According to new syllabus of all intermediate boards of Sindh.

Prof. Rawala's ....

PHYSICS

HELPING BOOK

For
Class XI
(All science students)

UNIT -8

Electric field.

CONTENTS

Thoroughly revised and updated 2026 – 2027

- ***Detailed notes.***
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Unit. 8**.....**

Electric field

Electrostatics:

Electrostatics is a branch of physics which deals with the behavior of charges at ***rest,***
Like charges (both positive or both negative) ***repel***
unlike charges (one positive other negative) ***attract*** each other.

***Unit of charge*:**

S.I unit of charge is ***coulomb***.

Comparison between electric and gravitational force:

- Gravitational force is ***attractive*** but electric force between charges may be ***attractive*** or ***repulsive*** in nature.
- Gravitational force is a ***long-range force*** but electric force is a ***short-range force***.

It means that the gravitational force acts over long distances but electric force acts over short distances.

- Gravitational force is ***weaker*** than electric force.
- Formation of our solar system is due to the gravitational force between sun and other planets.
- Formation of atoms, molecules etc. is due to electric force between oppositely charged electrons and protons or between oppositely charged ions.

Coulomb's law:

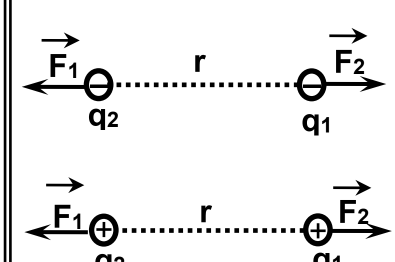
***Q.No.1*: State and explain Coulomb's law.**

***Statement*:**

"The force of attraction or of repulsion between two point charges is directly proportional to the product of charges and inversely proportional to the square of distance between them".

***Formula*:**

$$\vec{F} = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2}\hat{r}_{12}$$



Like charges repel

Derivation:

Since like charges repel and unlike charges attract each other, therefore, according to Coulomb's law, the magnitude of force "F_1" with which "$+q_1$" repels "$+q_2$" when the distance between them is "r", is given by:

$F_1 \propto q_1 q_2$ $\qquad$ $F_1 \propto \frac{1}{r^2}$

On combining both the proportionalities we get:

$$F_1 \propto \frac{q_1 q_2}{r^2}$$

$$F_1 = K \frac{q_1 q_2}{r^2}$$

Where "K" is the constant of proportionality, it's value depends upon ***nature of medium present between the charges*** and upon the ***system of units*** in which "F", "q" and "r" are measured.

The value of "K" for vacuum in S.I or M.K.S system is:

$$K = \frac{1}{4\pi\varepsilon_o}$$

Where "ε_o" is a universal constant, it represents the permittivity of free space. Its S.I value is $8.85\times10^{-12}\ C^2/N\text{-}m^2$. Hence.

$$K = \frac{1}{4\pi\varepsilon_o} = 9\times10^{9}\ N\text{-}m^2/C^2.$$

In other words, $F_1 = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2}$

OR $F_1 = 9\times10^{9}\frac{q_1 q_2}{r^2}$

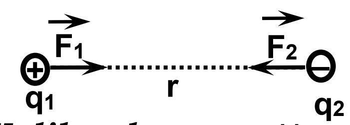
These equations give us the magnitude of force "F_1" with which $+q_1$ repels $+q_2$ (These equations help to solve numericals). Since "F_1" is a vector quantity, therefore, its direction must be specified.

To include its direction in the above formula, multiply the right side by a unit vector $\hat{r}_{12}$, directed from $+q_1$ to $+q_2$.

$$\boxed{\vec{F}_1 = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2}\hat{r}_{12}}$$

Since action and reaction are equal and opposite (Newton's third law), therefore, force "$\vec{F}_2$" exerted by "$+q_2$" on "$+q_1$" will be $\vec{F}_2 = -\vec{F}_1$. Hence $\vec{F}_2$ is given by:

$$\boxed{\vec{F}_2 = -\frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2}\hat{r}_{12}}$$



Unlike charges attract

Note that forces exerted by charges on each other always act along the ***line joining their centers*** and are always ***equal*** in magnitude but ***opposite*** in direction.

Note that when two charges exert force on a third charge, the total or net force on that charge is the ***vector sum*** of forces that the two charges would exert individually. Similarly, if there are more charges then net force on any charge will be the vector sum of forces exerted by all the other charges.

Effect of medium upon force between charges:

Q.No.2: What happens to force between charges when a medium is present between them?

Ans: As compared to vacuum, force between charges decreases by "ε_r" times when a medium is present between them.

$$\vec{F}_1 = \frac{\frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2}\hat{r}_{12}}{\varepsilon_r}$$

Constant "ε_r" is known as ***"relative permittivity of the medium"***, it is taken relative to the vacuum. Its value for a given medium is constant and depends upon nature of the medium. Force between two point charges with a medium of relative permittivity "ε_r" between them is given by:

$$\vec{F}_1 = \frac{1}{4\pi\varepsilon_o\varepsilon_r}\frac{q_1q_2}{r^2}\hat{r}_{12}$$

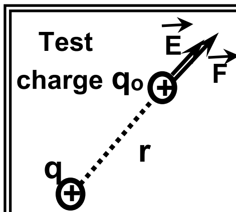
$$\boxed{\vec{F}_1 = \frac{1}{4\pi\varepsilon}\frac{q_1q_2}{r^2}\hat{r}_{12}}$$

Where $\varepsilon = \varepsilon_o\varepsilon_r$ is the (Total) permittivity of the medium.

- For air ε_r=1.0006, hence force between two point charges in air and in vacuum will be practically equal and can be calculated by above equations.
- For water "ε_r" is 80, ***it means that*** force between charges, as compare to vacuum, ***decreases*** by eighty times if they are put in water.

Electric field:

Q.No.1: What is electric field?



Electric field due to a positive charge q

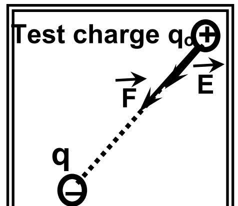
Ans: Electric field is said to exist at a point at which a positive test charge experiences a force of electrical nature.

OR

"The space around a charged body in which it attracts or repels other charges is called electric field".

An electric field modifies the space around a charge such that other charges experience a force when they are placed in this space (attraction when they are unlike, repulsion when they are like). This modified space around a charged body in which it attracts or repels other charges is called electric field of the charge.

Q.No.2: What are electric lines of force?

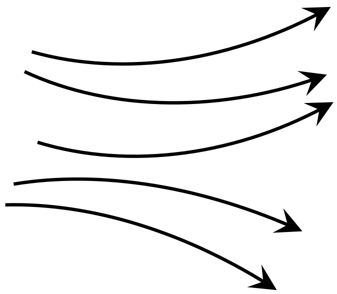


Electric field due to a negative charge −q

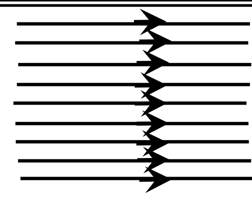
Ans: An electric line of force is an imaginary line drawn in such a manner that tangent to this line at a given point gives the direction of electric field at that point.

1. Electric lines of force show the direction of $\vec{E}$ at each point.
2. These lines are continuous, they originate from **positive** and terminate at the **negative** charge, and are directed from ***positive*** to ***negative*** charge.
3. Electric lines of force are radial and ***do not intersect*** each other.
4. Spacing of these lines give a general idea about the ***strength*** of the field, hence where lines of force are bunched together (closely spaced) $\vec{E}$ is ***strong*** and where they are farther apart $\vec{E}$ is ***weak***.
5. Parallel electric lines of force, equally spaced represent a ***uniform*** electric field.

