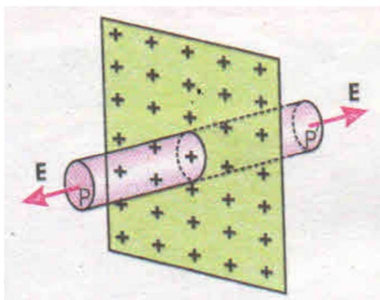


We divide the cylindrical Gaussian surface into three parts i.e., S_1, S_2 and S_3, where

S_1 = Left cross sectional area of cylindrical Gaussian surface

S_2 = Right cross sectional area of cylindrical Gaussian surface

S_3 = Area of curved of cylindrical Gaussian surface



Since $\mathbf{E}$ is parallel to the surface S_3, so there is no contribution to the flux from the curved wall of cylinder. While the flux through the two flat ends of the closed cylindrical surface is

$$\Phi_e = EA + EA = 2EA \quad \text{------------------- } \mathbf{(1)}$$

where A is the surface area of flat surface.

The charge enclosed by the Gaussian surface 'q' can be find out by using the expression:

$$\sigma = \frac{q}{A} \Longrightarrow q = \sigma A$$

Applying the Gauss's law,

$$\Phi_e = \frac{1}{\varepsilon_0} \times (\text{total charge enclosed by the closed surface})$$

$$\Phi_e = \frac{1}{\varepsilon_0} \times (\sigma A) \quad \text{-------------------} \ \mathbf{(2)}$$

Comparing eq. (1) and (2)

$$2EA = \frac{1}{\varepsilon_0} \times \sigma A$$

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

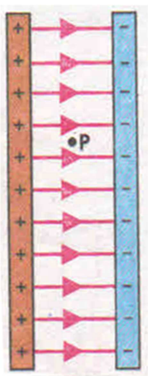
This is the expression of electric field intensity due to infinite sheet of charge.

In vector form

$$\mathbf{E} = \frac{\sigma}{2\varepsilon_0}\,\hat{\mathbf{r}}$$

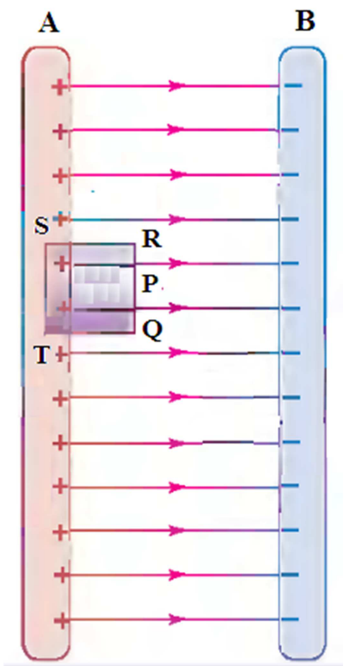
where '$\hat{\mathbf{r}}$' is a unit vector normal to the sheet directed away from it.

Q # 17. Calculate the electric field intensity between two oppositely charged plates.



Ans. Consider two oppositely charged plates 'A' and 'B' are placed at a very small distance as shown in the figure below. Suppose σ is the magnitude of surface charge density on each plate.

We want to find out electric field intensity at point 'P' due to oppositely charged plates. For this we consider a Gaussian surface in the form of a hollow box represented as QRST.



As the field lines are parallel to RS and TQ sides of Gaussian surface, so the flux through these will be zero. Thus the total electric flux through the Gaussian surface is the flux passing through the side QR, i.e.,

$$\Phi_e = EA \quad \text{-------------------} \ \mathbf{(1)}$$

The charge enclosed by the Gaussian surface 'q' can be find out by using the expression:

$$\sigma = \frac{q}{A} \Longrightarrow q = \sigma A$$

Applying the Gauss's law,

$$\Phi_e = \frac{1}{\varepsilon_0} \times (\text{total charge enclosed by the closed surface})$$

$$\Phi_e = \frac{1}{\varepsilon_0} \times (\sigma A) \quad \text{-------------------} \ \mathbf{(2)}$$

Comparing eq. (1) and (2)

$$EA = \frac{1}{\varepsilon_0} \times \sigma A$$

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

This is the expression of electric field intensity due to oppositely charged parallel plates.

In vector form

$$\mathbf{E} = \frac{\sigma}{\varepsilon_0}\,\hat{\mathbf{r}}$$

where '$\hat{\mathbf{r}}$' is a unit vector directed from positive to the negative plate.

