CHAPTER 12
ELECTROSTATICS

MULTIPLE CHOICE

1. **The number of electrons in one coulomb charge is:**
   A. 6.2×10^{18} B. 1.6×10^{-19}
   C. 6.2×10^{21} D. 1.6×10^{-27}
2. **The charge on electron was determined by:**
   A. Ampere B. Maxwell C. Millikan D. Bohr
3. **The relation $\frac{\Delta V}{\Delta r} = \frac{V}{d}$ represents.**
   A. P.D. B. Gauss's law
   C. electric intensity D. electric flux
4. **If atomic number of copper is 29 the contribution of electrons per atom in the block of copper will be:**
   A. One B. Two C. Three D. Zero
5. **If the distance between two charged bodies is halved, the force between them becomes:**
   A. Double B. Half
   C. Four times D. remains same
6. **The value of ε_r for various dielectrics is always:**
   A. Less than one B. Greater than one
   C. Equal to one D. Zero
7. **The unit of capacitance is.**
   A. coulomb B. farad C. joule D. watt
8. **The charge on an electron was measured by Millikan in.**
   A. 1880 B. 1789 C. 1909 D. 1921
9. **The intensity of electric field between two oppositely charged parallel plates close to each other is,**
   A. $\sigma \varepsilon_0$ B. $\frac{\sigma}{\varepsilon_0}$ C. $\frac{\sigma}{2\varepsilon_0}$ D. $\frac{2\sigma}{\varepsilon_0}$
10. **Electric field intensity at a point is defined by the equation,**
    A. $E = \frac{q}{F}$ B. $E = \frac{F}{q}$ C. $E = qF$ D. $E = \frac{q^2}{F}$
11. **If a charged body is moved against the electric field, it will gain**
    A. P.E. B. K.E.
    C. mechanical energy D. Electric P.E.
12. **The word "Xerography" means.**
    A. To take photograph B. Dry writing
    C. writing by machine D. To paint some thing

13. **In the xerographic machine the heart of the machine the drum is made of.**

A. ceramic B. semiconductor
C. strong plastic D. aluminium

14. **When current of one ampere is flowing across any cross-section of conductor in one second, the quantity of charge is:**

A. One coulomb B. Two coulomb
C. Three coulomb D. Half coulomb

15. **The force per unit charge is known as:**

A. Electric flux B. Electric intensity
C. Electric potential D. Electron volt

16. **An electric charge at rest produces:**

A. Only magnetic field B. Only electric field
C. Conservative field D. All above

17. **Gauss's law can only be applied to:**

A. Curved surface B. Flat surface
C. Closed surface D. Any surface

18. **Work done in bringing unit positive charge from infinity to that point in an electric field is:**

A. Potential difference B. Resistance
C. Capacitance D. Absolute potential

19. **The SI unit of electric flux is**

A. Nm^2C^{-1} B. $Nm\ C^{-1}$
C. Nm^2C D. $Nm^{-2}C^{1}$

20. **When area is held perpendicular to the field lines, then the magnitude of electric flux is**

A. Maximum B. Minimum
C. either A or B D. Negative

21. **Photocopier and inkjet printer are the applications of**

A. Electronics B. Electricity
C. Magnetism D. Electrostatics

22. **The expression for energy stored in a capacitor is given by**

A. $E = CV^2$ B. $E = \frac{1}{2}CV^2$
C. $E = \frac{1}{2}C^2V$ D. $E = \frac{1}{2}(CV)^2$

23. **A unit of electric charge is.**

A. volt B. Henry C. coulomb D. weber

24. **The value of $\frac{1}{4\pi\varepsilon_0}$ in $Nm\ C^{-2}$ is**

A. 9×10^9 B. 8×10^9
C. 9.1×10^9 D. 9×10^{19}

25. **The value of ε_r for transformer oil is.**

A. 2.0 B. 2.8 C. 2.1 D. 2.5

26. **The Coulomb's force in a medium of relative permittivity ε_r is given by:**

A. [illegible] B. $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}$

C. $F = \frac{1}{\varepsilon_0 \varepsilon_r}\frac{q_1 q_2}{r^2}$ D. F = [illegible]

27. **If an electron of charge "e" is accelerated through a potential difference V, it will acquire energy:**
A. Ve B. V/2 C. E/V D. Ve^2

28. **The earth's potential is considered as:**
A. Positive B. Negative C. Zero D. Infinite

29. **The absolute potential at a point distant 10cm from a charge of one μC is:**
A. $9 \times 10^2 V$ B. $9 \times 10^3 V$
C. $9 \times 10^4 V$ D. $9 \times 10^5 V$

30. **The value of ε_r for distilled water is:**
A. 78.0 B. 78.5 C. 80.0 D. 76.5

31. **The value of ε_r for Germanium is**
A. 15 B. 4.8 C. 17 D. 16

32. **A capacitor is a perfect insulator for:**
A. Direct current B. Alternating current
C. Both A & B D. Electric charge

33. **Coulomb/volt is called:**
A. Electron B. Farad C. Ampere D. Joule

34. **Due to electric polarization of dielectric, the capacity of a capacitor:**
A. Decreases B. Increases
C. Remains the same D. Becomes zero

35. **Photocopier and inkjet printer are application of:**
A. Magnetism B. Electricity
C. Electrostatics D. Thermo-electric effect

Answers:

1. A	2. C	3. C	4. A	5. C	6. B	7. B
8. C	9. B	10. B	11. D	12. B	13. D	14. A
15. B	16. B	17. C	18. D	19. A	20. A	21. B
22. B	23. C	24. A	25. C	26. A	27. A	28. C
29. C	30. B	31. D	32. A	33. B	34. B	35. C

SHORT & LONG QUESTIONS

Q1: State and explain Coulomb's law. Calculate the coulomb's force in (i) permittivity space ε_0 (ii) in a medium of relative permittivity ε_r?

Ans: Coulomb's law:

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

Mathematical form of Coulomb's law:

Coulomb's law mathematically expressed as

$$F \propto \frac{q_1 q_2}{r^2} \quad \text{or} \quad F = k\frac{q_1 q_2}{r^2}$$

C. $F = \frac{1}{\varepsilon_0 \varepsilon_r} \frac{q_1 q_2}{r^2}$ D. F = [illegible]

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Answers:

1. A	**2. C**	**3. C**	**4. A**	**5. C**	**6. B**	**7. B**
8. C	**9. B**	**10. B**	**11. D**	**12. B**	**13. D**	**14. A**
15. B	**16. B**	**17. C**	**18. D**	**19. A**	**20. A**	**21. B**
22. B	**23. C**	**24. A**	**25. C**	**26. A**	**27. A**	**28. C**
29. C	**30. B**	**31. D**	**32. A**	**33. B**	**34. B**	**35. C**

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If the medium between the two point charges is free space and the system of units is SI, then k is represented as

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

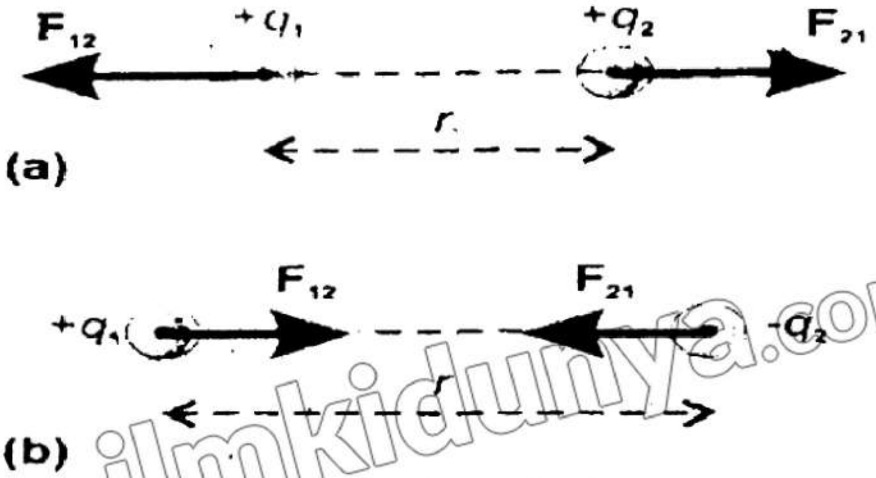
Where ε_0 is an electrical constant, known as permittivity of free space. In SI units, its value is $8.85 \times 10^{-12}\ Nm^2C^{-2}$. Substituting the value of ε_0 the constant

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

i. Coulomb's force in free space:

Thus Coulomb's force in free space is

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2} \quad \text{.........} \quad (1)$$



(a) Repulsive forces between like charges
(b) Attractive forces between unlike charges

ii. Vectorial form of coulomb's law:

If $\hat{r}_{21}$ is the unit vector directed from q_1 to q_2 and $\hat{r}_{12}$ is the unit vector directed from q_2 to q_1, then

$$F_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}\ \hat{r}_{21} \quad \text{..........} \quad (2)$$

and

$$F_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}\ \hat{r}_{12} \quad \text{........} \quad (3)$$

It can be seen that $\hat{r}_{21} = -\hat{r}_{12}$, so Eqs. Show that

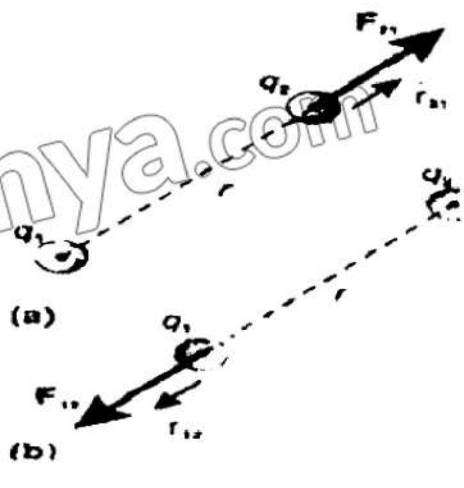
$$F_{21} = -F_{12}$$

Effect of medium between the two charges upon the Coulomb's force:

If the medium is an insulator, it is usually referred as dielectric. It has been found that the presence of a dielectric always reduces the electrostatic force as compared with that in free space by a certain factor which is a constant for the given dielectric. This constant is known as relative permittivity and is represented by ε_r.

iii. The Coulomb's force in a medium of relative permittivity ε_r is given by

$$F = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1q_2}{r^2}$$



Q2: Describe the values of relative permittivity of different dielectrics?

Ans: The values of relative permittivity of different dielectrics are given in Table.

Material	ε_r
Vacuum	1
Air (1 atm)	1.0006
Ammonia (liquid)	22 - 25
Bakelite	5 – 18
Benzene	2.284
Germanium	16
Glass	4.8 – 10
Mica	3 – 7.5
Paraffined paper	2
Plexiglas	3.40
Rubber	2.94
Teflon	2.1
Transformer oil	2.1
Water (distilled)	78.5

Q3: Which one reduces the Coulomb's force, transformer oil or distilled water?

Ans: Since

$$F = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1q_2}{r^2}$$

This relation shows that presence of relative permittivity (ε_r) as ε_r for transformer oil is 2.1 and for distilled water 78.5 therefore Coulomb's force is reduced by distilled water is more compared to transformer oil.

Q4: Write the names of basic force of nature?

Ans: Basic forces in nature are:

i. Gravitational force

ii. Electromagnetic force

iii. Strong force

iv. Weak nuclear force

Comparison of basic forces:

G.F	:	EF	:	WF	:	S.F
1	:	10^{38}	:	10^{26}	:	10^{40}

Note:

Strong force is responsible to hold the positively charged protons in the nucleus.

Q5: Describe the Michael Faraday concept of electric field?

Ans: To describe the mechanism by which electric force is transmitted, Michael Faraday (1791-1867) introduced the concept of an electric field. According to his theory, it is the intrinsic property of nature that an electric field exists in the space around an electric charge. This electric field is considered to be a force field that exerts a force on other charges placed in that field.

Q6: Determine the electric field intensity with the help of Coulomb's law?

Ans: The field of charge q interacts with q_0 to produce an electrical force. The interaction between q and q_0 is accomplished in two steps:

i. The charge q produces a field and

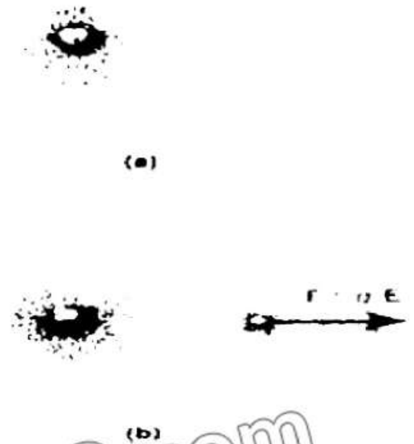
ii. The field interacts with charge q_0 to produce a force F on q_0.