6. Hence for oppositely charged plates the electric field or ***in other words*** lines of electric force are directed from a ***positively charged*** to a ***negatively charged*** plate.



Different directions, Different spacing. Non-uniform electric field.



Same direction, Less spacing Strong, uniform electric field

Note that the test charge must be positive and of a very small magnitude.

It must be very small so that it does not alter the already existing electric field whose intensity it is to measure.

Strength of electric field or Electric intensity:

Q.No.3: Define electric intensity at a point in an electric field. Also give its S.I unit.

Ans: ***"Electric intensity or strength of an electric field at a point in an electric field is the force experienced by the test charge divided by the magnitude of test charge".***

OR

"Electric intensity at a point is the force per unit charge'.

$$\boxed{\vec{E} = \frac{\vec{F}}{q_o}}$$

"q_o" is the magnitude of test charge.

Electric intensity is a ***vector quantity;*** its direction is **same** as the direction of ***electric force*** experienced by a ***positive*** test charge.

- Electric intensity due to a ***positively charged*** body is directed ***away*** from the body. (Because a positively charged body repels positive test charge).
- Electric intensity due to a ***negatively charged*** body is directed ***towards*** the body. (Because a negatively charged body attracts positive test charge).

S.I unit of electric intensity:

The S.I unit of electric intensity is N/c (newton per coulomb) or v/m (volt per meter).

Q.No.4: Derive an expression for electric intensity at a point near an isolated point charge.

Ans: Consider an isolated point charge "+q". If a positive test charge "+q_o" is placed at distance "r" from it in its electric field, the test charge will experience a repulsive force, according to the strength of the field at that point.

According to Coulomb's law the force $\vec{F}$ with which "+q" repels the test charge "+q_o" is given by:

$$\vec{F} = \frac{1}{4\pi\varepsilon_o}\frac{q\,q_o}{r^2}\,\hat{r}$$

"$\hat{r}$" is a unit vector directed away from the field producing charge (i.e. away from point charge +q). Hence electric intensity $\vec{E}$ at a distance "r" from "+q" is given by:

$$\vec{E} = \frac{\vec{F}}{q_o}$$

Hence,

$$\vec{E} = \frac{\frac{1}{4\pi\varepsilon_o}\frac{q\,q_o}{r^2}\,\hat{r}}{q_o}$$

$$\therefore \quad \boxed{\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}\,\hat{r}}$$

For a negative point charge "– q", electric intensity at a point is given by:

$$\therefore \quad \boxed{\vec{E} = -\frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}\,\hat{r}}$$

In this case the direction of $\vec{E}$ will be opposite to the direction of $\hat{r}$ (i.e. towards the charge).

Effect of medium upon electric intensity:

Q.No.5: What is the effect of the presence of a medium upon electric intensity at a point?

Ans: Electric intensity at a point ***decreases*** by ε_r times if a medium is present between the field producing charge and the given point (ε_r is the relative permittivity of the medium).

In other words, a test charge placed at such a point will experience a weaker force as the electric field has become weak.

Q.No.6: How is net (or resultant) electric intensity at a point due to a distribution of several isolated point charges found?

Ans: If there are two or more isolated point charges distributed randomly, then the net (or resultant) electric intensity at a point due to such a charge distribution will be equal to the ***vector sum*** of intensity due to individual point charges.

In such a case, first of all using the above formula, find the intensity at the given point due to each point charge separately. Then considering their directions find their vector sum.

If $\vec{E}_1$, $\vec{E}_2$, $\vec{E}_3$,……. represent strength of electric fields (or electric intensities) at a point due to charges q_1, q_2, q_3, …… etc. then the net electric intensity $\vec{E}$ at the point is given by:

$$\boxed{\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3, \ldots\ldots}$$

Electric dipole:

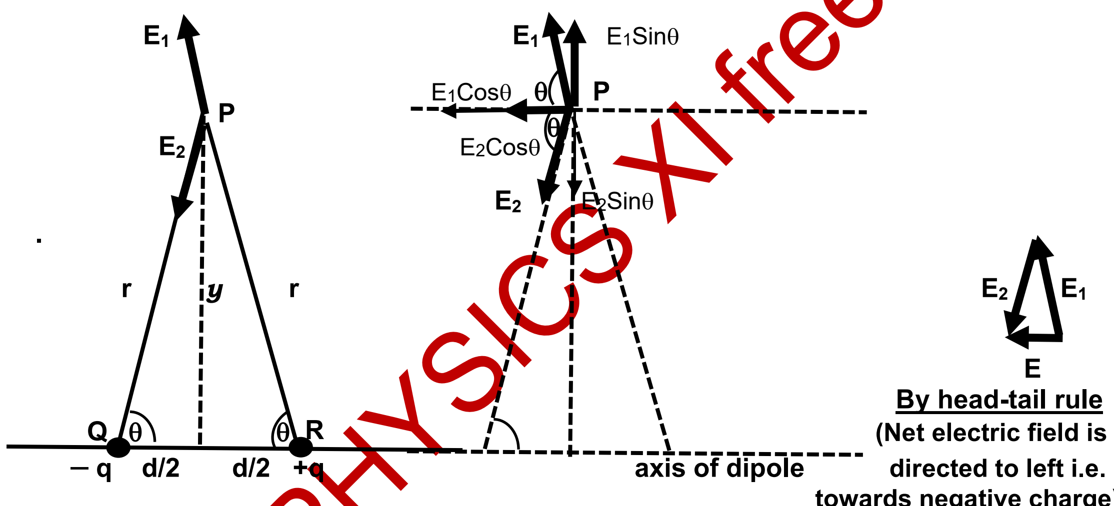
Q.No.7: What is an electric dipole?

Ans: An ***electric dipole is a pair of two equal and opposite charges "+q" and "– q" separated by a very small distance "d"***.

Electric field produced by an electric dipole at any point is directed from positive to the negative charge and it has maximum strength along a straight line joining the two charges, called **axis of the dipole**.

Q.No.8: What is electric dipole moment?

Ans: ***Electric dipole moment*** $\vec{p}$ is a ***vector*** quantity. Its magnitude p is equal to the product "q d" the magnitude of charge "q" and the distance "d" between the charges, it represents the strength of the dipole and is directed from the **negative charge** "–q" **to positive charge** "+q".



Electric field due to a dipole at "P"

Electric field due to a dipole at a point perpendicular to its axis:

Q.No.9: Derive a formula for electric field due to a dipole at a point perpendicular to its axis?

Ans: Consider two **equal and opposite** charges "+q" and "–q" forming a dipole, these charges are separated by a **very small distance "d"**, as shown in the above diagram.

Horizontal line joining a dipole "+q" and "–q" shows its axis. Strength of electric field due to individual charge at a point "P" at an equal distance "r" from each charge will be equal to "E_1" and "E_2".