Q # 18. Define following

i. Electric Potential Difference ii. Absolute Electric Potential

Ans.

i. Electric Potential Difference

The work done per unit charge in moving it from one point to another point in an electric field is called electric potential difference. The SI unit of electric potential difference is joule/coulomb, called volt.

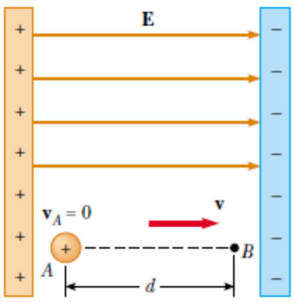
If W_{AB} is the work done in moving a test charge q_0 from point A to B in an electric field, then work done per unit charge from point A to point B is described as:

$$\text{Electric Potential Difference } \Delta V = \frac{W_{AB}}{q_0}.$$

ii. Absolute Electric Potential

Work done per unit charge in moving it from infinity to a specific point in the field is known electric potential or absolute electric potential. The SI unit of electric potential is joule/coulomb, called volt.

Q # 19. Show that electric potential is the negative gradient of electric potential.



Ans. Consider a positive charge q_0 is placed in a uniform electric field, between two oppositely charged plates. The potential difference between A and B is expressed as:

$$V_A - V_B = \frac{W_{AB}}{q_0} \qquad \text{------------------- (1)}$$

Where W_{AB} is the work done in displacing a test charge from point A to point B, against the electric field.

$$W_{AB} = \mathbf{F}.\mathbf{d} = Fd\cos 180° = -Fd$$

$\because F = q_0 E$ and d is the displacement between point A and B.

$$W_{AB} = -q_0 E d$$

The equation (1) will become

$$\Delta V = V_A - V_B = \frac{-q_0 Ed}{q_0}$$

$$\Delta V = -Ed$$

$$E = -\frac{\Delta V}{d} \qquad \text{------------------- (2)}$$

If the plates A & B are separated by infinitesimally small distance Δr, then the equation (2) will become

$$E = -\frac{\Delta V}{\Delta r} \qquad \text{------------------- (3)}$$

The quantity $\frac{\Delta V}{\Delta r}$ gives the maximum rate of change of potential with respect to distance which is called the potential gradient. Hence, the electric field intensity is the negative gradient of electric potential. The negative sign indicate that the direction of E is along the decreasing potential. From equation (3) indicated that the unit of electric field intensity is Vm^{-1}.

Q # 20. Prove that $\quad 1\,\frac{volt}{meter} = 1\,\frac{newton}{coulomb}$

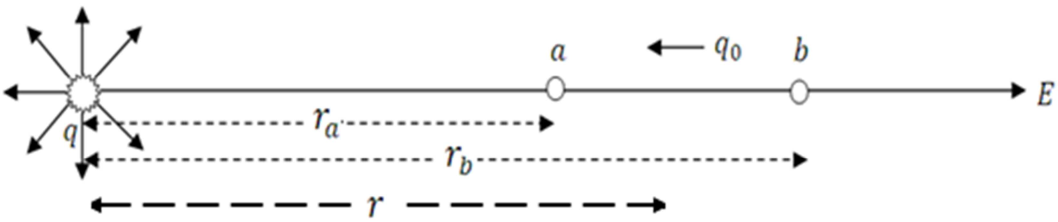
Ans. $L.H.S. = 1\,\frac{volt}{meter} = 1\frac{joule/coulomb}{meter}$

$$= 1\frac{joule}{meter\times coulomb} = 1\frac{newton\times meter}{meter\times coulomb}$$

$$= 1\frac{newton}{coulomb} = R.H.S.$$

Q # 21. Calculate the electric potential at a point due to a point charge.

Ans. Consider two points A and B in the electric field of a point charge q as shown in the figure below. The distance of points A and B from point charge q are r_a and r_b, respectively.