We may define electric field strength or electric field intensity E at any point in the field as Force per unit charge.

$$E = \frac{F}{q_0} \qquad (1)$$

Unit:

It is measured in newton per coulomb in SI units. It is a vector quantity and its direction is the same as that of the force F.



(a) Dots surrounding the positive charge indicate the presence of the electric field. The density of the dots is proportional to the strength of the electric field at different points. (b) Interaction of the field with the charge q.

Electric intensity due to a point charge:

Let we place a positive test charge q_0 at this point. The Coulomb's force that this charge will experience due to q is

$$F = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r^2}\hat{r} \ldots\ldots\ldots\ldots (2)$$

Where $\hat{r}$ is a unit vector directed from the point charge q to the test point where q_0 has been placed, i.e. the point where the electric intensity is to be evaluated. By Eq. 1

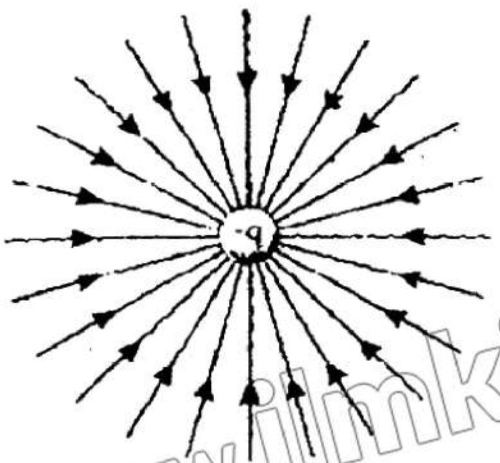
$$E = \frac{F}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r^2}\hat{r} \times \frac{1}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r} \qquad (3)$$

Q7: Define electrical field lines. Which type of information can be determined by these lines?

Ans: Electrical field lines:

The electric field lines "map" also provides information about the strength of the electric field.

i. Field lines are closer to each other near the charges where the field is strong while they continuously spread out indicating a continuous decrease in the field strength.

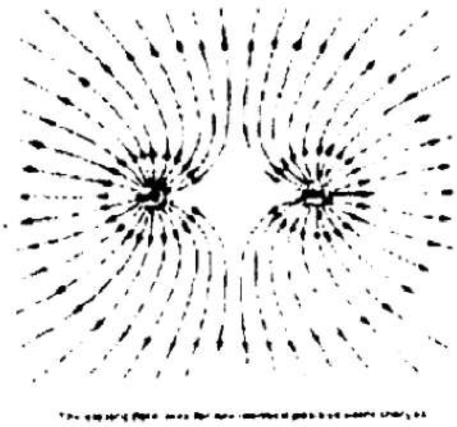


The electric field lines are directed radially inward towards a negative point charge -q.

ii. "The number of lines per unit area passing perpendicularly through an area is proportional to the magnitude of the electric field".

Q8: How can you find the electric field line for two identical charges?

Ans: **i.** The electric field lines are curved in case of two identical separated charges. Fig. shows the pattern of lines associated with two identical positive point charges of equal magnitude.



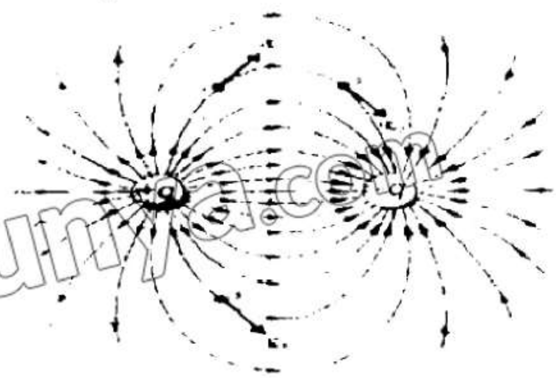
ii. It **reveals** that the lines in the region between two like charges seem to repel each other. The behaviour of two identical negatively charges will be exactly the same.

iii. Zero field spot or neutral zone:

The middle region shows the presence of a zero field spot or neutral zone.

Q9: Draw electric field pattern for unlike charges?

Ans: The Fig. shows the electric field pattern of two opposite charges of same magnitudes



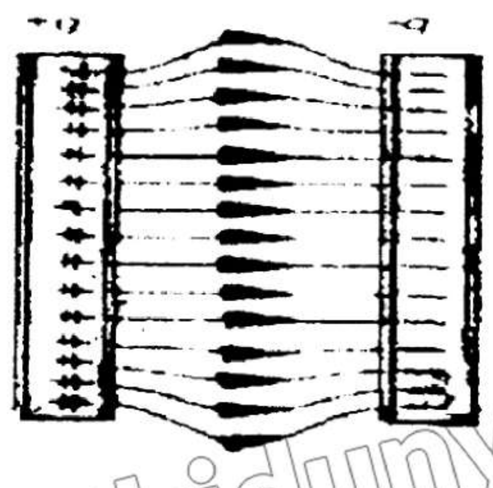
i. The field lines start from positive charge and end on a negative charge. The electric field at points such as 1, 2, 3 is the resultant of fields created by the two charges at these points.

ii. The directions of the resultant intensities are given by the tangents drawn to the field lines at these points

Q10: Draw electric field of lines for parallel plate capacitor?

Ans: Electric field of lines for parallel plate capacitor:

In the regions where the field lines are parallel and equally spaced, the same number of lines passes per unit area and therefore, field is uniform on all points



In the central region of a parallel plate capacitor the electric field lines are parallel and evenly spaced, indicating that the electric field there has the same magnitude and direction at all points

Fig shows the field lines between the plates of a parallel plate capacitor The field is uniform in the middle region where field lines are equally spaced

Q11: Write down the properties of electric field lines?

Ans: Properties of electric field lines:

1. Electric field lines originate from positive charges and end on negative charges.
2. The tangent to a field line at any point gives the direction of the electric field at that point.
3. The lines are closer where the field is strong and the lines are farther apart where the field is weak.
4. No two lines cross each other. This is because E has only one direction at any given point. If the lines cross, E could have more than one direction.

Q12: Enlist the applications of electrostatics?

Ans: Application of electro statistics:

i. Xerography or photocopier

ii. Inkjet printers

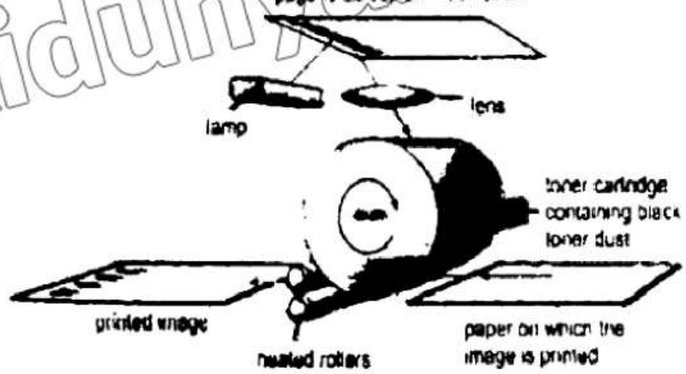
Q13:- Explain the process of Xerography or photocopier? OR Describe the construction and working of photocopier?

Ans: Xerography (photocopier):

The copying process is called xerography, from the Greek word "xeros" and "graphos", meaning "dry writing".

Construction:

The heart of machine is a drum which is an aluminium cylinder coated with a layer of selenium. Aluminium is an excellent conductor. On the other hand, selenium is an insulator in the dark and becomes a conductor when exposed to light; it is a photoconductor. As a result, if a positive charge is sprinkled over the selenium it will remain there as long as it remains in dark.



The basics of photocopying. The lamp transfers an image of the page to the drum, which leaves a static charge. The drum collects toner dust and transfers it to the paper The toner is melted onto the page.

Working:

If the drum is exposed to light, the electrons from aluminium pass through the conducting selenium and neutralize the positive charge.

Function of drum:

If the drum is exposed to an image of the document to be copied, the dark and light areas of the document produce corresponding areas on the drum. The dark areas retain their positive charge, but light areas become conducting, lose their positive charge and become neutral.

In this way, a positive charge image of the document remains on the selenium surface. Then a special dry, black powder called "toner" is given a negative charge and spread over the drum, where it sticks to the positive charged areas.

The toner from the drum is transferred on to a sheet of paper on which the document is to be copied.

Function of toner:

Heated pressure rollers then melt the toner into the paper which is also given an excess positive charge to produce the permanent impression of the document.

Q14: Describe the construction and working of inkjet printers?

Ans: Inkjet printers:

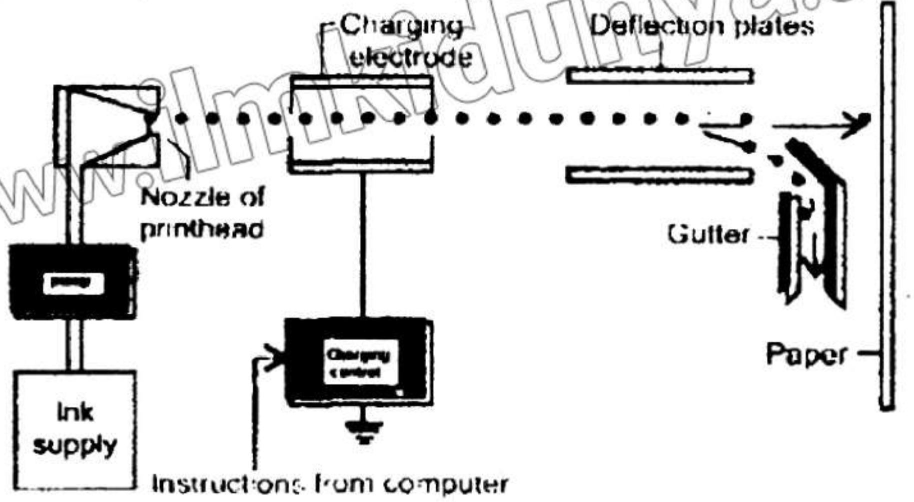
An inkjet printer is a type of printer which uses electric charge in its operation.

Construction and working of inkjet printers:

i. While shuttling back and forth across the paper, the inkjet printer "ejects" a thin stream of ink. The ink is forced out of a small nozzle and breaks up into extremely small droplets. During their flight, the droplets pass through two electrical components, a "charging electrode" i and the "deflection plates" (a parallel plate capacitor).

ii. When the printhead moves over regions of the paper which are not to be inked, the charging electrode is left on and gives the ink droplets a net charge. The deflection plates divert such charged drops into a gutter and in this way such drops are not able to reach the paper.

iii. Whenever ink is to be placed on the paper, the charging control, responding to computer, turns off the charging electrode. The uncharged droplets fly straight through the deflection plates and strike the paper.



Inkjet printers can also produce coloured copies.

Note:

An inkjet print head ejects a steady flow of ink droplets. The charging electrodes are used to charge the droplets that are not needed on the paper. Charged droplets are deflected into a gutter by the deflection plates, while unchanged droplets fly straight onto the paper.

Q15: Define electric flux (ϕ). Determine flux (ϕ) when

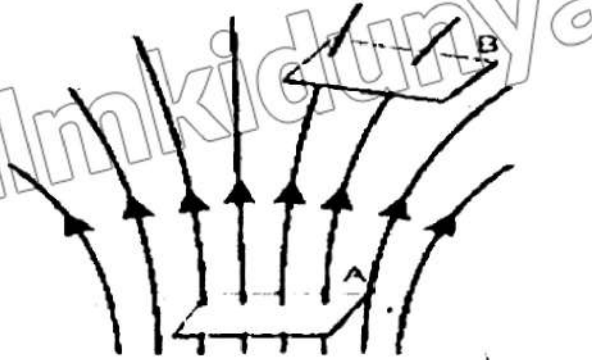
i. Area is held perpendicular to the field of lines.

ii. Area is held parallel to the field of lines.

iii. Area is neither perpendicular nor parallel to the field of lines?

Ans: Electric flux:

The number of the field lines passing through a certain element of area is known as electric flux through that area. It is usually denoted by Greek letter ϕ.