Electric intensity "E_1" due to **positive** charge is **away** and "E_2" due to **negative** charge is **towards** the charge. Resolving E_1 and E_2 into horizontal and vertical components we see that vertical components $E_1 \sin\theta$ and $E_2 \sin\theta$ cancel each other (Since they are equal and opposite to each other, because "q" and "r" for each charge is equal). But horizontal components $E_1 \cos\theta$ and $E_2 \cos\theta$ are in the **same** direction (**towards** the negative charge) hence they will add up, net strength of electric field at point P is given by:

$$E = E_1 \cos\theta + E_2 \cos\theta \qquad E_1 = E_2 = \frac{K\,q}{r^2}$$

$$E = 2\frac{Kq}{r^2}\cos\theta$$

In triangle PQR: $\cos\theta = \frac{d/2}{r}$

$$E = 2\frac{Kq}{r^2}\,\frac{d/2}{r} = \frac{\cancel{2}\,Kqd}{\cancel{2}\,r^3} = \frac{Kqd}{r^3} = \frac{1}{4\pi\varepsilon_o}\,\frac{qd}{r^3}$$

(where $K = \frac{1}{4\pi\varepsilon_o}$ it is called Coulomb's constant)

But $qd = P$ (called **electric dipole moment**)

$$E = \frac{1}{4\pi\varepsilon_o}\,\frac{P}{r^3}$$

In triangle PQR: $r^2 = (d/2)^2 + y^2$ therefore, $r = \sqrt{(d/2)^2 + y^2}$

Hence
$$E = \frac{1}{4\pi\varepsilon_o}\,\frac{P}{\left\{(d/2)^2 + y^2\right\}^{3/2}}$$

Distance "d" between the two charges, forming a dipole is <u>**very small**</u> as compared to "y" hence it's higher power terms are negligibly small. Neglecting $(d/2)^2$ we get:

$$E = \frac{1}{4\pi\varepsilon_o}\,\frac{P}{y^3}$$

"y" can be taken as equal to "r" since d/2 is negligible.

$$\boxed{E = \frac{1}{4\pi\varepsilon_o}\,\frac{P}{r^3}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

Comparing equations (*i*) and (*ii*) we conclude that the electric field is stronger at a point along the axis of a dipole than at an equal distance from charges perpendicular to the axis.

Type of electric field due to a dipole is used in microwave oven. Food to be heated is subjected to an alternating electric field.

- ❖ Due to high electro-negativity shared pair of electrons shifts slightly towards oxygen atom in a water molecule, due to which a <u>**small negative charge**</u> appears at Oxygen end and a <u>**small positive charge**</u> at Hydrogen ends. As a result of which water molecules behave as a <u>**dipole**</u>. When electric field is applied to a water molecule it turns to align with the direction of applied field. If an alternating field is applied, water molecules start vibrating/rotating (as it tends to align itself with the direction of electric field), thereby rubbing with their neighboring molecules. As a result of which its temperature rises.
- ❖ In a Microwave oven food to be heated is subjected to an alternating field, due to the presence of water molecules in the food, it is heated by the mechanism described above.

<u>***Electric flux***</u>:

<u>Q.No.1</u>: Define electric flux passing through a surface.

<u>Ans</u>: "Electric flux "$\Delta\phi$" passing through a surface is the scalar or dot product of electric intensity "$\vec{E}$" and vector area "$\vec{\Delta A}$" of the surface".

$$\boxed{\Delta\phi = \vec{E} \cdot \vec{\Delta A}}$$

Electric flux is a ***scalar quantity***. The magnitude of electric flux is given by:

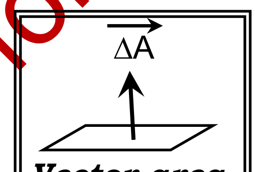
$$\Delta\phi = E\ \Delta A \text{ Cos } \theta$$

Where "θ" is the angle between the electric intensity $\vec{E}$ and vector area "$\vec{\Delta A}$" (When tails of $\vec{E}$ and $\vec{\Delta A}$ are joined together).

- Physically the electric flux is a measure of ***number of lines of electric force passing normally*** through a surface in an electric field.
- S.I unit of electric flux is N m^2/C.

Q.No.2: What is vector area "$\vec{\Delta A}$" ?

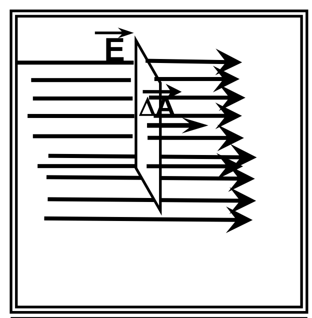
Ans: Area normally is a scalar quantity, but in this case area of a surface has a ***directional effect*** upon the number of lines of force passing through the surface. Because if the surface makes different angles with the electric field then the flux passing through it (i.e. the number of lines passing through it) is different for different angles. Hence area of the surface is taken as a ***vector***. It is called ***vector area*** of the surface. Its magnitude is equal to the ***geometrical area of the surface*** and its direction is taken ***along the outward drawn normal*** to the surface.



Vector area

Q.No.3: Under what condition is flux passing through a surface:
(i) maximum (ii) minimum?

Ans: (*i*) ***Condition for maximum flux***:
If a surface is perpendicular to the electric field, then "$\vec{E}$" will be parallel to the vector area "$\vec{\Delta A}$", so that angle between them is "θ=0°". Under this condition maximum number of lines of force will pass through it, ***in other words*** flux passing through it will be ***maximum***.

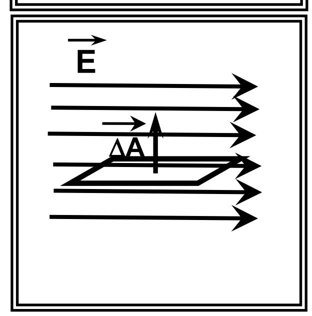


Magnitude of maximum flux passing through a surface is given by:

$$\Delta\phi = E\ \Delta A \text{ Cos } 0°$$

$$\Delta\phi = E\ \Delta A \qquad (\text{Con } 0° = 1)$$

(*ii*) If the surface is ***parallel*** to the electric field, then "$\vec{E}$" will be perpendicular to the vector area "$\vec{\Delta A}$", so that "θ = 90°". Under this condition no line of force will pass through the surface, ***in other words***, flux passing though the surface will ***zero***. This is the condition for ***minimum*** flux.



$$\Delta\phi = E\ \Delta A \text{ Cos } 90°$$

$$\Delta\phi = 0 \qquad (\text{Con } 90° = 0)$$

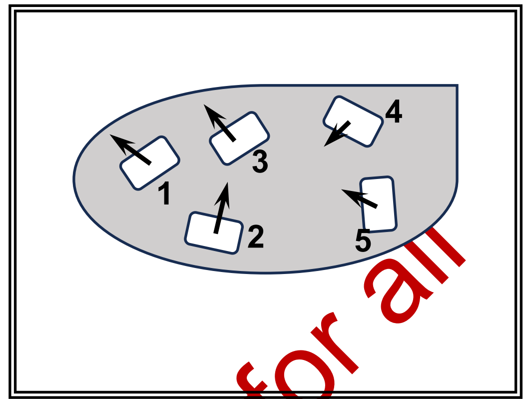
Electric flux through surface of any shape enclosing a charge:

By following these necessary steps electric flux passing through a closed surface of any geometrically regular or irregular shape can be determined:

Step 1: Divide the given surface into a large number of patches.

The process of dividing the surface into patches should be continued until each patch obtained must be ***plane*** in shape.

Step 2: Determine the electric flux through each patch.



Let
$$\Delta\phi_1 = (\vec{E} \cdot \vec{\Delta A})_1$$
$$\Delta\phi_2 = (\vec{E} \cdot \vec{\Delta A})_2$$
$$\Delta\phi_3 = (\vec{E} \cdot \vec{\Delta A})_3$$
$$\vdots$$
$\Delta\phi_n = (\vec{E} \cdot \vec{\Delta A})_n$ be the flux through 1st, 2nd, 3rd, …., n^{th} patch.

Step 3: Since electric flux is a **scalar** quantity, therefore, total flux through the given closed surface will be equal to the sum of flux through all the patches.