We want to find out electric field intensity at point P which is at the distance r from point charge. The magnitude of electric field intensity at point P is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} \qquad \text{------------------- (1)}$$

Consider $\Delta r = r_b - r_a$

$\Rightarrow r_b = r_a + \Delta r$

As r represents midpoint of interval between A and B, so

$$r = \frac{r_a + r_b}{2} = \frac{r_a + r_a + \Delta r}{2} = \frac{2r_a + \Delta r}{2}$$

$$r^2 = \left(\frac{2r_a + \Delta r}{2}\right)^2 = \frac{4{r_a}^2 + \Delta r^2 + 4r_a\Delta r}{4}$$

As Δr is very small so neglecting Δr^2, we have

$$r^2 = \left(\frac{2r_a+\Delta r}{2}\right)^2 = \frac{4{r_a}^2+4r_a\Delta r}{4} = {r_a}^2 + r_a\Delta r$$

Substituting the value of Δr

$$r^2 = {r_a}^2 + r_a(r_b - r_a) = {r_a}^2 + r_a r_b - {r_a}^2 = r_a r_b$$

Substituting values in equation (1)

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r_a r_b} \quad \text{------------------- (2)}$$

As electric field intensity is the negative gradient of electric potential, therefore

$$E = -\frac{\Delta V}{\Delta r} = \frac{-(V_b - V_a)}{(r_b - r_a)} = \frac{(V_a - V_b)}{(r_b - r_a)}$$

Putting values of equation (2)

$$\frac{(V_a - V_b)}{(r_b - r_a)} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r_a r_b}$$

$$V_a - V_b = \frac{q}{4\pi\varepsilon_0}\frac{r_b - r_a}{r_a r_b}$$

$$V_a - V_b = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r_a} - \frac{1}{r_b}\right] \quad \text{------------------- (3)}$$

This is the expression of electric potential difference between two points A and B. to calculate the absolute electric potential due to a point charge at point A, the point B is assume to be at infinity (i.e., $V_b = 0$, and $r_b = \infty$). Thus, the equation (3) will become

$$V_a - 0 = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r_a} - \frac{1}{\infty}\right]$$

$$V_a = \frac{q}{4\pi\varepsilon_0}\frac{1}{r_a} \quad \text{------------------- (4)}$$

The equation (4) gives the value of absolute electric potential at point A. the absolute electric potential at point P, which is at the distance r from point charge will be:

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

Q # 22. What do you know about electron volt? Also prove that 1eV $= 1.6 \times 10^{-19}$J.

Ans. The electron volt is the unit of energy which is defined as

"the amount of energy acquired or lost by an electron when it is displaced across two points having a potential difference of one volt". It is denoted by eV.

Proof: If the charge is free to move along the direction of field, it will acquire kinetic energy. In the present case, the loss of potential energy (ΔU) is equal to the gain in kinetic energy ($\Delta K.E$).

$$\Delta K.E = \Delta U$$

$$\Delta K.E = q\Delta V$$

If $q = 1.6 \times 10^{-19}\,C$ and $\Delta V = 1\,V$, therefore,

$$\Delta K.E = (1.6 \times 10^{-19}\,C)(1\,V)$$

As the kinetic energy acquired by the electron will acquire the kinetic energy of one electron as it move through a potential difference of one volt, is called electron volt. Therefore

$$1\ eV = 1.6 \times 10^{-19}\ CV$$

Or $$1\ eV = 1.6 \times 10^{-19}\ J \qquad \because CV = J$$

Hence proved.

Q # 23. Describe the similarities and difference among electrical and gravitational force.

Ans. The electrical force between two charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between them:

$$F = k\frac{q_1 q_2}{r^2} \qquad \text{------------------- (1)}$$

The gravitational force between two masses is directly proportional to the product of their masses and inversely proportional to the square of the distance between them:

$$F = G\frac{m_1 m_2}{r^2} \qquad \text{------------------- (2)}$$

Similarities among the Electrical and Gravitational Force

(i) Both forces are the conservative forces.

(ii) Both forces obey the inverse square law.

Differences among the Electrical and Gravitational Force

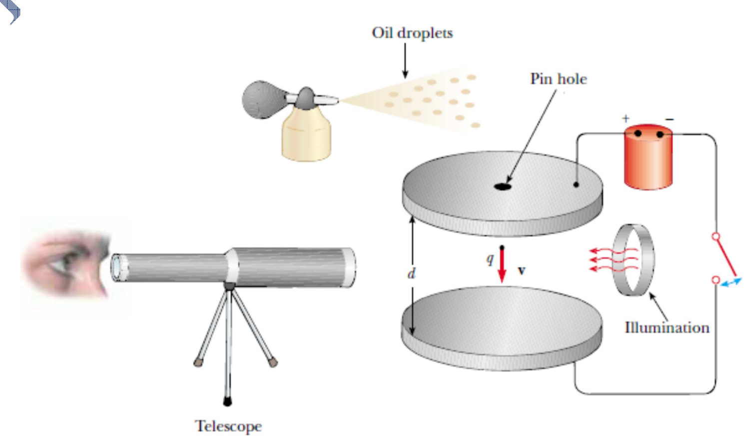
(i) Electrical force is might be attractive as well as repulsive while the gravitational force is only attractive.