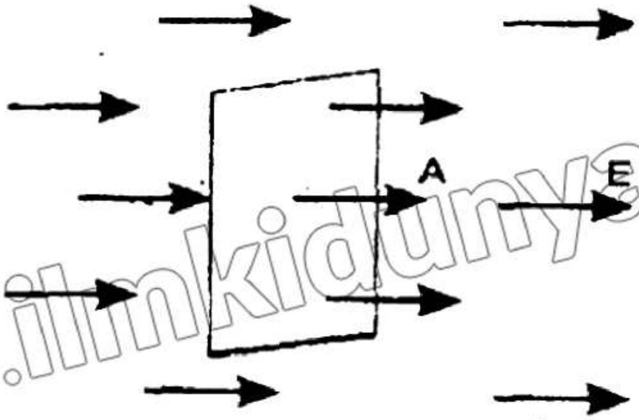
Electric flux through a surface normal to E.

Case I:

When area is held perpendicular to the field lines then $EA_{\perp}$ lines pass through it. The flux ϕ_e in this case is

$$\phi_e = EA_{\perp}$$

Where $A_{\perp}$ denotes that the area is held perpendicular to field lines.



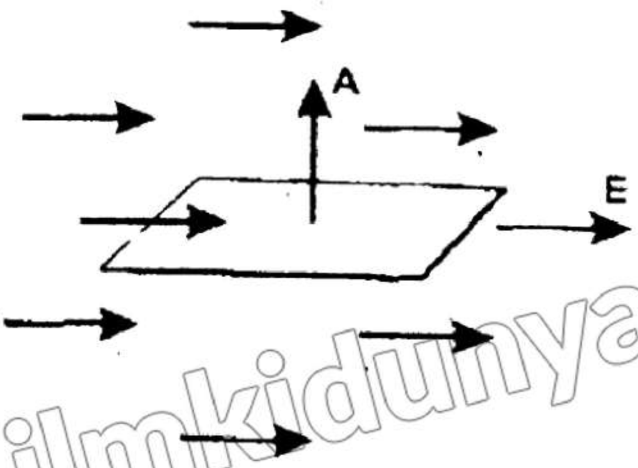
Maximum

Case II:

When area A is held parallel to field lines and as is obvious no lines cross this area, so that flux ϕ_e in this case is

$$\phi_e = EA_{\parallel} = 0$$

Where $A_{\parallel}$ indicates that A is held parallel to the field lines.



Minimum

Case III:

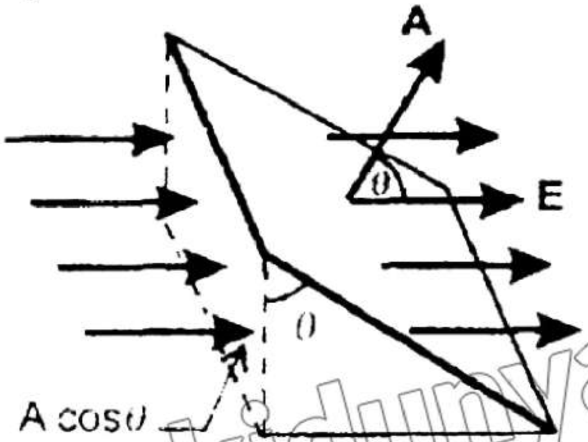
When A is neither perpendicular nor parallel to field lines but is inclined at angle θ with the lines. In this case we have to find the projection of the area which is perpendicular to the field lines. The area of the projection is $A\cos\theta$. The flux ϕ in this case is

$$\phi_e = EA_{\perp}\cos\theta$$

The electric flux ϕ_e through a patch of flat surface in terms of E and A is then given by

$$\phi_e = EA\cos\theta = \mathbf{E}.\mathbf{A}$$

Where θ is the angle between the field lines and the normal to the area.



Unit of electric flux (ϕ):

Electric flux being a scalar product, is a scalar quantity. Its SI unit is Nm^2C^{-1}

Q16: Show that flux through the closed surface (sphere) does not depend upon shake or geometry of the closed surface?

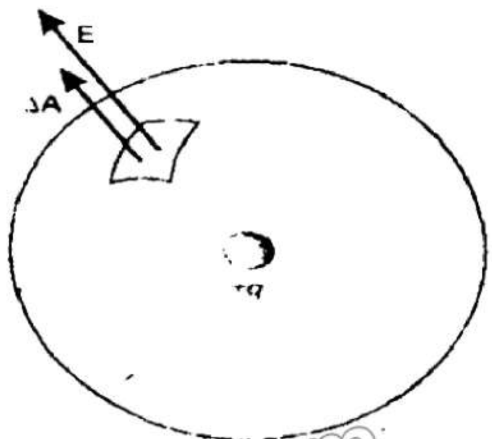
Ans: Electric flux through a surface enclosing a charge:

i. Let us calculate the electric flux through a closed surface, in shape of a sphere of radius r due to a point charge q placed at the centre of sphere.

ii. Total surface area of the sphere is divided into n small patches with areas of magnitudes $\Delta A_1, \Delta A_2, \Delta A_3 \ldots\ldots \Delta A_n$.

The corresponding vector areas are $\Delta \mathbf{A}_1$, $\Delta \mathbf{A}_2$, $\Delta \mathbf{A}_3$,..... $\Delta \mathbf{A}_n$ respectively. The direction of each vector area is along perpendicular drawn outward to the corresponding patch.

iii. The electric intensities at the centers of vector areas $\Delta \mathbf{A}_1$, $\Delta \mathbf{A}_2$, $\Delta \mathbf{A}_3$,..... $\Delta \mathbf{A}_n$ are E_1, E_2,........E_n respectively



The total electric flux through the surface of the sphere due to a charge q at its centre is q/ε_0.

iv. The total flux passing through the closed surface is

$$\phi_e = \mathbf{E}_1.\Delta\mathbf{A}_1 + \mathbf{E}_2.\Delta\mathbf{A}_2 + \mathbf{E}_3.\Delta\mathbf{A}_3 ..... + \mathbf{E}_n.\Delta\mathbf{A}_n \quad (1)$$

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

$$|E_1| = |E_2| = |E_3| = ... = |E_n| = E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} \quad (2)$$

$$\phi_e = E\Delta A_1 + E\Delta A_2 + E\Delta A_3 + \ldots\ldots + E\Delta A_n$$
$$= E \times (\Delta A_1 + \Delta A_2 + \Delta A_3 + \ldots\ldots + \Delta A_n)$$
$$= E \times \text{(total spherical surface area)}$$

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

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

$$\phi_e = \frac{q}{\varepsilon_0} \qquad (3)$$

Note:

So we can conclude that total flux through a closed surface does not depend upon the shape or geometry of the closed surface. It depends upon the medium and the charge enclosed.

Q17: State and prove Gauss's law?

Ans: Gauss's law:

"The flux through any closed surface is $1/\varepsilon_0$ times the total charge enclosed in it".

Explanation:

Suppose point charges $q_1, q_2, q_3, \ldots\ldots, q_n$ are arbitrarily distributed in an arbitrary shaped closed surface.

The electric flux passing through the closed surface is

$$\phi_e = \frac{q_1}{\varepsilon_0} + \frac{q_2}{\varepsilon_0} + \frac{q_3}{\varepsilon_0} + \ldots\ldots + \frac{q_n}{\varepsilon_0}$$

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

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

$$\phi_e = \frac{1}{\varepsilon_0} \times Q \qquad \ldots\ldots\ldots \qquad (1)$$

Where $Q = q_1 + q_2 + q_3 + \ldots\ldots + q_n$, is the total charge enclosed by closed surface.

Q18: Enlist the application of gauss's law?

Ans: Application of gauss's law:

i. Gauss s law is applied to calculate the electric intensity due to different charge configurations. In all such cases, an imaginary closed surface is considered which passes through the point at which the electric intensity is to be evaluated. This closed surface is known as **Gaussian surface**. Its choice is such that the flux through it can be easily evaluated.

ii. Charge enclosed by Gaussian surface is calculated and finally the electric intensity is computed by applying Gauss's law.

Q19: Illustrate intensity of field inside a hollow charged sphere by using Gauss's law?

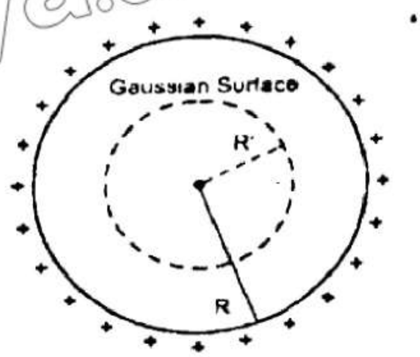
Ans: Intensity of field inside a hollow charged sphere:

i. Suppose that a hollow conducting sphere of radius R is given a positive charge q.

ii. Now imagine a sphere of radius $R' < R$ to be inscribed within the hollow charged sphere. The surface of this sphere is the Gaussian surface.

Applying Gaussian law, we have

$$\phi_e = \frac{q}{\varepsilon_0} = 0$$



Since $\phi_e = E.A = 0$ as $A \neq 0$,
therefore, $E = 0$

Note:

i. The interior of a hollow charged metal sphere is a **field free region**.

ii. As a consequence, any apparatus placed within a metal enclosure is "**shielded**" from electric fields.

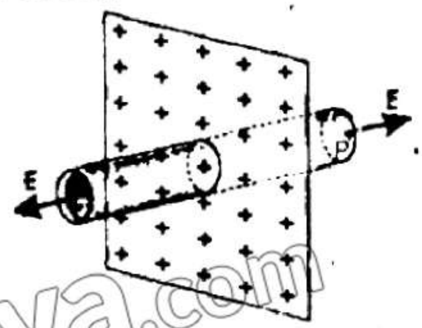
Q20: Illustrate electric intensity due to an infinite sheet of charge by using Gauss's law?

Ans: Electric intensity due to an infinite sheet of charge:

i. Suppose we have a plane sheet of infinite extent on which positive charges are uniformly distributed.

ii. The uniform surface charge density is, say, σ. A finite part of this sheet is shown in Fig.

iii. To calculate the electric intensity E at a point P, close to the sheet, imagine a closed Gaussian surface in the form of a cylinder passing through the sheet, whose one flat face contains point P.



The closed surface is in the form of a cylinder whose one face contains the point P at which electric intensity has to be determined.

iv. From symmetry we can conclude that E points at right angle to the end faces and away from the plane.

v. Since E is parallel to the curved surface of the cylinder, so there is no contribution to flux from the curved wall of the cylinder. While it will be, EA + EA = 2 EA, through the two flat end faces of the closed cylindrical surface, where *A* is the surface area of the flat faces.

vi. As the charge enclosed by the closed surface is σA, therefore, according to Gauss's law,

$$\phi_e = \frac{1}{\varepsilon_0} \times \text{charge enclosed by closed surface}$$

$$\phi_e = \frac{1}{\varepsilon_0} \times \sigma A \quad .... \quad (1)$$

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

or $E = \frac{\sigma}{2\varepsilon_0} A \quad .... \quad (2)$

In vector form, $E = \frac{\sigma}{2\varepsilon_0} \hat{r} \quad (3)$

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

Q21: Illustrate electric intensity between two oppositely charged parallel plates?

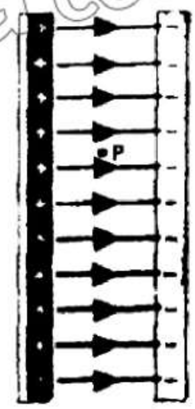
Ans: Electric intensity between two oppositely charged parallel plates:

i. Suppose that two parallel and closely spaced metal plates of infinite extent separated by vacuum are given opposite charges. Under these conditions the charges are essentially concentrated on the inner surfaces of the plates.

ii. The field lines which originate on positive charges on the inner face of one plate terminate on negative charges on the inner face of the other plate.

iii. The charges are uniformly distributed on the inner surface of the plate in a form of sheet of charges of surface density $\sigma = q/A$, where A is the area of plate and q is the amount of charge on either of the plates.

iv. Thus the total flux ϕ_e through the Gaussian surface is EA. The charge enclosed by the Gaussian surface is σA.



The lines of force between the plates are normal to the plates and are directed from the positive plate towards the negative one

v. Applying Gauss's law

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

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

or

$$E = \frac{\sigma}{\varepsilon_0} \qquad (1)$$

vi. The field intensity is the same at all points between the plates.

vii. The direction of field is from positive to negative plate because a unit positive charge anywhere between the plates would be repelled from positive and attracted to negative plate and these forces are in the same direction.

viii. In vector form

$$E = \frac{\sigma}{\varepsilon_0}\hat{r} \qquad (2)$$

Where $\hat{r}$ is a unit vector directed from positive to negative plate.