Hence, total flux "ϕ" through the surface having n patches is given by:

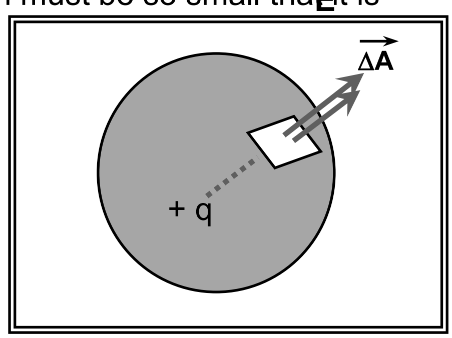
$$\phi = \sum_{i=n}^{i=1} \Delta\phi_n$$

OR
$$\phi = \sum_{i=n}^{n=1} (\vec{E} \cdot \vec{\Delta A})_n$$

$\sum_{i=n}^{n=1}$ is read as sigma i=1 to i=n. ***It means that*** the closed surface has been divided into "n" patches and to find the total flux "ϕ" add flux through patches number 1 to patch number n.

Q.No.4: ***Derive a formula for electric flux through the surface of a sphere due to a point charge "+q" at its center.***

Ans: Imagine a small positive point charge "+q" located at the center of a sphere of radius "r". To find the electric flux through the surface of a sphere, divide the surface into large number of small patches each of area "$\vec{\Delta A}$". Each patch must be so small that it is practically plane in shape, so that the direction of "$\vec{\Delta A}$" comes out to be the ***same*** at all points on a patch. Since the point charge is located at the center, lines of force will originate from the center of the sphere. ***In other words***, each patch will be perpendicular to the electric feild (i.e. to $\vec{E}$). Hence electric flux through each patch will be ***maximum*** and is given by:



$\Delta\phi = E\,\Delta A \cos 0°$ ($\vec{E}$ and $\vec{\Delta A}$ are parallel to each other)

$\Delta\phi = E\,\Delta A$

Since flux is a ***scalar quantity***, therefore, the total flux through the sphere will be equal to the sum of flux through individual patches.

Total flux through the sphere $\phi = \Sigma\, E\,\Delta A$

But the magnitude of electric intensity at the surface of the sphere due to a point charge "+q" at its center is given by:

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

$\therefore$ Total flux through the sphere $\phi = \Sigma \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}\Delta A$

Since each patch is at equal distance from the point charge "+q" therefore, $\vec{E}$ is same for all the patches and can be taken as common in the above summation.

$\therefore$ Total flux through the sphere $\phi = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}\Sigma.\Delta A$

But $\Sigma.\Delta A = 4\pi r^2$ = Total surface area of the sphere.

$\therefore$ Total flux through the sphere $\phi = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2} 4\pi r^2$

$$\therefore \quad \boxed{\phi = \frac{q}{\varepsilon_o}}$$

This formula shows that the electric flux through the surface of a sphere is independent of position of the point charge inside the sphere.

<u>Gauss's law</u>:

According to Gauss's law:

"Electric flux passing through any closed surface (of any shape) is 1/ε_o times the total charge enclosed by that closed surface".

Hence: $\phi = \frac{1}{\varepsilon_o} \times$ Total charge enclosed

$$\therefore \quad \boxed{\phi = \frac{q}{\varepsilon_o}}$$

<u>Electric potential</u>:

<u>Q.No.1</u>: Define potential difference between two points in an electric field.

<u>Ans</u>. Potential difference between two points in an electric field may be defined as:

"The amount of work done to move a positive test charge from one point to another divided by the magnitude of the test charge".

$$\text{Potential difference} = \frac{\text{Work done}}{\text{Test charge}}$$

$$\Delta V = \frac{\Delta U}{q_o}$$

Note that when work is done **<u>on</u>** a charge it **<u>gains</u>** electric P.E but when work is done **<u>by</u>** the charge it **<u>looses</u>** electric

OR ***"It is the change in potential energy per unit charge".***

Potential difference is a ***<u>scalar</u>*** quantity.

<u>Q.No.2</u>: Define S.I unit of potential difference.

<u>Ans</u>. The S.I unit of potential difference is ***<u>volt</u>***.

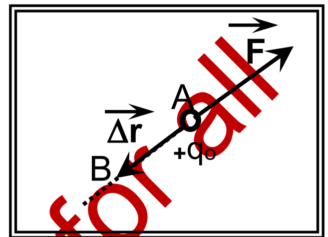
Potential difference between two points in an electric field is said to be one volt *(*1V*)* if one joule *(*1J*)* of work is done to move one coulomb (1 c) charge from one point to another.

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

Potential difference between two points:

Q.No.3: Derive an expression for potential difference between two points in an electric field.

Ans. If a small charge "$+q_o$" is moved from point "A" to another point "B" against the direction of electric field then work has to be done **on it**. Let "$\vec{\Delta r}$" be the displacement of charge "q_o" from point A to point B,



and $\vec{F}$ be the force on charge 'q_o' in the electric field, then the amount of work done (work is the dot product of $\vec{F}$ and $\vec{\Delta r}$) is given by

$$\Delta W = \vec{F} \cdot \vec{\Delta r}$$

But $\vec{F} = q_o \vec{E}$ where $\vec{E}$ is the electric intensity (or strength of electric field) throughout displacement $\vec{\Delta r}$.

$$\Delta W = q_o \vec{E} \cdot \vec{\Delta r}$$

This work done on 'q_o' is ***independent of the path followed***, it changes electrical potential energy of the charge. The change in electric potential energy "ΔU" (increase in P.E) of charge "$+q_o$" is equal to the amount of **work done on** it.

$$\Delta U = \Delta W$$

But $\Delta W = q_o \vec{E} \cdot \vec{\Delta r}$ $\therefore$ $\Delta U = q_o \vec{E} \cdot \vec{\Delta r}$

$$\therefore \quad \frac{\Delta U}{q_o} = \vec{E} \cdot \vec{\Delta r}$$

$\Delta U/q_o$ represents the **change in potential energy per unit charge** or the ***work done per unit charge***. But work done per unit charge is called **potential difference ΔV** between the two points A and B. $\therefore$

$$\boxed{\Delta V = \vec{E} \cdot \vec{\Delta r}}$$

Potential difference between two points is also the ***dot*** or ***scalar product*** of ***electric intensity $\vec{E}$*** and the ***displacement $\vec{\Delta r}$***.

Note that: This formula for calculating potential difference between two points ***is valid only when the electric field is uniform throughout the displacement "$\vec{\Delta r}$"***. Electric intensity between two given points may be uniform only through small displacements, hence this formula can be applied when the displacement $\vec{\Delta r}$ is ***small***.

Absolute potential:

Q.No.4: Define absolute potential at a point in an electric field.

Ans. Absolute potential at a point in an electric field may be defined as:

"The amount of work done per unit charge when the charge is moved from infinity to that point".

- The point at infinity is outside the electric field. Hence, it will be at zero potential (no work is done to move a test charge).

Absolute potential at a point in electric field due charge "q" (at distance "r" from the field producing charge "q") is given by::

$$\therefore \quad \boxed{V = \frac{1}{4\pi\varepsilon_o}\frac{q}{r}}$$

***Potential difference between any two points*:**

Potential difference between any two points in an electric field can also be determined by finding the difference in absolute potential at these points.

To find the potential difference between two points 1 and 2 in electric field produced by a charge "q" let the distance of each point from charge "q" be "r_1" and "r_2" respectively. Potential (absolute potential) at each point will be:

$$V_1 = \frac{1}{4\pi\varepsilon_o}\frac{q}{r_1} \qquad \text{and} \qquad V_2 = \frac{1}{4\pi\varepsilon_o}\frac{q}{r_2}$$

Hence the potential difference between these points is given by:

$$\boxed{\Delta V = V_2 - V_1 = \frac{q}{4\pi\varepsilon_o}\left\{\frac{1}{r_2} - \frac{1}{r_1}\right\}}$$

This is a general formula for finding potential difference between any two points in an electric field produced by a charge "q".