(ii) Electrostatic force is medium dependent and can be shielded while the gravitational force lack this property.

(iii) The value of gravitational constant is very small while the electrical constant is very large. It is because of the fact that gravitational force is very weak as compared to electrical force.

Q # 24. Calculate the charge on an electron by Millikan's method.

Ans. In 1909, R.A Millikan's devised a technique that resulted in precise measurement of the charge on an electron. The experimental set up of Millikan's oil drop experiment is shown in figure below:



The setup consist of parallel plates separated by a distance d. The upper plate has a small hole. A voltage V is applied to the plates and so an electric field between the plates is set up. The magnitude of **E** is given by

$$\mathrm{E} = \frac{\mathrm{V}}{d} \quad \text{……………………} \quad \textbf{(1)}$$

An atomizer is used for spraying oil drop through a nozzle. The oil drop gets charged due to friction with the walls of atomizer. Some of these drops will pass through the hole in the upper plate. A telescope is used to observe the path of motion of one of these charged droplets.

A given droplet between the two plates could be suspended in air if the gravitational force $F_g = mg$ acting on the drop is equal to the electrical force $F_e = qE$. The F_e can be adjusted equal to F_g by adjusting the voltage. In this case we can write:

$$F_e = F_g$$

$$qE = mg$$

By using equation (1), we get

$$q\,\frac{\mathrm{V}}{d} = mg$$

$$\Longrightarrow q = \frac{mgd}{V} \quad \text{……………………} \quad \textbf{(2)}$$

In order to determine the mass of the droplet, the electric field between the plates is switched off. The droplet falls under the action of gravity through air. Its terminal velocity v_t is determined by timing the fall of droplet over measured distance. The drag force on the droplet can be find out using Stokes's law:

$$F = 6\pi\eta r v_t = mg \quad \text{……………………} \quad \textbf{(3)}$$

where r is the radius of the droplet and η is the coefficient of viscosity of air. If ρ is the density of droplet, then

$$m = \frac{4}{3}\pi r^3 \rho \quad \text{……………………} \quad \textbf{(4)}$$

Hence the equation (3) will become,

$$6\pi\eta r v_t = \left(\frac{4}{3}\pi r^3 \rho\right) g$$

$$r^2 = \frac{9\eta v_t}{2\rho g}$$

Knowing the value of r, the mass can be calculated using equation (4). This value of m is substituted in equation (2) to get value of charge q on the droplet.

Millikan measured the charge on many drops and found that each charge was an integral multiple of minimum value of charge equal to $1.6 \times 10^{-19} C$. He, therefore, concluded that this minimum value of charge is the charge on electron.

Q # 25. What do you about a capacitor?

Ans. A capacitor is a device that can store charge. It consists of two metal plates placed near one another separated by air, vacuum or any other insulator. When plates of a capacitor are connected with a battery of voltage V, the battery places a charge $+Q$ on the plate connected with its positive terminal and a charge $-Q$ on the other plate which is connected to its negative terminal. It is found that amount of charge on one plate of capacitor Q is directly proportional to the potential difference

$$Q \propto C$$

$$Q = CV$$

where C is the constant of proportionality and is called capacitance of the capacitor. Its value depends upon the geometry and medium between them.

Q # 26. What do you know about the capacitance of a capacitor?

Ans. The ability of a capacitor to store charge is called capacitance of a capacitor. It can also be defined as

" The amount of charge on one plate necessary to raise the potential of the plate by one volt with respect to the other".

Q # 27. Derive a relation for the capacitance of a parallel plate capacitor

Ans. Consider a parallel plate capacitor consists of two plane metal plates, each of area A, separated by a distance d as shown in figure below:

We want to find out the expression of capacitance for a parallel plate capacitor, whose plates are separated by air.