Q22: Why T.V and computers are enclosed within metal boxes?

Ans: To determine stray electric field interference, circuits of sensitive electronics devices such as T.V and computers are often enclosed within metal boxes to shield from electric fields.

Q23: Differentiate between potential difference and electric potential?

Ans: Potential difference:

i. The potential difference between two points A and B in an electric field is defined as the work done in carrying a unit positive charge from A to B while keeping the charge in equilibrium, that is,

$$\Delta V = V_B - V_A = \frac{W_{AB}}{q_0} = \frac{\Delta U}{q_0} \quad .... \quad (1)$$

Where V_A and V_B are defined electric potentials at point A and B respectively.

ii. Electric potential energy difference and electric potential difference between the points A and B are related as

$$\Delta U = q_0 \Delta V = W_{AB} \quad .... \quad (2)$$

Thus the potential difference between the two points can be defined as the difference of the potential energy per unit charge.

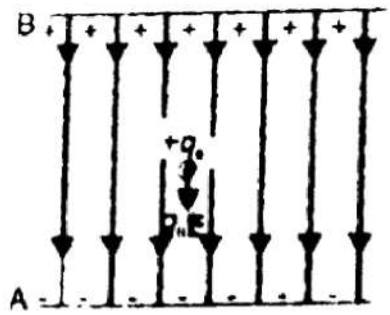
Unit of potential difference:

The unit of potential difference is joule per coulomb. It is called volt such that,

$$1 \text{ volt} = \frac{1\ joule}{1\ coulomb} \quad .... \quad (3)$$

Volt:

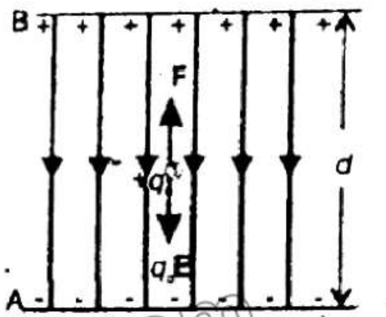
A potential difference of 1 volt exists between two points if work done in moving a unit positive charge from one point to other, keeping equilibrium, is one joule.



Electric potential:

i. In order to give a concept of electric potential at a point in an electric field, we must have a reference to which we assign zero electric potential. This point is usually taken at infinity. Thus in Eq. 1, if we take A to be at infinity and choose $V_A=0$, the electric potential at B will be $V_B=W_{\infty B}/q_0$ or dropping the subscripts.

$$V = \frac{W}{q_0} \qquad (4)$$



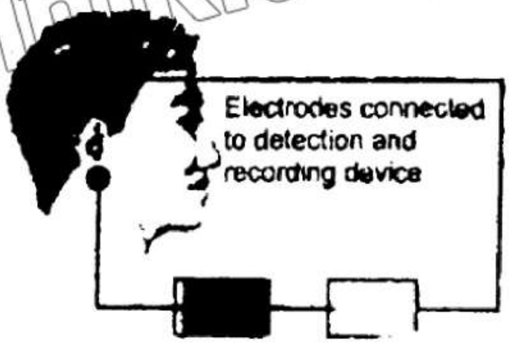
ii. The electric potential at any point in an electric field is equal to work done in bringing a unit positive charge from infinity to that point keeping it in equilibrium.

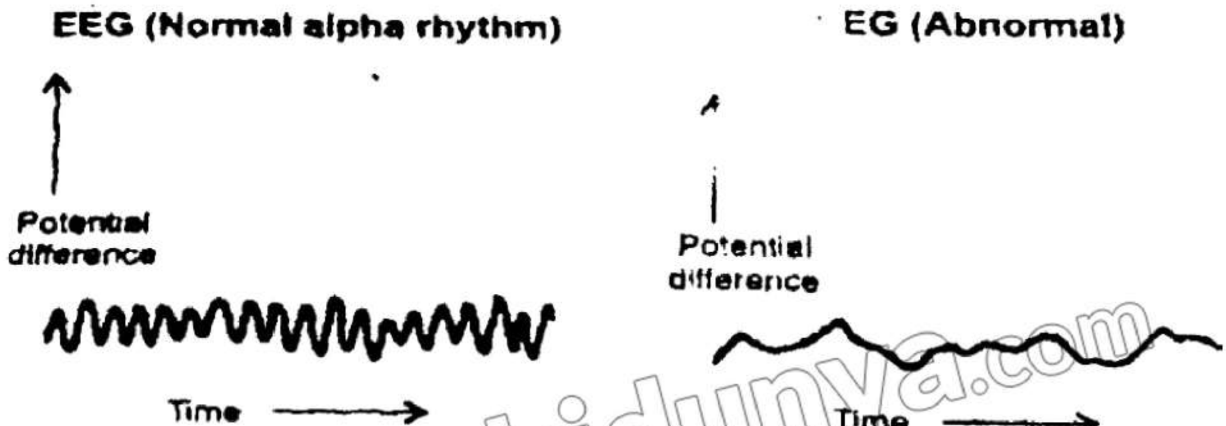
Note:

Both potential and potential differences are scalar quantities because both W and q_0 are scalars.

Q24: How EEG is used to detect abnormal behaviour of man?

Ans: In electroencephalography the potential differences created by the electrical activity of the brain are used for diagnosing abnormal behaviour.





Q25: What is a function of ECG?

Ans: An ECG records the "voltage" between points on human skin generated by electrical process in the heart. This ECG is made in running position providing information about the heart's performance under stress.

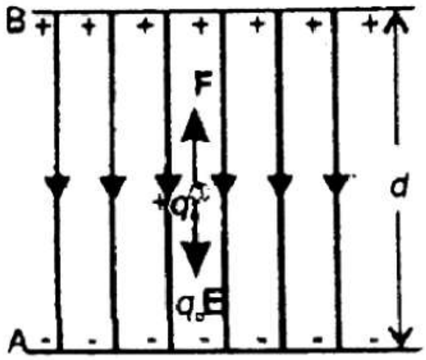
Q26: How will you establish the relation between potential difference (V) and electric intensity (E)?

OR

How electric field acts as potential gradient?

Ans: Electric field act as potential gradient:

Let electric field between the two charged plates is uniform, let its value be E. The potential difference between A and B is given by the equation



$$V_B - V_A = \frac{W_{AB}}{q_0} \quad .... \quad (1)$$

Where $W_{AB} = Fd = -q_0Ed$ (the negative sign is needed because F must be applied opposite to q_0E so as to keep it in equilibrium). With this, Eq. 1 becomes

$$V_B - V_A = -\frac{q_0Ed}{q_0} = -Ed$$

$$E = -\frac{(V_B - V_A)}{d} = -\frac{\Delta V}{d} \quad ..... \quad (2)$$

If the plates A & B are separated by infinitesimally small distance Δr, the Eq. 2 is modified as

$$E = -\frac{\Delta V}{\Delta r} \quad .... \quad (3)$$

Potential gradient:

The quantity $\frac{\Delta V}{\Delta r}$ gives the maximum value of the rate of change of potential with distance because the charge has been moved along a field line along which the distance Δr between the two plates is minimum. It is known as potential gradient. Thus the electric intensity is equal to the negative of the gradient of potential. The negative sign indicates that the direction of E is along the decreasing potential.

Q27: Show that $1\frac{V}{m} = NC^{-1}$? OR Convert volt/metre in terms of the unit of electric intensity (NC^{-1})?

Ans: The unit of electric intensity is volt/metre which is equal to NC^{-1} as shown below:

$$L.H.S = 1\frac{V}{m} = 1\frac{\text{volt}}{\text{metre}} = 1\frac{\text{joule/coulomb}}{\text{metre}}$$

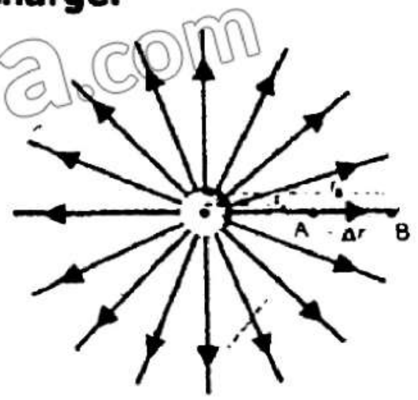
$$= 1\frac{\text{newton} \times \text{metre}}{\text{metre} \times \text{coulomb}} = 1\frac{\text{newton}}{\text{coulomb}} = NC^{-1}$$

Q28: Derive a relation for the absolute potential at a point due to a point charge?

Ans: Electrical potential at a point due to a point charge:

Case I:

i. Let us take two points A and B, infinitesimally close to each other, so that E remains almost constant between them.



ii. The distance of points A and B from q are r_A and r_B respectively and distance of midpoint of space interval between A and B is r from q. Then according to Fig.,

$$r_B = r_A + \Delta r \quad .... \quad (1)$$

$$\Delta r = r_B - r_A \quad (2)$$

iii. As 'r' represents midpoint of interval between A and B so

$$r = \frac{r_A + r_B}{2} \quad .... \quad (3)$$

iv. The magnitude of electric intensity at this point is,

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

v. As the points A and B are very close then, as a first approximation, we can take the arithmetic mean to be equal to geometric mean which gives

$$\frac{r}{r_A} = \frac{r_B}{r}$$

$$\left\{r_A, r, r_B \text{ are in G.M,} \quad \text{where common ratio} = \frac{2nd\ term}{1st\ term}\right\}$$

$$r^2 = r_A r_B \quad .... \quad (5)$$

Thus, Eq. 4 can be written as

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r_A r_B} \quad .... \quad (6)$$

Case II:

vi. Now, if a unit positive charge is moved from B to A, the work done is equal to the potential difference between A and B,

$$V_A - V_B = -E\,(r_A - r_B)$$

$$V_A - V_B = E\,(r_B - r_A)$$

Substituting value of E from Eq. 6,

$$V_A - V_B = \frac{q}{4\pi\varepsilon_0}\left(\frac{r_B - r_A}{r_B r_A}\right)$$

$$V_A - V_B = \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{r_A} - \frac{1}{r_B}\right)$$

To calculate absolute potential or potential at A, point B assumed to be infinity point so that $V_B = 0$ and hence

$$\frac{1}{r_B} = \frac{1}{r_\infty} = \frac{1}{\infty} = 0$$

This gives, $$V_A = \frac{1}{4\pi\varepsilon_0}\frac{q}{r_A}$$

vii. The general expression for electric potential V_r, at a distant r from q is,

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

Q29: Define electron volt and show that 1 eV = 1.6×10^{-19} J?

Ans: Electron volt:

The amount of energy equal to 1.6×10^{-19} J is called one electron-volt and is denoted by 1eV. It is defined as "the amount of energy acquired or lost by an electron as it traverses a potential difference of one volt". Thus,

$$1\ eV = 1.6 \times 10^{-19} J \quad .... \quad (1)$$

Derivation:

Suppose charge carried by the particle is $q = e = 1.6 \times 10^{-19}$ C.
Thus, in this case, the energy acquired by the charge will be

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

Moreover, assume that ΔV = 1 volt, hence

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

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

Thus $$1\ eV = 1.6 \times 10^{-19} J \quad ... \quad \text{Proved}$$

Q30: Illustrate the comparison of electric and gravitational forces?

Ans: Electric and gravitational forces (a comparison):

i. Gravitational force:

Gravitational force is a conservative force, that is, work done in such a field is independent of path.

ii. Electric force:

Coulomb's electrostatic force is also conservative force. The electric force between two charges $F = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$, is similar in form to the gravitational force between the two point masses, $F = G\frac{m_1 m_2}{r^2}$

iii. Similarity between gravitational and electric force:

Both forces vary inversely with the square of the distance between the two charges or the two masses.

iv. Dissimilarity between gravitational and electric force:

a. The value of gravitational constant G is very small as compared to electrical constant $\frac{1}{4\pi\varepsilon_0}$. It is because of this fact that the gravitational force is a very weak force as compared to electrostatic force.

b. As regards their qualitative aspect, the electrostatic force could be attractive or repulsive while, on the other hand, gravitational force is only attractive.

c. Another difference to be noted is that the electrostatic force is medium dependant and can be shielded while gravitational force lacks this property.