***Q.No.5*: Derive a relation between electric intensity E and potential difference ΔV. (2015 Karachi Board)**

Ans. Potential difference between two nearby points in an electric field is given by:

$$\Delta V = \vec{E} \cdot \Delta\vec{r}$$

$$\Delta V = E\,\Delta r \cos\theta$$

Where "θ" is the angle between the direction of electric field $\vec{E}$ and the direction of displacement $\Delta\vec{r}$. In this case θ = 180°, because the displacement $\Delta\vec{r}$ is opposite to the direction of electric field $\vec{E}$.

$$\therefore \quad \Delta V = E\,\Delta r \cos 180^\circ$$

$$\therefore \quad \Delta V = -E\,\Delta r$$

$$\therefore \quad \boxed{E = -\frac{\Delta V}{\Delta r}}$$

- ΔV/Δr is called the ***space rate of variation of potential*** between the points. The space rate of variation or the ***rate of change of potential with respect to distance*** is called "***potential gradient***". Hence,
  "***Electric intensity at a point is equal to the negative potential gradient at that point***".

This is also the relation between electric intensity E, potential difference ΔV and the distance Δr between the points.

- The above formula also gives "***volt/meter***" as the unit of electric intensity.
- ***Note that*** when a charge is moved ***against*** an electric field work has to be done ***on*** it and it ***gains*** potential energy but if it moves ***in the direction*** of a field work is done ***by*** it and therefore, it ***loses*** potential energy.

If a charge is free to move, then the positive charge moves from a point at ***higher*** potential to a point at ***lower*** potential, whereas a negative charge moves from a point at ***lower*** potential to a point at ***higher*** potential.

***Q.No.6*: Give a relation between kinetic energy and potential difference.**

***Ans*.** Since ,

$$\text{Potential difference } \Delta V = \frac{\Delta W}{q}$$

$$\Delta W = q\, \Delta V$$

Where ΔW is the work done, it is also equal to the change in potential energy ΔU. When a charge looses electrical potential energy it gains an equal amount of kinetic energy and vice versa. Hence if a charge is allowed to fall through (or accelerated by) a potential difference ΔV then it loses potential energy given by:

$$\Delta U = q\, \Delta V$$

At the same time, it will gain an equal amount of kinetic energy, given by:

$$\Delta U = \tfrac{1}{2}\, m\, v^2$$

In other words,

$$\boxed{\tfrac{1}{2}mv^2 = q\, \Delta V}$$

Electron volt:

***Q.No.7*: What is electron volt?**

***Ans*. "Electron volt"** is the unit of **energy** commonly used in atomic and nuclear physics.

"One electron volt (1ev.) is the amount of energy gained by an electron when it is accelerated through a potential difference of 1 volt".

Hence,

$\Delta V = 1$ volt, $q = e = 1.6021\times10^{-19}$ cool.

The kinetic energy gained by the electron is given by:

$$\tfrac{1}{2}mv^2 = q\, \Delta V$$

$$\tfrac{1}{2}mv^2 = 1.6021\times10^{-19}\times 1$$

$$\tfrac{1}{2}mv^2 = 1.6021\times10^{-19}\ \text{J}$$

$$\therefore \quad \boxed{1\ \text{ev.} = 1.6021\times10^{-19}\ \text{J}}$$

Similarly:

$1\ \text{Mev} = 10^{6}\ \text{ev}$

$1\ \text{Bev} = 10^{12}\ \text{ev}$

Section–A Multiple-Choice Questions MCQs:

Q.No.1: A 2 μC point charge is located at a distance "d" away from 6 μC point charge, what is the ratio of F_{12}/F_{21}?
(A) 1/3 (B) 3 (C) 1 (D) 12

Q.No.2: The minimum charge on an object cannot be less than:
(A) 1.6×10^{-19} C. (B) 3.2×10^{-19} C.
(C) 9.1×10^{9} C.
(D) No definite value exists

Q.No.3: Two charges are placed at a certain distance. If the magnitude of each charge is doubled the force will become:
(A) ¼th of its original value.
(B) 4 times its original value.
(C) 1/8th of its original value.
(D) 8 times its original value.

Q.No.4: Which of the following can be deflected while moving in the electric field?
(A) neutron. (B) photon.
(C) electron. (D) (A) and (B)

Q.No.5: The flux through a flat surface of area "**A**" in a uniform electric field "**E**" is maximum when the surface area is:
(A) Parallel to **E** (B) perpendicular to E
(C) placed 45°to **E** (D) placed 60° to **E**.

Q.No.6: The product of charge "q" and small separation "d" between two charges of same magnitude and opposite in nature is known as:
(A) Electric dipole. (B) Moment arm.
(C) Electric dipole moment.
(D) Flux of electric field.

Q.No.7: 12 J of work is to be done against an electric field to take a charge of 0.01 C from one point A to another point B. The potential difference between B and A is:
(A) 120 V. (B) 1200 V.
(C) 1.2 V. (D) 12 V.

Q.No.8: The force between two charges placed in air is F. If air is replaced by a medium of relative permittivity ε_r then force is reduced to:
(A) F ε_r (B) F / ε_r (C) ε_r / F (D) $\varepsilon\ \varepsilon_r$

Q.No.9: The negative gradient of potential is:
(A) potential energy. (B) voltage.
(C) electric field intensity. (D) electric flux.

Q.No.10: The electric flux through a plane area will be half of its maximum value when area is held at an angle of ……. With electric field.
(A) 30° (B) 60° (C) 45° (D) 90°

Q.No.11: The concept of electric lines of force was introduced by a famous scientist called: (***2006 Karachi Board***)
(A) Newton. (B) Einstein.
(C) Coulomb. (D) Faraday.

Q.No.12: Which of the following cannot be the unit of electric intensity?
(***2007 Karachi Board***)
(A) N/coulomb. (B) Volt/meter.
(C) Joule./ coul.-meter. (D) Joule/coulomb.

Q.No.13: Two positive point charges repel each other with a force of 4×10^{-4} N when placed at a distance of 1 meter. If the distance between them is increased to 2 m, the force of repulsion will be:
(***2008 Karachi Board***)
(A) 1×10^{-4} N. (B) 8×10^{-4} N.
(C) 2×10^{-4} N. (D) 4×10^{-4} N.

Q.No.14: The change in potential energy per unit charge between the two points in an electric field is called:
(***2009 Karachi Board***)
(A) Intensity. (B) Flux.
(C) Potential difference. (D) Permittivity.

Q.No.15: This is not a scalar quantity:
(***2018, 2014 Karachi board***)
(A) Electric flux. (B) Electric intensity.
(C) E.M.F. (D) Electric potential.

Q.No.16: The scalar product of electric intensity ($\vec{E}$) and vector area ($\Delta\vec{A}$) is called:
(***2019 Karachi Board***)
(A) electric flux. (B) electric force.
(C) electric potential.
(D) electric flux density

Q.No.17: Joule per coulomb is equal to:
(***2021, 2014, 2012 Karachi board***)
(A) Farad (B) Henry (C) Ampere (D) Volt

Q.No.18: When a dielectric is placed in an electric field, it becomes.
(***2021 Karachi Board***)

(A) Negatively charged only.
(B) Positively charged.
(C) Polarized (D) Conductive

Q.No.19: If the separation of two positive charges is halved then electrostatic force of repulsion becomes:
(***2021,2015, 2007 Karachi Board***)
(A) $\frac{1}{4}$ times. (B) $\frac{1}{2}$ times.
(C) 2 times. (D) 4 times.

Q.No.20: The unit of potential gradient is:
(***2023 Karachi Board***)
(A) Volt/meter. (B) Coulomb/meter.
(C) Volt/Ampere. (D) Volt × Ampere.