By definition, the capacitance is

$$C_{vac} = \frac{Q}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where Q is the charge on the capacitor and V is the potential difference between the parallel plates. The magnitude E of electric intensity is given by

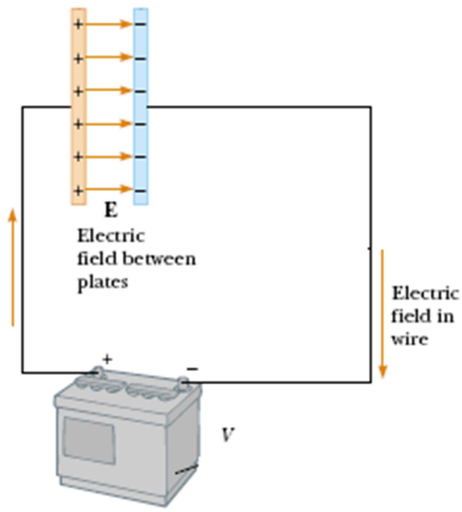
$$E = \frac{V}{d} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The electric intensity between two oppositely charged plates is given by

$$E = \frac{\sigma}{\varepsilon_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where $\sigma = \frac{Q}{A}$ is the surface charge density on each plate. Hence, equation (3) will become

$$E = \frac{Q}{A\varepsilon_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$



By comparing (2) and (4), we get

$$\frac{V}{d} = \frac{Q}{A\varepsilon_0}$$

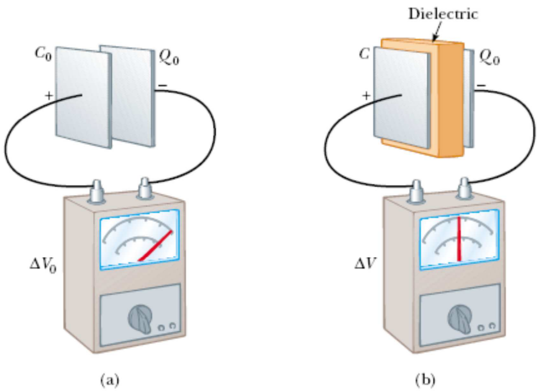
Or $$\frac{Q}{V} = \frac{A\varepsilon_0}{d}$$

Putting values in equation (1)

$$C_{vac} = \frac{A\varepsilon_0}{d} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

This is the expression of capacitance of a parallel plate capacitor, whose plates are separated by vacuum.

Q # 28. Describe the effect on the capacitance of a parallel plate capacitor, when a dielectric medium is place between its plates.



Ans. The presence of a dielectric medium of dielectric constant ε_r has resulted in decrease in the potential difference between the plates as shown in the figure below:

Since Q remains constant, therefore the capacitance C increased as we placed the dielectric medium between the plates of a capacitor. Thus, the expression of capacitance of capacitor when a dielectric medium of dielectric constant ε_r is placed between the plates of capacitor will be:

$$C_{med} = \frac{A\varepsilon_0\varepsilon_r}{d}$$

Q # 29. Define dielectric constant of a substance.

Ans. The dielectric constant of a substance is defined as

"*The ratio of the capacitance of a parallel plate capacitor with an insulating substance as medium between the plates to its capacitance with vacuum as medium between them*"

Mathematically, it is described as:

$$C_{med} = \frac{A\varepsilon_0\varepsilon_r}{d}$$

$$C_{med} = \varepsilon_r C_{vac}$$

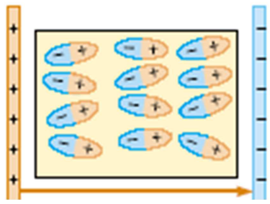
Or $$\varepsilon_r = \frac{C_{med}}{C_{vac}}$$

Q # 30. Write a short note on electric polarization of dielectric.

Ans. The dielectric consists of atoms and molecules which are electrically neutral. The centers of positive and negative charges coincide in the absence of an electric field. When a dielectric is placed in an electric field between the plates of a capacitor, the centers of positive and negative charges now no longer coincide with each other. Thus the molecules of the dielectric under the action of electric field become dipoles and the dielectric is said to be polarized.

Q # 31. How the electric polarization of dielectric result in the enhancement of capacitance of capacitor?

Ans. The positively charged plate attracts the negative end of the molecular dipoles and negatively charged plate attracts the positive end. Thus the surface of the dielectric which is in contact with the positively charged plate places a layer of negative charges on the plate. Similarly the surface of the dielectric in contact with the negatively charged plate places a layer of positive charges. It decreases the surface density of the charge σ on the plates, which result in decrease in electric intensity $E = \frac{\sigma}{\varepsilon_0}$. This decrease of potential difference between the plates. As the capacitance is inversely proportional to the potential difference between plates. Therefore, the capacitance of capacitor increased due to electric polarization of a dielectric.