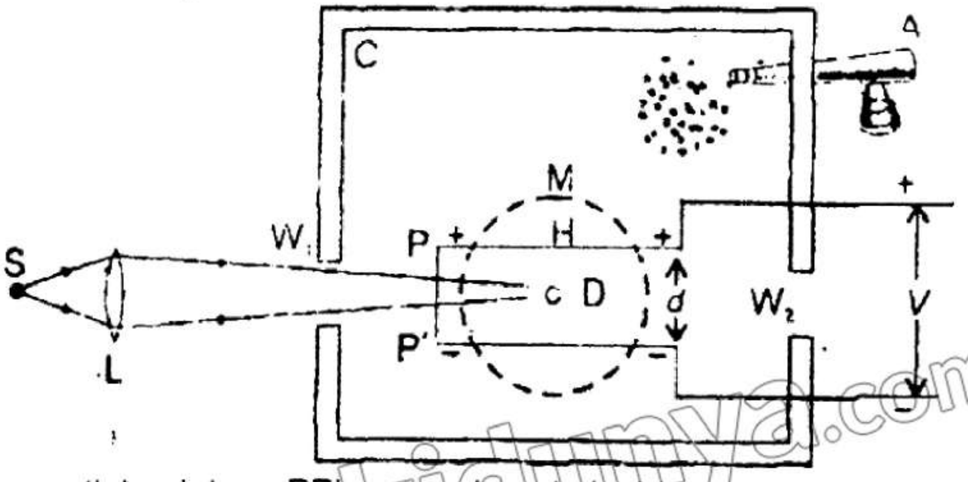
Q31: Briefly explain charge on an electron by Millikan's method?

Ans: Charge on an electron by Millikan's method:

In 1909, R.A Millikan devised a technique that resulted precise measurement of the charge on an electron.

Construction and working:

i. A schematic diagram of the Millikan oil drop experiment shown in Fig.



ii. Two parallel plates PP' are placed inside a container C, to avoid disturbances due to air currents. The separation between the plates is *d*.

iii. The upper plate P has a small hole H, as shown in the figure.

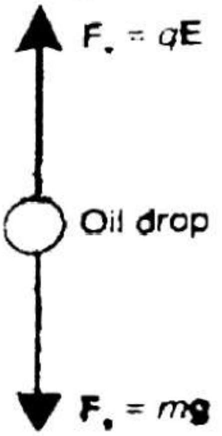
iv. A voltage V is applied to the plates due to which the electric field E setup between the plates. The magnitude of its value is $E = V/d$

v. An atomizer A is used for spraying oil drops into the container through a nozzle. The oil drop gets charged because of friction between walls of atomizer and oil drops. These oil drops are very small, and are actually in the form of mist. Some of these drops happen to pass through the hole in the upper plate

vi. The space between the plates is illuminated by the light coming from the source S through the lens L and window W_1. The path of motion of these drops can be carefully observed by a microscope M.

vii. 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 $F_e = qE$, as shown in Fig.

viii. The F_e can be adjusted equal to F_g by adjusting the voltage. In this case, we can write,



Oil drop balanced by the gravitational force and the Coulomb's law.

$$F_e = F_g$$

or

$$qE = mg \quad .... (1)$$

ix. Determination of the charge on electron:

If V is the value of p.d. between the plates for this setting, then

$$E = \frac{V}{d}$$

We may write from Eq. 1

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

$$q = \frac{mgd}{V} .... \quad (2)$$

x. Determination the mass 'm' of the droplet:

In order to determine the mass m of the droplet, the electric field between the plates is switched off. The droplet falls under the action of gravity through air. It attains terminal speed v, almost at the instant the electric field is switched off.
Its terminal speed v_t is determined by timing the fall of the droplet over a measured distance. Since the drag force F due to air acting upon the droplet when it is falling with constant terminal speed is equal to its weight. Hence, using Stokes's law

$$F = 6\pi\eta r v_t = mg$$

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

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

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

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

Note:

i. Knowing the value of r, the mass m can be calculated by using Eq. 3. This value of m is substituted in Eq. 2 to get the value of charge q on the droplet.

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

Q32: Briefly describe about capacitor and its capacitance?

Ans: Capacitor:

A capacitor is a device that can store charge.

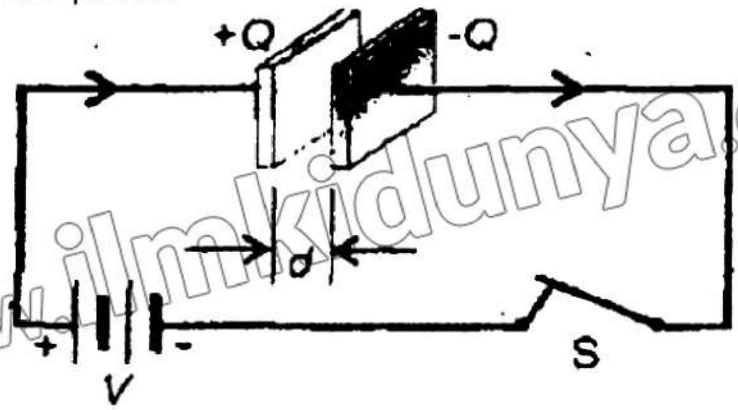
Construction:

Dielectric:

Capacitor consists of two conductors placed near one another separated by vacuum, air or any other insulator, known as dielectric. Usually the conductors are in the form of parallel plates, and the capacitor is known as parallel plate capacitor.

Working of capacitor:

i. When the plates of such a capacitor are connected to a battery of voltage V, it establishes a potential difference of V volts between the two plates and the battery places a charge +Q on the plate connected with its positive termini and a charge -Q on the other plate, connected to its negative terminal, let Q be the magnitude of the charge on either of the plates.



Capacitance of a capacitor:

It is a measure of the ability of capacitor to store charge.

The capacitance of a capacitor can be defined as the amount of charge on one plate necessary to raise the potential of that plate by one volt with respect to the other.

It is found that

$$Q \propto V \quad \text{or} \quad Q = CV \quad \text{or} \quad C = \frac{Q}{V} \ldots (1)$$

The proportionality constant C is called the capacitance of the capacitor.

Factors affecting capacitance of a capacitor:

Capacitance depends upon the geometry of the plates and the medium between them.

Unit of capacitance:

The SI unit of capacitance is coulomb per volt, which because of its frequent use, is commonly called farad (F), after the famous English scientist Faraday.

Farad:

"The capacitance of a capacitor is one farad if a charge of one coulomb, given to one of the plates of a parallel plate capacitor, produces a potential difference of one volt between them".

Note:

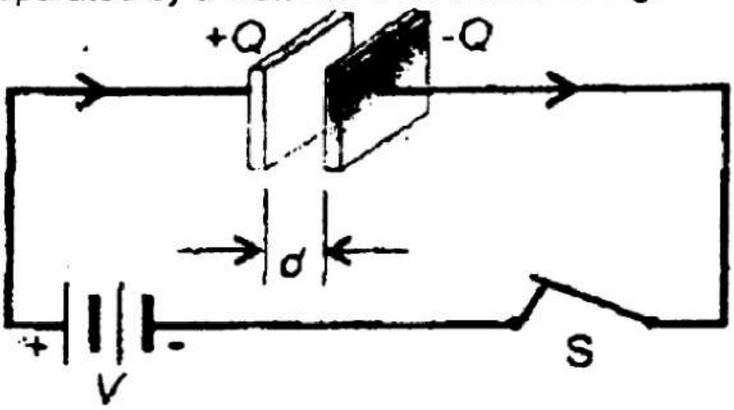
One farad is an enormous amount of capacitance. For practical purposes its sub-multiple units are used which are given below, 1 micro-farad 1 $\mu F = 10^{-6}$ farad

1 pico-farad = 1 pF = 10^{-12} farad

Q33: Derive a relation for capacitance of a parallel plate capacitor. Also calculate dielectric coefficient or dielectric constant?

Ans: capacitance of a parallel plate capacitor:

i. Consider a parallel plate capacitor consisting of two plane metal plates, each of area A, separated by a distance d as shown in Fig.



ii. The distance d is small so that the electric field E between the plates is uniform and confined almost entirely in the region between the plates.

iii. Let initially the medium between the plates be air or vacuum. Then

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

Where Q is the charge on the capacitor and V is the potential difference between the parallel plates.

iv. The magnitude E of electric intensity is related with the distance d by Eq. as

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

v. As Q is the charge on either of the plates of area A. the surface density of charge on the plates is as

$$\sigma = \frac{Q}{V}$$

vi. The electric intensity between two oppositely charged plates is given by $E = \frac{\sigma}{\varepsilon_0}$. Substituting the value of σ, we have

$$E = \frac{Q}{A\varepsilon_0} \quad \text{........} \quad (3)$$

By comparing Eq. 2 and 3 we get,

$$\frac{V}{d} = \frac{Q}{A\varepsilon_0} \quad \text{.........} \quad (4)$$

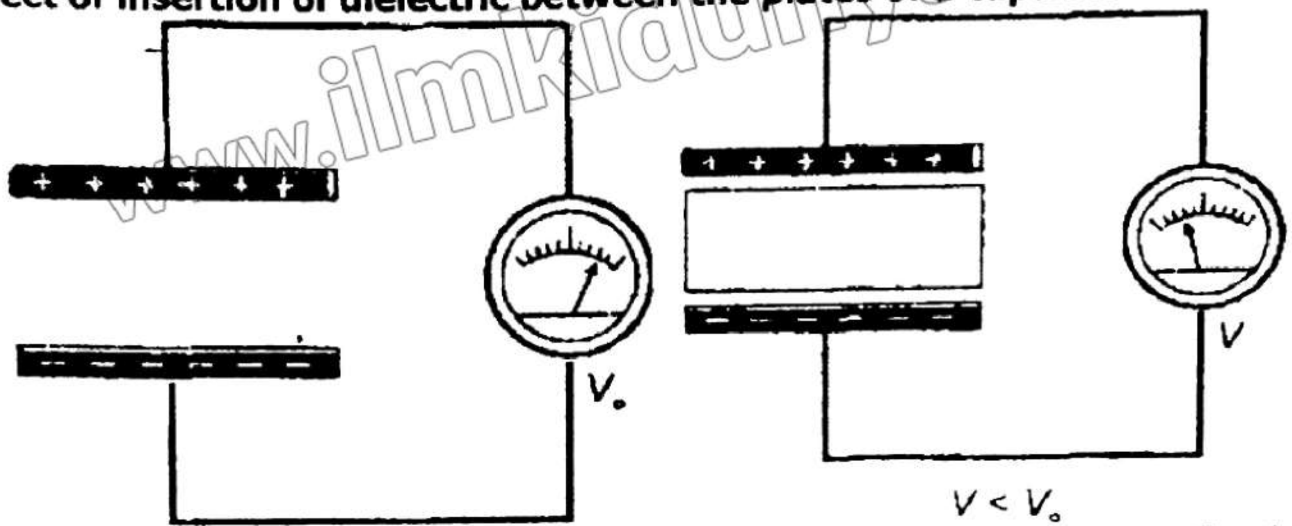
$$\frac{Q}{V} = \frac{A\varepsilon_0}{d}$$

By using Eq. 1 $\quad C_{vac} = \frac{A\varepsilon_0}{d} \quad \text{..........} \quad (5)$

Dielectric constant (ε_r):

If an insulating material, called dielectric, of relative permittivity ε_r is introduced between the plates, the capacitance of capacitor is enhanced by the factor ε_r. Capacitors commonly have some dielectric medium, thereby ε_r, is also called as dielectric constant.

Effect of insertion of dielectric between the plates of a capacitor:



Consider a charged capacitor whose plates are connected to a voltmeter. The deflection of the meter is a measure of the potential difference between the plates. When a dielectric material is inserted between the plates, reading drops indicating a decrease in the potential difference between the plates.

From the definition, C = Q/V, since V decreases while Q remains constant, the value of C increases. Then

$$C_{med} = \frac{A\varepsilon_0\varepsilon_r}{d} \qquad (6)$$

Eq. 5 shows the dependence of a capacitor upon the area of plates, the separation between the plates and medium between them.

Expression for dielectric constant (ε_r):

Dividing Eq. 6 by Eq. 5 we get expression for dielectric constant as,

$$\varepsilon_r = \frac{C_{med}}{C_{vac}} \ldots\ldots\ldots \qquad (7)$$

Dielectric co-efficient or dielectric constant (ε_r):

Dielectric co-efficient or dielectric constant 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 (or air) as medium between them."