Q.No.21: The flux through an area "$\vec{A}$" in a uniform electric field "$\vec{E}$" is maximum when the angle between $\vec{E}$ and $\vec{A}$ is:
(***2025 Karachi Board***)
(A) 0° (B) 30° (C) 60° (D) 90°

Q.No.22: Coulomb's force in dielectric medium is less than in vacuum, due to:
(***2026 Karachi Board***)
(A) Ionization. (B) Electric polarization.
(C) Magnetization. (D) Superposition

Q.No.23: The S.I unit of electric current is:
(***2026 Karachi Board***)
(A) Volt. (B) Ampere.
(C) Coulomb. (D) Ohmn

***Answers**:*

(1) (C) 1
(2) (A) 1.6×10^{-19} C.
(3) (B) 4 times its original value.
(4) (C) electron.
(5) (A) Parallel to **E**
(6) (C) Electric dipole moment.
(7) (B) 1200 V.
(8) (B) F / ε_r
(9) (C) electric field intensity.
(10) (B) 60°
(11) (D) Faraday.
(12) (D) Joule/coulomb.
(13) (A) 1×10^{-4} N.
(14) (C) Potential difference
(15) (B) Electric intensity.
(16) (A) electric flux.
(17) (D) Volt
(18) (C) Polarized
(19) (D) 4 times
(20) (A) Volt/meter.
(21) (A) 0°.
(22) (B) Electric polarization.
(23) (B) Ampere.

Numericals:

Q.No.1: (a) Calculate the value of two equal charges if they repel one another with a force of 0.1 N when situated 50 cm apart in vacuum.

(b) What would be the size of charges if they were situated in an insulating liquid whose permittivity is ten times that of vacuum?

Data:

(a) Charges in vacuum $q_1 = q_2 = ?$

Force between charges $F = 0.1$ N

Distance between charges $r = 50$ cm. $= 0.5$ m

(b) Charges in insulating medium $q_1 = q_2 = ?$

Permittivity of medium $\varepsilon_r = 10\ \varepsilon_o$

Solution:

(a) Force between charges in vacuum is given by:

$$F = k\frac{q_1q_2}{r^2} \quad \left(k = \frac{1}{4\pi\varepsilon_o} = 9\times10^9 Nm^2/C^2\right)(q_1=q_2=q)$$

$$q^2 = \frac{F\,r^2}{k} = \frac{0.1\times(0.5)^2}{9\times10^9} = 2.778\times10^{-12}\ C^2$$

$q = \sqrt{2.778\times10^{-12}} =$ **1.667×10^{-6} C. OR $1.667\ \mu$C.**

Value of each charge in vacuum is **1.67×10^{-6} C**. or **$1.667\ \mu$C.**

(b) For an insulating medium (coulomb constant)

$$K = \frac{k}{\varepsilon_r} = \frac{9\times10^9}{10} = 9\times10^8 Nm^2/C^2$$

Force between charges in the medium:

$$F = K\frac{q^2}{r^2}$$

$$\therefore \quad q^2 = \frac{F\,r^2}{K} = \frac{0.1\times(0.5)^2}{9\times10^8} = 2.778\times10^{-11}\ C^2$$

$q = \sqrt{2.778\times10^{-11}} =$ **5.271×10^{-6} C.**

OR $5.271\ \mu$C.

Value of each charge in an insulating medium is **5.271×10^{-6} C**. or **$5.271\ \mu$C.**

Q.No.2: How far apart must two protons be if the magnitude of electrostatic force acting on either one due to the other is equal to the magnitude of gravitational force on a proton at Earth's surface?

(Mass of proton $= 1.67\times10^{-27}$ Kg.
charge on proton $= 1.6\times10^{-19}$ C)

Data:

Distance between proton $r = ?$

Mass of proton $m = 1.67\times10^{-27}$ Kg.

Charge on proton $e = 1.6\times10^{-19}$ C

Electrostatic force on either = Gravitational force on a proton at earth surface is equal to its weight mg.

Solution:

Electrostatic force between protons $F = \frac{K\,e^2}{r^2}$

$$F = \frac{9\times10^9\,(1.6\times10^{-19})^2}{r^2} = \frac{2.304\times10^{-28}}{r^2}$$

Since: $F = m\,g$ (gravitational force)

$$\therefore \quad \frac{2.304\times10^{-28}}{r^2} = 1.67\times10^{-27}\times9.8$$

$$r^2 = \frac{2.304\times10^{-28}}{1.6366\times10^{-26}} = 0.014$$

$\therefore \quad r = \sqrt{0.014} =$ **0.119 m.**

Distance between protons is **0.119 m**

Q.No.3: An electron of charge 1.6×10^{-19} C is situated in a uniform electric field of intensity 1200 volt/cm. Find the force on it, it's acceleration and the time it takes to travel 2 cm. from rest.

(electronic mass $= 9.1\times10^{-31}$ kg)

Data:

Charge of electron $q = e = 1.6\times10^{-19}$ C.

Mass of electron $m = 9.1\times10^{-31}$ kg.

Electric intensity $E = 1200$ volt/cm.

$= 1200\times100$ V/m. $= 12\times10^4$ volt/m.

Force on electron $F = ?$

Acceleration of electron $a = ?$

Distance moved $S = 2$ cm. $= 0.02$ m

Initial velocity $v_i = 0$

Time taken $t = ?$

Solution:

Force on electron is given by:

$F = q\,E = 1.6\times10^{-19}\times12\times10^4$

$F =$ 1.92×10^{-14} N.

Since: $F = m\,a$ (Newton's second law).

$\therefore \quad 1.92\times10^{-14} = 9.1\times10^{-31}\times a$

$$a = \frac{1.92\times10^{-14}}{9.1\times10^{-31}} = \mathbf{2.11\times10^{16}\ m/s^2}.$$

Since: $S = v_i\,t + \frac{1}{2}\,a\,t^2$

$\therefore\quad 0.02 = 0 + \frac{1}{2} \times 2.11\times10^{16}\,t^2$

$$t^2 = \frac{0.02}{1.055\times10^{16}} = 1.8957\times10^{-18}$$

$$t = \sqrt{1.8957\times10^{-18}} = \mathbf{1.3769\times10^{-9}\ s}.$$

***Q.No.4*: An alpha particle (nucleus of helium atom) has a mass of 6.64×10^{-27} kg and a charge of 2e. What are the (a) magnitude and (b) direction of the electric field that will balance the gravitational force on the particle.**

***Data*:**

Mass of alpha particle $m = 6.64\times10^{-27}$ kg

charge of alpha particle $q = 2e$

$= 2\times1.6\times10^{-19}C = 3.2\times10^{-19}C$

Magnitude and direction of electric field =?

Electric force = gravitational force.

***Solution*:**

Since: Electric force = gravitational force.

$\therefore\quad qE = mg$

$$E = \frac{mg}{q} = \frac{6.64\times10^{-27}\times9.8}{3.2\times10^{-19}} = \mathbf{2.0335\times10^{-7}\,N/C}$$

Gravitational force is downward therefore, electric field must be **upward** so that it exerts an upward force on the alpha particle to balance the gravitational force acting it.

***Q.No.5*: A proton and an electron form two corners of an equilateral triangle of side length 2.0×10^{-6} m. What is the magnitude of net electric field due to these two particles produce at the third corner?**

***Data*:**

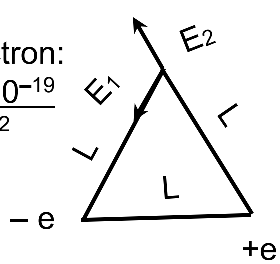
Charge of proton = Charge of electron = e

Length of each side of equilateral triangle

$L = 2.0\times10^{-6}$ m.