Q # 32. Find out the expression of energy stored in the electric field of a capacitor.

Ans. Consider a capacitor having capacitance C is connected with a battery having a terminal potential difference V.

We want to find out the expression of energy stored in electric field of a charged capacitor. The charge on the plate possesses electrical potential energy which arises work is to be done to deposit the charge on the plate. With each small increment of charge, the potential difference between the plates increases. This is due to the fact that a larger amount of work is needed to bring up next increment of charge.

Initially, when the capacitor is uncharged, the potential difference between the plates is zero and finally it becomes V when charge q is deposited on each plate. Thus average potential difference is $\frac{0+V}{2} = \frac{1}{2}V$.

Therefore the energy stored in the capacitor is:

$$E = \frac{1}{2}qV$$

$$\because q = CV \; for \; a \; capacitor$$

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

Substituting $V = Ed$ an d $C = \frac{A\varepsilon_0\varepsilon_r}{d}$, we get:

$$E = \frac{1}{2}\left(\frac{A\varepsilon_0\varepsilon_r}{d}\right) (Ed)^2$$

$$E = \frac{1}{2}\left(\frac{A\varepsilon_0\varepsilon_r}{d}\right) E^2 d^2$$

$$E = \frac{1}{2} \varepsilon_0\varepsilon_r E^2 (Ad)$$

Where Ad is the volume between the plates.

Energy Density

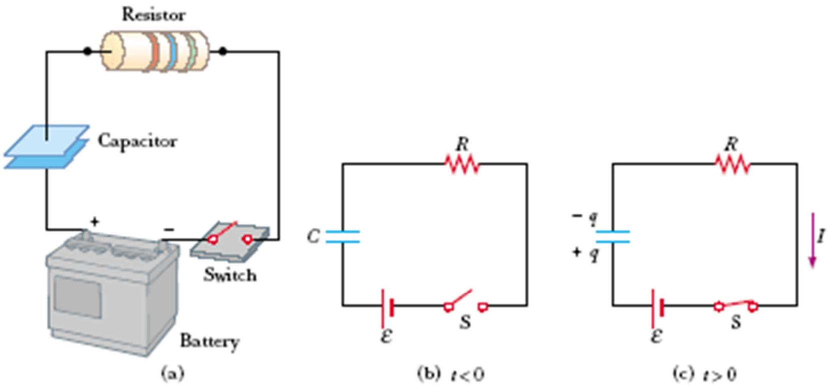
The energy density can be find out by dividing the energy stored in the capacitor by volume of the capacitor:

$$Energy\ Density = \frac{E}{Volume} = \frac{E}{Ad}$$

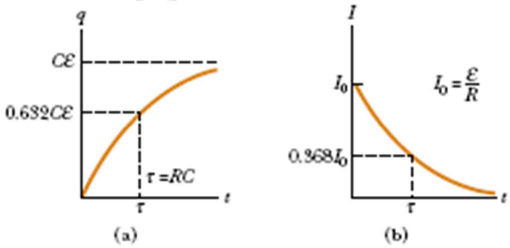
$$Energy\ Density = \frac{1}{2}\varepsilon_0\varepsilon_r E^2$$

Q # 33. Describe the phenomenon of charging and discharging of a capacitor

Ans. The electrical circuits consist of both capacitor and resistors are called RC circuit. When the RC circuit is connected to a battery, it starts charging the capacitor through resistor R.



The capacitor is not charged immediately, rather charges built up gradually to the equilibrium value $q_0 = CV_0$. The growth of charge with time is shown in the graph (a). According to the graph, $q = 0$ at $t = 0$ and increases gradually with time till it reaches the equilibrium value $q_0 = CV_0$.



Graph (b) shows the discharging of a capacitor through resistor. The graph shows that discharging begins at $t = 0$ when $q = CV_0$ and decreases gradually to zero.

RC Time Constant

How fast or how slow the capacitor is charging or discharging, depends upon the product of the resistance and the capacitance. As the unit of the product RC is that of time, so this product is known as the time constant and is defined as the time required by "*the capacitor to deposit 0.63 times the equilibrium charge*".