Q34: Briefly explain the electric polarization of dielectrics?

Ans: Electric polarization of dielectrics:

The increase in the capacity of a capacitor due to presence of dielectric is due to electric polarization of dielectric.

Explanation:

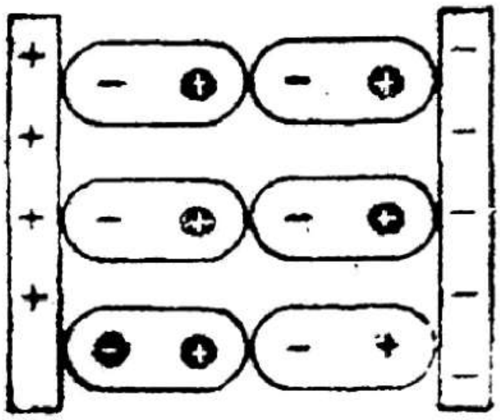
i. The dielectric consists of atoms and molecules which electrically neutral on the average, i.e., they contain equal amounts of negative and positive charges. The distribution of these charges in the atoms and molecules is such that the centre of the positive charge coincides with the centre of negative charge.

ii. When the molecules of dielectric are subjected to an electric field between the plates of a capacitor, the negative charges (electrons) are attracted towards the positively charged plate of the capacitor and the positive charges (nuclei) towards the negatively charged plate.

iii. The electrons in the dielectric (insulator) are not free to move but it is possible that the electrons and nuclei can undergo slight displacement when subjected to an electric field. As a result of this displacement the centre of positive and negative charges now no longer coincide with each other and one end of molecules shows a negative charge and the other end, an equal amount of positive charge but the molecule as a whole is still neutral.

iv. Two equal and opposite charges separated by a small distance are said to constitute a dipole. Thus the molecules of the dielectric under the action of electric field become dipoles and the dielectric is said to be polarized.

Effect of the polarization of dielectric:



i. The positively charged plate attracts the negative end of the molecular dipoles and the 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.

ii. Similarly the surface of the dielectric in contact with the negatively charged plate places a layer of positive charges. It effectively decreases the surface density of the charge a on the plates.

As the electric intensity E between the plates is $\frac{\sigma}{\varepsilon_0}$ so E decreases due to polarization of the dielectric. These results into a decrease of potential difference between the plates due to presence of dielectric.

Q35: Briefly describe how energy stored in a capacitor?

Ans: Energy stored in a capacitor:

i. A capacitor is a device to store charge. The charge on the plate possesses electrical potential energy which arises because work is to be done to deposit charge on the plates. This is due to the fact that with each small increment of charge being deposited during the charging process, the potential difference between the plates increases and a larger amount of work is needed to bring up next increment of charge.

ii. Initially when the capacitor is uncharged, the potential difference between plates is zero and finally it becomes V when q charge is deposited on each plate.

Thus, the average potential difference is $\frac{0+V}{2} = \frac{1}{2}V$

Therefore $\quad$ P.E. = Energy $= \frac{1}{2} q V$

Using the relation q = CV for capacitor we get

$$\textbf{Energy} = \frac{1}{2} CV^2 \quad \ldots\ldots \quad (1)$$

By substituting V = Ed and C $= \frac{A\varepsilon_0\varepsilon_r}{d}$ in Eq.1 we get,

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

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

As (Ad) is volume between the plates so

$$\text{Energy density} = \frac{Energy}{Volume} = \varepsilon_0\varepsilon_r E^2 \qquad (2)$$

Note:

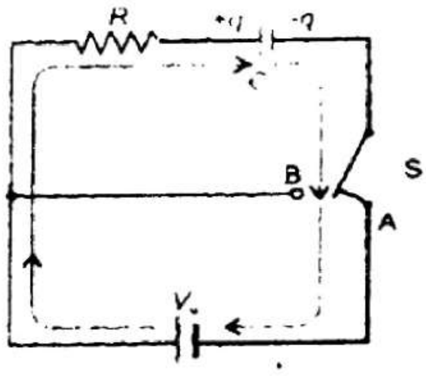
This equation is valid for any electric field strength.

Q36: Explain briefly charging and discharging process of a capacitor?

Ans: Charging of a capacitor:

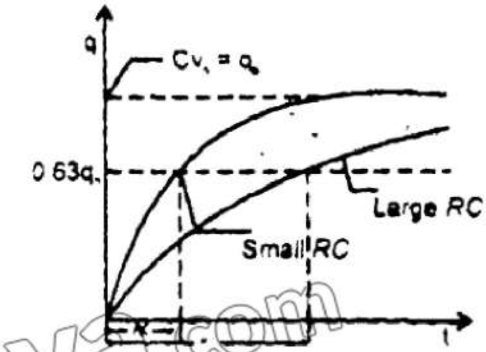
i. R-C circuit:

Many electric circuits consist of both capacitors and resistors. Fig. shows a resistor-capacitor circuit called R-C-circuit. When the switch S is set at terminal A, the R-C combination is connected to a battery of voltage V_0 whit starts charging the capacitor through the resistor *R*



Graphical explanation of charging of a capacitor:

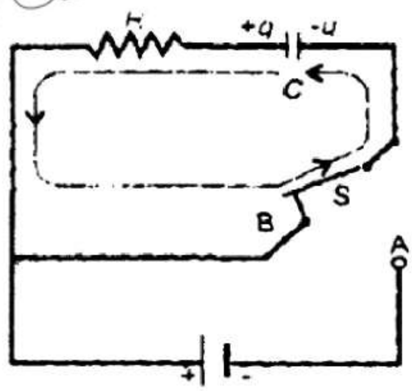
The capacitor is not charged immediately, rather charge build up gradually to the equilibrium value of $q_o = CV_0$. The growth of charge with time for different resistances is show in Fig.



According to this graph $q = 0$ at $t = 0$ and increases gradually with time till it reaches its equilibrium value $q_o = CV_0$. The voltage V across capacitor at any instant be obtained by dividing *q* by C, as V = q/C.

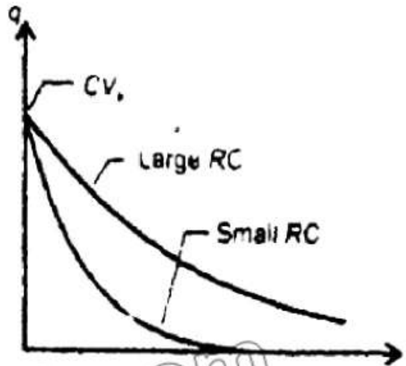
Time constant:

How fast or how slow the capacitor is charging or discharging, depends upon the product of the resistance R and the capacitance C used in the circuit. As the unit of product *RC* is that of time, so this product is known as time constant and is defined as the time required by the capacitor to deposit 0.63 times the equilibrium charge q_o. The graphs of Fig. show that the charge reaches its equilibrium value sooner when the time constant is small.



Discharging of a capacitor:

Fig. illustrates the discharging of a capacitor through a resistor. In this figure, the switch S is set at point B so the charge +q on the left plate can flow anti-clockwise through the resistance and neutralize the charge *-q* on *W* right plate.



Graphical explanation of discharging of a capacitor:

The graphs in Fig. shows that discharging begins at t = 0 when $q = CV_0$ and decreases gradually to zero. Smaller values of time constant *RC* lead to a more rapid discharge.

Application of charging/discharging of a capacitor:

Windshield wipers:

The charging/discharging of a capacitor enables some windshield wipers of cars to be used intermittently during a light drizzle. In this mode of operation the wipers remain off for a while and then turn on briefly. The timing of the on-off cycle is determined by the time constant of a resistor-capacitor combination.

SUMMARY

1. The Coulomb's law states that the force between two point charges is directly proportional to the product of the magnitudes of charges and inversely proportional to the square of the distance between them.
2. Electric field force per unit charge at a point is called electric field strength or electric field intensity at that point.
3. The number of the field lines passing through a certain element of area is known as electric flux through that area, denoted by ϕ.
4. The electric flux ϕ through a vector area A, in the electric field of intensity E is given by $\phi = E.A = EA\cos\theta$, where θ is the angle between the field lines and the normal to surface area.
5. Gauss's law is stated as "the flux through any closed surface is $1/\varepsilon_0$ times the total charge enclosed in it
6. The interior of a hollow charged metal sphere is a field free region.
7. The electric intensity between two oppositely charged parallel plates is $E = \frac{\sigma}{\varepsilon_0}$
8. The amount of work done in bringing a unit positive charge from infinity to a point against electric field is the electric potential at that point.
9. Capacitance of a capacitor is a measure of the ability of a capacitor to store charge.
10. The capacitance of a parallel plate capacitor is $C_{vac} = \frac{Q}{V} = \frac{A\varepsilon_0}{d}$.
11. The increase in the capacitance of a capacitor due to presence of dielectric is duet electric polarization of the dielectric.

SOLUTION OF EXERCISE

12.1. The potential is constant throughout a region of space. Is the electric field zero or non-zero in this region? Explain.

Ans: Since $E = K\frac{q}{r^2}$

If we move a unit positive charge from one point to other at infinity, no worth will be done, i.e., all the points at infinity will be at the same potential. Electric field intensity being inversely proportional to the square of distance is zero at infinity ($\because \frac{1}{0} = \infty$).

12.2. Suppose that you follow an electric field line due to a positive point charge. Do the electric field and electric potential increase or decrease?

Ans: Both electric field and electric potential will decrease. Since $E = K\frac{q}{r^2}$ and $V = K\frac{q}{r}$ clearly as we follow the field line due to positive charge we will move away (i.e. r increases because in case of positive point charge electric filed lines move outward) thus the values of electric field and electric potential will decrease.

SUMMARY

1. The Coulomb's law states that the force between two point charges is directly proportional to the product of the magnitudes of charges and inversely proportional to the square of the distance between them.
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12.3. How can you identify that which plate of a capacitor is positively charged?

Ans: Case 1.

Bring a positively charged object close to the plate if it is repelled the plate is positive otherwise not.

Case 2.

Bring the plate close to a positively charged electroscope if the leaves further diverge due to electrostatic induction it has positive charge otherwise not.

12.4. Describe a force or forces on a positive point charge placed between parallel plates

(a) With similar and equal charges

(b) With opposite and equal charges?

Ans: (a) In first case resultant force will be zero as it will be repelled by the plates with the same force which are equal and opposite.

(b) In second case resultant force will be two times the force of one plate as it will be repelled by one and attracted by the other plate. Net force on it will be from positive to negative plate.

12.5. Electric lines of force never cross each other. Why?

Ans: Electrical lines of force never cross because electric intensity has only one direction at any given point. If they cross, there will be two directions of electric force at one point which is not possible. Therefore, electric field lines will never cross each other.

12.6. If a point q of mass m is released in a non uniform electric field with field lines pointing in the same direction, will it make a rectilinear motion?

Ans: If the field is due to an isolated charge then charge will make a rectilinear motion. If the field is due to the combination of charges then the point charge will move along a curved path.

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

Ans: According to Gauss law

$$\phi_e = \frac{q}{\varepsilon_0} = 0$$

Since $\phi_e = E.A = 0$ as $A \neq 0$, therefore, $E = 0$

So at the centre the field must be zero due to spherical symmetry but anywhere else there might be some value of electric field due to polarization of the rubber balloon.

12.8. 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 it is true. Electric flux measures the number of electric field lines passing through a certain area. Also electric flux is directly proportional to charge enclosed. Hence 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.

12.9. Do electrons tend to go to the region of high potential or of low potential?

Ans: Electrons tend to go to the region of high potential. Because positive region to be at higher potential than a negative region, we can say electrons have tendency to go towards the region of high potential as electrons are negatively charged. Hence electrons will be attracted towards positive charge (high potential).

SOLUTION OF EXAMPLES

<u>Example 12.1:</u> Charges $q_1 = 100\ \mu C$ and $q_2 = 50\ \mu C$ are located in xy-plane at positions $\vec{r_1} = 3.0\ \hat{j}$ and $\vec{r_2} = 4.0\ \hat{i}$ respectively, where the distances are measured in meters. Calculate the force on q_2.