Magnitude of net electric field at third corner E=?

***Solution*:**



Electric field due to electron:

$$E_1 = k\frac{e}{L^2} = \frac{9\times10^9\times1.6\times10^{-19}}{(2.0\times10^{-6})^2}$$

$E_1 = \mathbf{360\ N/C.}$

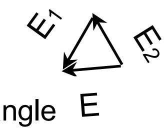
(Directed towards Electron, as shown)

Electric field due to proton:

$$E_2 = k\frac{e}{L^2} = \frac{9\times10^9\times1.6\times10^{-19}}{(2.0\times10^{-6})^2} = \mathbf{360\ N/C.}$$

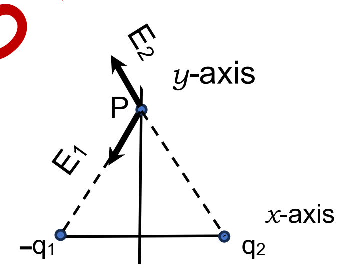
(Directed away from proton as shown)

Since the charges of equal magnitude are at the corners of an equilateral tringle (triangle of equal sides), therefore, all electric fields will also be equal in magnitude (as shown in vector diagram).



$\therefore$ Magnitude of net electric field at third side will also be **360 N/C.**

***Q.No.6*:** Figure shows two charged particles on x-axis $-q = -3.20\times10^{-19}$C at $x = -3.00$ m and $q = 3.20\times10^{-19}$ C at $x = 3.00$ m. What are the (a) magnitude and (b) direction (relative to the +direction of x-axis) of the net electric field produced at point P at y=4.00 m?



***Data*:**

Charge $q_1 = -3.20\times10^{-19}$ C.

Distance $x_1 = -3.00$ m.(along x-axis)

Charge $q_2 = 3.20\times10^{-19}$ C.

Distance $x_2 = 3.00$ m. (along x-axis)

Net electric field at point P E =?

Distance $y = 4.00$ m. (along y-axis)

***Solution*:**

Distance of q_1 from P (Pythagoras theorem)

$= \sqrt{(x_1)^2 + (y)^2} = \sqrt{(-3)^2 + (4)^2}$

$= \sqrt{9+16} = \sqrt{25} = \mathbf{5\ m.}$

Similarly distance of q_2 from P = **5 m.**

(a) Electric field due to q_1:

$$E_1 = k\frac{q_1}{5^2} = \frac{9\times10^9\times3.20\times10^{-19}}{25} = \mathbf{1.152\times10^{-10}\ N/C}$$

(E_1 is directed towards q_1 as shown)

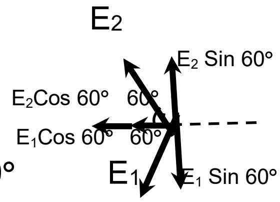
Electric field due to q_2:

$$E_2 = k\frac{q_2}{5^2} = \frac{9\times10^9\times3.20\times10^{-19}}{25} = \mathbf{1.152\times10^{-10}\ N/C}$$

(E_2 is directed **<u>away</u>** from q_2 as shown)

Net electric field (Electric intensity) at point P will be equal to the resultant of $\mathbf{E_1}$ and $\mathbf{E_2}$.

Resolving $\mathbf{E_1}$ and $\mathbf{E_2}$ into components we see that E_1 Sin 60° is cancelled by E_2 Sin 60°. (E_1 Sin 60° and E_2 Sin 60° are equal and opposite)



Hence the net electric field at point P will be:

$$E = E_1 \text{ Cos } 60° + E_2 \text{ Cos } 60°$$

(E_1 Cos 60° and E_2 Cos 60° are in the same direction)

$$E = 1.152\times10^{-10}\times0.5 + 1.152\times10^{-10}\times0.5$$

$$\mathbf{E = \underline{1.152\times10^{-10}\ N/C}}.$$

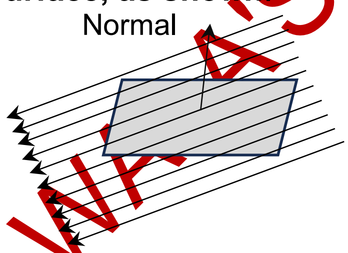
Net electric field **E** is directed along **<u>– x-axis</u>**.

***<u>Q.No.7</u>*: A proton and an electron form two corners of an equilateral triangle of side length 5 μm. What is the magnitude of net electric field these two particles produce at the third corner?**

***<u>Solution</u>*:**

See solution of Q.No.5.

***<u>Q.No.8</u>*: The square surface shown in fig, measures 3.2 mm on each side. It is immersed in a uniform electric field with magnitude E = 1800 N/C and with field lines at an angle of θ = 35° with a normal to the surface, as shown.**



Take that normal to be directed "outward" as though the surface were one face of a box. Calculate the electric flux through the surface.

***<u>Data</u>*:**

Length of each side L = 3.2 mm

$= 3.2\times10^{-3}$ m

Area of square A $= 3.2\times10^{-3}\times3.2\times10^{-3}\ m^2$

$= 1.024\times10^{-5}\ m^2$

(Vector area **A** is taken along the outward drawn normal to the surface)

Magnitude of electric field E = 1800 N/C

Angle with the normal = 35°

Angle between **E** and the normal (or **A**)

$\theta = 180 – 35 = 145°$

Electric flux ϕ =?

***<u>Solution</u>*:**

Electric flux through the surface is given by:

$$\phi = E\,A \text{ Cos } \theta$$

$$\phi = 1800 \times 1.024\times10^{-5} \text{ Cos } 145°$$

$$\phi = – \mathbf{\underline{1.51\times10^{-2}\ N\ m^2/C}}.$$

***<u>Q.No.9</u>*: An electron is liberated from the lower of two large parallel metal plates separated by a distance h = 2 cm. The upper plate has a potential of 2400 V relative to the lower. How long does the electron take to reach it?**

***<u>Data</u>*:**

Charge on electron e $= 1.6\times10^{-19}$ C

Mass of electron m $= 9.1\times10^{-31}$kg.

Separation of plates S = 2 cm.= 0.02 m

Potential difference V = 2400 volt.

Time taken t =?

Initial velocity of electron v_i =0

***<u>Solution</u>*:**

$F = q\,E$ and $E = V/d$

$$F = \frac{q\,V}{d} = \frac{1.6\times10^{-19}\times 2400}{0.02} = 1.92\times10^{-14}\ N$$

But F = ma (second law of motion)

$$1.92\times10^{-14} = 9.1\times10^{-31}\times a$$

$$a = \frac{1.92\times10^{-14}}{9.1\times10^{-31}} = 2.11\times10^{16}\ m/s^2.$$

Therefore, $S = v_i\,t + \frac{1}{2}\,a\,t^2$

$$0.02 = 0 + \tfrac{1}{2}\,2.11\times10^{16}\ t^2$$

$$t^2 = \frac{0.02}{1.055\times10^{16}} = 1.896\times10^{-18}\ .$$

$$\mathbf{\underline{t = 1.377\times10^{-9}\ s}}$$

Electron will take **<u>1.377×10⁻⁹ s</u>** to reach the upper plate.

***<u>Q.No.10</u>*: Two large parallel plates are 1.5 cm apart and have charges of equal magnitudes but opposite signs on their facing surfaces. Take the potential of the negative plate to be zero. If the potential half way**

between the plates is 5.0 V, What is the electric field in the region between the plates?

***Data*:**

Separation of plates d=1.5 cm =0.015m

Potential of negative plate V_1 =0

Potential half way V_2 = 5.0 volts.

Electric field E =?