The charge reaches its equilibrium value sooner when the time constant is small. Similarly, smaller values of time constant RC leads to a more rapid discharge.

EXERCISE SHORT QUESTIONS

Q # 1. The potential is constant throughout a given region of space. Is the electric field zero or non zero in this region? Explain.

Ans. The electric field intensity is described by the relation:

$$E = -\frac{\Delta V}{\Delta \mathrm{r}}$$

According to the relation, the electric field is negative gradient of electric potential. If the electric potential is constant throughout given region of space, then change in electric potential $\Delta V = 0$, hence $E = 0$.

Q # 2. Suppose that you follow an electric field line due to a positive point charge. Do electric field and the potential increases or decreases.

Ans. If we follow an electric field line due to a positive point charge, then it means that we are moving await from point charge. Thus the distance from the charge increases. Due to increase of distance from positive charge, both electric field intensity and electric potential decreases as:

$E \propto \frac{1}{r^2}$ and $V \propto \frac{1}{r}$

Q # 3. How can you identify that which plate of capacitor is positively charged?

Ans. The presence of charge on a body is detected by a device called gold leaf electroscope. The leaves of gold leaf electroscope are diverged by giving them negative charge.

- If the disc is touched with any plate of the charged capacitor and the divergence of the leaves increases, the plate of capacitor is negatively charged .
- If the divergence of leaves decreases, then that plate of capacitor is positively charged.

Q # 4. Describe the force or forces on a positive point charge when placed between parallel plates:

i. **With similar and equal charges**
ii. **With opposite and equal charges**

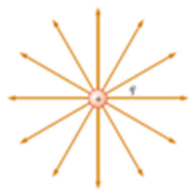
Ans. When a positive point charge is placed between parallel plates with similar and equal charges, then the electric field intensity due to one plate is equal in magnitude but opposite in direction of electric intensity due to other plate. So the value of resultant electric field intensity E is zero. Hence the net force on the positive point charge is zero. Thus it will remain at rest.

When a positive point charge is placed between parallel plates with opposite but equal amount of charge, then electric field intensity due to one plate is equal in magnitude but in same direction of the electric field intensity due to other plate. So the value of resultant electric field intensity is non zero. Hence the point charge will be accelerated towards negative plate.

Q # 5. Electric lines of force never cross. Why?

Electric lines of force never cross each other. This is because of the reason that electric field intensity has only one direction at any given pint. If the lines cross, electric intensity could have more than one direction which is physically not correct.

Q # 6. If a point charge of mass m is released in a non-uniform electric field with field lines in the same direction pointing, will it make a rectilinear motion.



Ans. A non-uniform field of a positive point charge is shown in the figure:

If a point charge q of mass m is placed at any point in the field, it will follow straight or rectilinear path along the field line due to repulsive force.

Q # 7. Is E necessarily zero inside a charged rubber balloon if the balloon is spherical. Assume that charge is distributed uniformly over the surface.

Ans. Yes, E is necessarily zero inside a charged rubber balloon if balloon is spherical. If the Gaussian surface is imagined inside charged balloon, then it does not contain any charge i.e., q=0.

Applying Gausses law:

$$\Phi_e = \frac{q}{\varepsilon_0} = 0 \quad \text{----------} \quad (1)$$

Also,

$$\Phi_e = E.A \quad \text{-----------} \quad (2)$$

Comparing (1) and (2), we have:

$$E.A = 0$$

As $A \neq 0$, therefore, $E = 0$

Hence electric field intensity will be zero inside a spherical balloon.

Q # 8. Is it true that Gauss's law states that the total number of lines of force crossing any closed surface in the outward direction is proportional to the net positive charge enclosed within surface?

Ans. Yes, the above statement is true.

Electric flux is defined as the measure of number of electric lines of force passing through a certain area. According to Gauss's law, the flux through any close surface is $\frac{1}{\varepsilon_0}$ times the total charged enclosed in it.

Electric flux = $\frac{1}{\varepsilon_0}$ (Total Charge Enclosed)

Electric flux = constant (Total Charge Enclosed)

Electric flux ∝ (Total Charge Enclosed)

Q # 9. Do electrons tends to go to region of high potential or of low potential?

Ans. The electrons being negatively charge particle when released in electric field moves from a region of lower potential (negative end) to a region of high potential (positive end).

Govt. Degree College Naushera

District Khushab