Solution:

$q_1 = 100\ \mu C = 100 \times 10^{-6}\ C$

$q_2 = 50\ \mu C = 50 \times 10^{-6}\ C$

Position of charge $q_1 = r_1 = 3.0\ \hat{j}$ m

Position of charge $q_2 = r_2 = 4.0\ \hat{i}$ m

The magnitude and direction of $\vec{F_{21}} = ?$

The position vector of charge q_2 with respect to q_1 is $\vec{r_{21}}$. Therefore,

$$\vec{r_{21}} = \vec{r_2} - \vec{r_1} \quad \text{.............. (1)}$$

Using value in equation we get,

$$\vec{r_{21}} = (4\hat{i} - 3\hat{j})\ m$$

Magnitude of $\vec{r_{21}} = r = \sqrt{16m^2 + 9m^2} = 5\ m$

Now by definition, $\hat{r_{21}} = \dfrac{\vec{r_{21}}}{r}$

$$\hat{r_{21}} = \frac{(4\hat{i} - 3\hat{j})m}{5m} = \frac{(4\hat{i} - 3\hat{j})}{5} \quad \text{.............. (2)}$$

Force on charge q_2 due to charge 'q_1' can be determined by using the formula,

$$\vec{F_{21}} = K\frac{q_1 q_2}{r^2}\hat{r}_{21} \quad \text{.............. (3)}$$

$$\vec{F_{21}} = \frac{9\times10^9 Nm^2C^{-2}\times100\times10^{-6}C\times50\times10^{-6}C}{25} \times \frac{4-3}{5}$$

or $\vec{F_{21}} = (1.44\hat{i} - 1.08\hat{j})N$

The magnitude of $\vec{F_{21}}$ can be written as,

$$F_{21} = F = \sqrt{(F_x)^2 + (F_y)^2} \quad \text{............ (4)}$$

The magnitude of $\vec{F_{21}}$ can be written as,

$$F_{21} = F = \sqrt{(1.44)^2 + (-1.08)^2} = 1.8N$$

Direction of $\vec{F_{21}} = \tan^{-1}\frac{F_y}{F_x}$ .... (5)

Now using the values in equation (5) we get,

Direction of $\vec{F_{21}} = \tan^{-1}(\frac{-1.08}{1.44})$

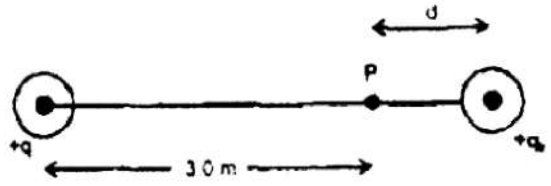
Direction of $\vec{F_{21}} = -37^0$ with x-axis

Example 12.2: **Two positive point charges $q_1 = 16.0\ \mu C$ and $q_2 = 4.0\ \mu C$ are separated by a distance of 3.0 m, as shown in the figure. Find the spot on the line joining the two charges where electric field is zero.**

Solution:

$q_1 = 16.0\ \mu C = 16.0 \times 10^{-6} C$

$q_2 = 4.0\ \mu C = 4.0 \times 10^{-6} C$



Distance between the charges = d = 3.0 m

Spot on the line where electric field is zero = ?

As the charges are similar, therefore, electric field would be zero at point 'P', where the magnitude of 'E_1' is equal to the magnitude of 'E_2'. i.e. $E_1 = E_2$

For Charge q_1

$$E_1 = \frac{1}{4\pi\varepsilon_0} \frac{q_1}{(3.0 - d)^2}$$

For Charge q_2

$$E_2 = \frac{1}{4\pi\varepsilon_0} \frac{q_2}{d^2}$$

As E_1 is equal to E_2, therefore we can equate above two formulae,

$$\frac{1}{4\pi\varepsilon_0} \frac{q_1}{(3.0 - d)^2} = \frac{1}{4\pi\varepsilon_0} \frac{q_2}{d^2}$$

$$\frac{q_1}{(3.0 - d)^2} = \frac{q_2}{d^2}$$

$$\frac{16.0 \times 10^{-6}}{(3.0 - d)^2} = \frac{4.0 \times 10^{-6}}{d^2}$$

$16.0d^2 = 4.0\,(3.0 - d)^2$

$16d^2 = 4(9 + d^2 - 6d) = 36 + 4d^2 - 24d$

$-4d^2 + 16d^2 + 24d - 36 = 0$

$12d^2 + 24d - 36 = 0 \Rightarrow 12(d^2 + 2d - 3) = 0 \Rightarrow d^2 + 2d - 3 = 0$

By factorizing, we get

$d^2 - d + 3d - 3 = 0 \Rightarrow d\,(d-1) + 3(d-1) = 0 \Rightarrow (d-1)(d+3) = 0$

After simplification, we have

$d = 1$ m or $d = -3$ m

We only consider +ve value of distance, because distance is always positive therefore d = 1m

Example 12.3: **Two opposite point charges, each of magnitude 'q' are separated by a distance 2d. What is the electric potential at a point 'P' mid-way between them?**

Solution:

Distance between the charges = 2d

Distance between their mid-point = d

$q_1 = -q$ and $q_2 = +q$

$r_1 = \frac{2d}{2} = d$ $\quad$ $r_2 = \frac{2d}{2} = d$

Electric potential = V = ?

We know that,

$$V^{+} = \frac{1}{4\pi\varepsilon_0}\frac{q}{d}$$

And $$V^{-} = -\frac{1}{4\pi\varepsilon_0}\frac{q}{d}$$

Electric potential at point 'P' due to both the charges is

$$V = V^{+} + V^{-}$$

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

$$V = 0$$

Hence electric potential at point 'P' due to two equal and opposite charges is zero i.e. V = 0

<u>Example 12.4:</u> A particle carrying a charge of 2e falls through a potential difference of 3.0V. Calculate the energy acquired by it.

Solution:

Charge carried = q = 2e

Potential difference = ΔV = 3

Energy acquired = $\Delta K.E.$ = ?

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

$\Delta K.E. = 2e \times 3.0V$

$\Delta K.E. = 6.0eV$

Since ($1eV = 1.6 \times 10^{-19}J$)

$\Delta K.E. = 6.0 \times 1.6 \times 10^{-19}J = 9.6 \times 10^{-19}J$

<u>Example 12.5:</u> In Millikan oil drop experiment, an oil drop of mass 4.9×10^{-15} kg is balanced and held stationary by the electric field between two parallel plates. If the potential difference between the plates is 750V and the spacing between them is 5.0mm, calculate the charge on the droplet. Assume $g=9.8ms^{-2}$.

Solution:

Mass of drop = m = 4.9×10^{-15} kg

Potential difference = V = 750 V

Spacing between plates = d = 5.0 mm

= 5.0×10^{-3}m (∵1mm =

Acceleration due to gravity = g = $9.8ms^{-2}$

Charge on the droplet = q = ?

The formula for electric force in terms of electric intensity is,

$$F = qE$$

But $$E = \frac{V}{d}$$

$$F = q\frac{V}{d}$$

The magnitude of this force must be equal to the weight i.e. mg so we can write,

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

$$q = \frac{4.9 \times 10^{-15} \times 9.8 \times 5.0 \times 10^{-3}}{750} = \frac{4.9 \times 9.8 \times 5.0 \times 10^{-15} \times 10^{-1}}{75}$$

$$q = 3.2 \times 10^{-19}C$$

Example 12.6: **The time constant of a series RC circuit is t=RC. Verify that an ohm times farad is equivalent to second.**

Solution:

By Ohm's law

$$V = IR$$

Also,

$$I = \frac{q}{t}$$

$$V = \frac{q}{t}R$$

$$R = \frac{Vt}{q} \quad \text{.......... (i)}$$

We know that

$$q = CV$$

Or

$$C = \frac{q}{V} \quad \text{(ii)}$$

Multiplying Eqs (i) and (ii), we have

$$RC = \frac{Vt}{q} \times \frac{q}{V} = t$$

$$RC = t$$

Since 1 ohm × 1 farad = 1 second

Hence proved

SOLUTION OF PROBLEMS

12.1 Compare magnitudes of electrical and gravitational forces exerted on an object (mass= 10.0g, charge = 20.0μC) by an identical object that i placed 10.0 cm from the first ($G = 6.67 \times 10^{-11}\ Nm^2kg^{-2}$)

Solution:

Mass = m = 10.0 g = 10×10^{-3} kg

Charge = q = 20.0 μC = 20×10^{-6}C

Distance = r = 10.0 cm = 0.1 m

$G = 6.67 \times 10^{-11} Nm^2kg^{-2}$

$K = 9 \times 10^{10} Nm^2C^{-2}$

$$\frac{F_e}{F_g} = ?$$

The formula for the electric force in case of identical charges is,

$$F_e = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2} \quad (1)$$

The formula for the gravitational force in case of identical masses is,

$$F_g = G\frac{m^2}{r^2} \quad (2)$$

Dividing equation (1) by (2) we get,

$$\frac{F_e}{F_g} = K\frac{q^2}{r^2} \times \frac{r^2}{Gm^2} = \frac{Kq^2}{Gm^2} \quad \text{.. (3)}$$

Using values in equation (3) we get,

$$\frac{F_e}{F_g} = \frac{9 \times 10^9 \times (20 \times 10^{-6})^2}{6.67 \times 10^{-11} \times (0.01)^2} = \frac{9 \times 10^9 \times 400 \times 10^{-12}}{6.67 \times 10^{-11} \times 1.0 \times 10^{-4}} = \frac{3600 \times 10^{9-12+11+4}}{6.67}$$

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Also,

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$$V = \frac{q}{t}R$$

$$R = \frac{Vt}{q} \quad \text{.......... (i)}$$

We know that

$$q = CV$$

Or

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$$RC = t$$

Since 1 ohm × 1 farad = 1 second

Hence proved.

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$G = 6.67\times 10^{-11} Nm^2kg^{-2}$

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$$\frac{F_e}{F_g} = ?$$

The formula for the electric force in case of identical charges is,

$$F_e = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2} \quad (1)$$

The formula for the gravitational force in case of identical masses is,

$$F_g = G\frac{m^2}{r^2} \quad (2)$$

Dividing equation (1) by (2) we get,

$$\frac{F_e}{F_g} = K\frac{q^2}{r^2} \times \frac{r^2}{Gm^2} = \frac{Kq^2}{Gm^2} \quad \text{.. (3)}$$

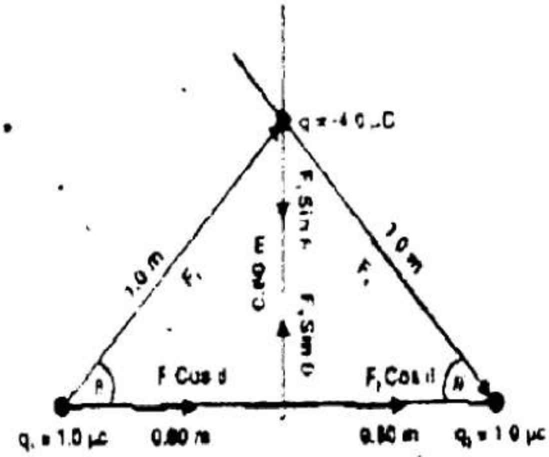
Using values in equation (3) we get,

$$\frac{F_e}{F_g} = \frac{9\times10^9\times(20\times10^{-6})^2}{6.67\times10^{-11}\times(0.01)^2} = \frac{9\times10^9\times400\times10^{-12}}{6.67\times10^{-11}\times1.0\times10^{-4}} = \frac{3600\times10^{9-12+11+4}}{6.67}$$

$$\frac{F_e}{F_g} = \frac{36\times10^{14}}{6.67} = 5.4\times10^{14}$$

12.2 Calculate vectorially the net electrostatic force on q as shown in the figure.

Solution:



From figure it is clear that the vertical components of electric forces cancel each other whereas horizontal components are in the same direction.