***Solution*:**

Potential difference $\Delta V = V_2 - V_1$

$= 5 - 0 = 5$ volt

Distance of the point half between the plates where electric field is required

$$d = \frac{\text{Total separation of plates}}{2} = \frac{0.015}{2} = 0.0075 \text{ m}$$

Electric field in this region between the plates can be found by:

$\Delta V = E\,d$ OR $5 = E \times 0.0075$

$$E = \frac{5}{0.0075} = \underline{666.67 \text{ V/m.}}$$

***Q.No.11*: Two unequal point charges repel each other by a force of 10 newtons when they are 10 cm. apart. Find the force which they exert on each other when they are 1 cm apart. If the magnitude of one point charge is – 4.25×10⁻⁶ C, find the magnitude of the other. (*2018 Karachi Board*)**

***Data*:**

F_{10} = 10 N, d = 10 cm = 0.1 m

F_1 = ? when d = 1 cm = 0.01 m

$q_1 = -4.25\times10^{-6}$ C q_2 = ?

***Solution*:**

$$F_{10} = 9\times10^9 \frac{q_1\,q_2}{(0.1)^2}$$

$$10 = 9\times10^9 \frac{q_1\,q_2}{(0.1)^2}$$

$$q_1\,q_2 = \frac{10\times(0.1)^2}{9\times10^9} = 1.1111111\times10^{-11} \text{ C}^2$$

$$F_1 = 9\times10^9 \frac{q_1\,q_2}{(0.01)^2} \quad (q_1q_2 = 1.111111\times10^{-11} \text{ C}^2)$$

$$F_1 = 9\times10^9 \frac{1.11111111\times10^{-11}}{(0.01)^2} \boxed{=\mathbf{1000\ N.}}$$

Force between charges when they are 1 cm apart will be ***1000 N***.

(Distance between charges <u>decreases</u> by 10 times, therefore, force <u>increases</u> by 10^2 times Coulomb's law)

$q_1\,q_2 = 1.1111111\times10^{-11}$ C²

But $q_1 = -4.25\times10^{-6}$ C

∴ $-4.25\times10^{-6}\times q_2 = 1.1111111\times10^{-11}$

$$q_2 = \frac{1.1111111\times10^{-11}}{-4.25\times10^{-6}} \boxed{= \mathbf{-2.614\times10^{-6}C}}$$

Magnitude of the other charge is ***– 2.614×10⁻⁶C***.

***Q.No.12*: A charged particle of charge 2× 10⁻⁹ C, in an electric field between two parallel metal plates 4 cm. apart, is acted upon by a force of 10⁻⁴N.**

(a) What is the intensity of electric field?

(b) What is potential difference between the plates? (*2022 Karachi Board*)

***Data*:**

$q = 2\times10^{-9}$C, d = 4 cm.= 0.04 m $F = 10^{-4}$ N.

E =? V =?

***Solution*:**

(a) $E = \frac{F}{q} = \frac{10^{-4}}{2\times10^{-9}}$ $\boxed{\mathbf{E = 5\times10^4\ N/C}}$

(b) $V = E\,d = 5\times10^4\times0.04$ $\boxed{\mathbf{V = 2000\ volt.}}$

***Q.No.13*: A particle of charge 3.2×10⁻¹⁹ C and mass 2.48×10⁻²⁷ kg is held motionless between two horizontal parallel plates separated by 5 cm. Find the potential difference between the plates. (*2023, 16, 09 Karachi Board*)**

***Data*:**

Mass of particle $m = 2.48\times10^{-27}$kg

Charge of α-particle $q = 3.2\times10^{-19}$ C

Separation of plates d = 5 cm = 0.05 m

Potential difference between plates V = ?

***Solution*:**

Since particle is in equilibrium, therefore,

upward force F = down ward force mg

But $F = q\,E$ and $E = \frac{V}{d}$

∴ $q\frac{V}{d} = m\,g$

$$3.2\times10^{-19}\frac{V}{0.05} = 2.48\times10^{-27}\times 9.8$$

$$V = \frac{2.48\times10^{-27}\times9.8\times0.05}{3.2\times10^{-19}}$$

$$V = \frac{1.2152\times10^{-27}}{3.2\times10^{-19}}$$

$$\boxed{\mathbf{V = 3.8\times10^{-7}\ volt}}$$

Potential difference between the plates to make the particle motionless is ***3.8×10⁻⁷ volt.***

***Q.No. 14*: How many electrons should be removed from each of the two similar spheres each of 10 gm. so that the e.s. repulsion be balanced by gravitational force. (*2015,2010, 2006 Karachi Board*)**

Data:

Mass of each sphere m = 10 gm = 0.010 kg.
Charge on each electron $e = 1.6 \times 10^{-19}$ C.
No. of electrons to be removed from each sphere n =?

Solution:

On removing electrons from spheres each of them becomes positively charged and so they repel each other. In this case,

e.s. repulsion = Gravitational force

$$\frac{1}{4\pi\varepsilon_o}\frac{q\,q}{\cancel{r^2}} = G\frac{m\,m}{\cancel{r^2}}$$

$$9\times10^9 \times q^2 = 6.67\times10^{-11}\times0.010\times0.010$$

$$q^2 = 7.41\times10^{-25}$$

$$q = 8.609\times10^{-13}\ \text{Coulomb}$$

'q' is the charge on each sphere for which e.s. repulsion is balanced by gravitational attraction between the two spheres.

But $q = n\,e$

Where 'n' is the number of electrons and 'e' is the charge on each electron.

$$\therefore \quad n = \frac{q}{e} = \frac{8.609\times10^{-13}}{1.6\times10^{-19}}$$

$$\boxed{n = 5.38\times10^{6}\ \text{electrons}}$$

5.38 × 10⁶ electrons must be removed from each sphere so that e.s. repulsion between the spheres is balanced by gravitational force.

Q.No. 15: **Calculate the value of one of the two equal charges if they repel one another with a force of 0.1 N when situated 10 cm apart in vacuum.**

(***2026 Karachi Board***)

Solution: See solution of **Q. No. 1** of this chapter.

Microwave oven ....

Idea:

When a charged particle is subjected to an electric field it experiences a force. If the charged particle is free to move, then under the action of this force positively charged particle moves in the direction of force and negative particle moves opposite to it. If the electric field is alternating then the charged particle will *vibrate*, moving in one direction during a half cycle and in opposite direction during the next half cycle. It's frequency of vibration is same as the frequency of the alternating field. This is the basic idea on which working of a microwave oven is based.

Polarization of water molecule:

In a water molecule, because of higher electronegativity of oxygen, shared pair of electrons shifts slightly towards oxygen end. Thus a partial negative charge "−2δ" appears on oxygen and a partial positive charge "+δ" on each hydrogen atom in a water molecule. Like partial charge on two hydrogen atoms in a H_2O molecule repel each other, increasing the bond angle to about 104.5°. Thus each water molecule is said to be highly *polarized*.

Logic behind heating:

In a microwave oven alternating electric and magnetic fields, vibrating perpendicular to each other, is applied. Water molecules present in the food start vibrating due to alternating electric field, their K.E increases resulting in a rise in temperature, thus heating the food.

In microwave oven food is heated by a process called *dielectric heating*. Main difference between *ordinary heating* and *dielectric heating* is that in ordinary heating food is heated from *outside in*, whereas in dielectric heating it is heated *inside out*. For uniform heating throughout the body of food a rotating disc is also provided in a microwave oven.

In microwave oven food to be heated is placed in the middle on the rotating disc, it is then subjected to a beam of high powered resonating electromagnetic microwaves, produced by a device called *magnetron*.

Food having high water content can be heated quickly, cheaply and efficiently.