Hence the total force will be equal to the sum of only the horizontal components of the forces due to q_1 and q_2. So we can write,

$$F_{net} = F_1\cos\theta + F_2\cos\theta$$

As the magnitude of the charges q_1 and q_2 are equal therefore the magnitudes of the forces due to q_1 and q_2 will also be equal i.e.

$$F_1 = F_2 = F$$

So we can also write that,

$$F_{net} = F\cos\theta + F\cos\theta = 2F\cos\theta$$

In vector form we get,

$$F_{net} = 2F\cos\theta\,\hat{\imath} \quad .... (1)$$

The magnitude of F as follows,

$$F = F_1 = \frac{1}{4\pi\varepsilon_0}\frac{qq_1}{r^2}$$

$$F = \frac{9\times10^{9}\times4\times10^{-6}\times1\times10^{-6}}{(1)^2} = 36\times10^{-3}\text{ N}$$

Also from figure we get,

$$\cos\theta = \frac{0.6}{1} = 0.6$$

$$F_{net} = 2F\cos\theta\,\hat{\imath}$$

$$F_{net} = 2\times36\times10^{-3}\times0.6 = 43.2\times10^{-3}\,\hat{\imath} = 0.0432\,\hat{\imath}\text{ N}$$

12.3 A point charge q = -8.0 × 10^{-8}C is placed at the origin. Calculate electric field at a point 2.0 m from the origin on the z-axis.

Solution:

Charge = q = -8.0×10^{-8} C

Distance = r = 2 m

Position vector along z-axis = $\vec{r} = \hat{k}$

$\vec{E}$ = ?

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r^2}\times\hat{r} \quad .... (1)$$

Using values in equation (1) we get,

$$\vec{E} = [9\times10^{9}\times\frac{-8\times10^{-8}}{(2)^2}\times\hat{k}] = -18\times10\,\hat{k}\text{ NC}^{-1}$$

$$\vec{E} = (-1.80\times10^{2}\,\hat{k})\text{ NC}^{-1}$$

12.4 Determine the electric field at the position $r = (4\hat{i} + 3\hat{j})$ m caused by a point charge $q = 5.0 \times 10^{-6}$ C placed at origin.

Solution:

$$q = 5 \times 10^{-6}\ C$$

$$\vec{r} = 4\hat{i} + 3\hat{j} = \sqrt{(4)^2 + (3)^2} = 5\ m$$

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r^3} \times \vec{r} \quad \ldots\ldots\ldots (1)$$

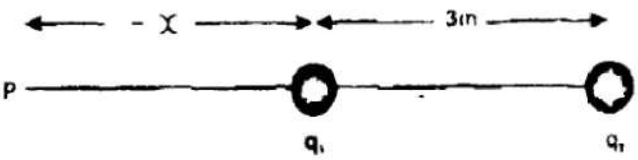
Using values in equation (1) we get,

$$\vec{E} = \frac{9\times10^9 \times 5\times10^{-6}}{(5)^3} \times (4\hat{i} + 3\hat{j}) = 360 \times (4\hat{i} + 3\hat{j})$$

$$\vec{E} = (1440\hat{i} + 1080\hat{j})\ NC^{-1}$$

12.5 Two point charges, $q_1 = -1.0 \times 10^{-6}$ C and $q_2 = +4.0 \times 10^{-6}$ C, are separated by a distance of 3.0 m. Find and justify the zero-field location.

Solution:



$$q_1 = -1 \times 10^{-6}\ C$$

$$q_2 = 4 \times 10^{-6}\ C$$

$$r_1 = 3\ m$$

$$r_2 = x + r_1$$

The distance of the point of zero field location with respect to

$$q_2 = x = ?$$

E_1 balances E_2 because both act in the opposite direction.

$$E_1 = E_2$$

$$\frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_1^2} = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_2^2}$$

$$\frac{q_1}{r_1^2} = \frac{q_2}{r_2^2}$$

$$\frac{q_1}{r_1^2} = \frac{q_2}{(x+r_1)^2}$$

Using values of q_1 and q_2, we get,

$$\frac{1\times10^{-6}}{r_1^2} = \frac{4\times10^{-6}}{(x+r_1)^2}$$

$$\frac{1}{r_1^2} = \frac{4}{(x+r_1)^2}$$

Taking square root of both sides,

$$\frac{1}{r_1} = \frac{2}{(x+r_1)}$$

$$x + r_1 = 2r_1$$

$$x = 2r_1 - r_1$$

$$x = r_1$$

Using the value of r_1, we get,

$$x = 3\ m$$

$$r_2 = 3\ m + 3\ m = 6\ m$$

Result:

Hence the zero field location exists at a distance of 3 m from q_1 and 6 m from q_2

Justification of the zero-filed location:

It is clear from the result that the zero field location exists at a point whose distance from q_2 is double than its distance from q_1. It is due to fact that the magnitude of q_2 is four times the magnitude of q_1. It is exactly in accordance with inverse square law

12.6 Find the electric field strength required to hold suspended a particle of mass 1.0 × 10^{-6} kg and charge 1.0 μC between two plates 10.0 cm apart.

Solution:

$m = 1.0 \times 10^{-6}$ kg

$q = 1.0 \times 10^{-6}$ kg

$d = 10$ cm $= 0.1$ m

The magnitude of electric force is given by

$$F = qE$$

And $W = mg$

In order to suspend the particle the magnitude of electric force must be equal but opposite to the weight of the particle.

$$qE = \frac{mg}{q} \qquad (1)$$

Using values in equation (1)

$$E = \frac{1.0\times10^{-6}\times9.8}{1.0\times10^{-6}} = 9.8\ NC^{-1} = 9.8\ V\,m^{-1}$$

12.7 A particle having a charge of 20 electrons on it falls through a potential difference of 100 volts. Calculate the energy acquired by it in electron volts (eV).

Solution:

Number of electron $= n = 20$

Charge of electron $= e = 1.6 \times 10^{-19}$C

$V = 100$V

Total charge = number of particles × charge on one particle

$$q = n \times e$$

Also the energy gained be a charge is equal to the product of the charge and the voltage across which it is moved so we can write

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

$$K.E = V \times n \times e \qquad (1)$$

Using the values in equation (1) we get

$$K.E = 100 \times 20 \times 1.6 \times 10^{-19} = 2000 \times 1.6 \times 10^{-19}J$$

Since $(1.6 \times 10^{-19}J = 1\ eV)$

$$K.E = \frac{2000\times1.6\times10^{-19}}{1.6\times10^{-19}}$$

$$K.E = 2000 = 2.0 \times 10^{3}\ eV$$

12.8 In Millikan's experiment, oil droplets are introduced into the space between two flat horizontal plates, 5 mm apart. The plate voltage is adjusted to exactly 780 V so that the droplet is held stationary. The plate voltage is switched off and the selected droplet is observed to fall a measured distance of 1.50 mm in 11.2 s. Given that the density of the oil used is 900 kg m^{-3}, and the viscosity of air at laboratory temperature is 1.80 × 10^{-5} N m^{-2} s, calculate.

(a) The mass, and

(b) The charge on the droplet (Assume g = 9.8 m s^{-2})

Solution:

Distance between the plates = $d = 5\text{ mm} = 5 \times 10^{-3}$ m

$V = 780$ volts

$S = 1.55 \times 10^{-3}$ m

$t = 11.2$ sec

$\eta = 1.8 \times 10^{-5}$ Nsm^{-2}

$\rho = 900$ kg m^{-3}

(a) $m = ?$ **(b)** $q = ?$

(a) The mass = m = ?

Since $v_t = \frac{S}{t}$

$$v_t = \frac{1.55\times10^{-3}}{11.2} = 0.1339 \times 10^{-3}\ ms^{-1}$$

Since $r = \sqrt{\frac{9\times\eta\times v_t}{2\rho g}}$

$$r = \sqrt{\frac{9\times\eta\times v_t}{2\rho g}} = \sqrt{\frac{9\times1.8\times10^{-5}\times0.1339\times10^{-3}}{2\times900\times9.8}} = 0.011 \times 10^{-4}\text{ m}$$

The mass of the droplet can be found by using the formula,

$$m = \frac{4}{3}\pi r^3 \times \rho$$

$$m = \frac{4}{3}3.142 \times (0.011\times10^{-4})^3 \times 900 = 5.01 \times 10^{-15}\text{ kg}$$

(b) The charge on the droplet (Assume g = 9.8 m s^{-2})

The value of charge on the particle is given as

$$q = \frac{mgd}{V}$$

$$q = \frac{5.018\times10^{-15}\times9.8\times5\times10^{-3}}{0.1339\times10^{-3}} = 3.2 \times 10^{-19}\text{ C}$$

12.9 A proton placed in a uniform electric field of 5000 NC^{-1} directed to right to allowed to go a distance of 10.0 cm from A to B. Calculate.

(a) Potential Difference between the two points.

(b) Work done by the field

(c) The change in P.E. of proton

(d) The change in K.E. of the proton

(e) Its velocity (mass of proton is 1.67×10^{-27}kg)

Solution:

$E = 5000$ NC^{-1}

$d = 10$ cm $= 0.10$ m

$m = 1.67 \times 10^{-27}$ kg

(a) Potential Difference = V = ?

(b) Work = W = ?

(c) Change in P.E of proton = ΔU = ?

(d) Change in K.E. of proton = ΔK.E = ?

(e) Velocity = v = ?

(a) Potential Difference between the two points.

Since $V = -Ed$

$$V = -5000 \times 0.10\text{ volt} = -500\text{ volts}$$

(b) Work done by the field

Since $W = V \times q$

$W = 500 \times 1.6 \times 10^{-19}$ J

Since $(1\text{ eV} = 1.6 \times 10^{-19}\text{ J})$

$W = \frac{500 \times 1.6 \times 10^{-19}}{1.6 \times 10^{-19}}$ eV

Work Done = W = 500 eV

(c) The change in P.E. of proton

Since $\Delta U = -W$

$\Delta U = -500$ eV

(d) The change in K.E. of the proton

When the charge moves along the field it will gain kinetic energy as it moves. The magnitude of this energy will be equal to decrease in the potential energy (or the work done by the charge). Due to increase in K.E. it will be written positive sign.

$\Delta K.E. = W$

$\Delta K.E. = 500$ eV

(e) Its velocity (mass of proton is 1.67×10^{-27}kg)

The formula for the kinetic energy in present case can be written as.

$$\Delta (K.E) = \frac{1}{2} mv^2$$

$$\frac{2 \times \Delta(K.E)}{m} = v^2$$

$$v = \sqrt{\frac{2 \times \Delta(K.E)}{m}}$$

$$V = \sqrt{\frac{2 \times 500 \times 1.6 \times 10^{-19}}{1.67 \times 10^{-27}}} = 3.097 \times 10^5 \text{ m s}^{-1}$$

12.10 Using zero reference point at infinity determine the amount by which: point charge of 4.0×10^{-8} C alters the electric potential at a point 1.2 n away, when

(a) Charge is positive **(b) Charge is negative**

Solution:

(a) Charge is positive

$q = 4.0 \times 10^{-8}$ C

$r = 1.2$m

$k = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$

As the proton will

$$\Delta V = k\frac{q}{r}$$

$$\Delta V = 9 \times 10^9 \times \frac{4.0 \times 10^{-8}}{1.2} = 300 \text{ volts}$$

$\Delta V = +3.0 \times 10^2$ volts

(b) Charge is negative

$q = -4.0 \times 10^{-8}$C

$r = 1.2$m

$k = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$

$$\Delta V = k\frac{q}{r}$$

$$\Delta V = 9 \times 10^9 \times \frac{-4.0 \times 10^{-8}}{1.2} = -300 \text{ volts}$$

$\Delta V = -3.0 \times 10^2$ volts

12.11 In Bohr's atomic model of hydrogen atom, the electron is in an orbit around the nuclear proton at a distance of 5.29×10^{-11} m with a speed of 2.18×106 ms^{-1} ($e = 1.60 \times 10^{-19}$ C, mass of electron $= 9.10 \times 10^{-31}$ kg). Find

(a) The electron potential that a proton exerts at this distance

(b) Total energy of the atom in eV

(c) The ionization energy for the atom in eV.

Solution:

$r = 5.29 \times 10^{-11} m$

$v = 2.18 \times 10^{6} ms^{-1}$

$e = 1.6 \times 10^{-31} C$

$m = 9.1 \times 10^{-31} Kg$

(a) Electron Potential $= V = ?$

(b) Total Energy in eV $= E = ?$

(c) Ionization Energy in eV $= E_I = ?$

(a) The electron potential that a proton exerts at this distance

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

Using values in the above formula, we get,

$$V = 9 \times 10^{9} \times \frac{1.6 \times 10^{-19}}{5.29 \times 10^{-11}} = 27.22 \text{ Volts } \textbf{Ans}$$

(b) Total energy of the atom in eV

According to Bohr's theory for hydrogen atom,

$$E = -\frac{Ke^2}{2r_n}$$

$$E = -\frac{9 \times 10^{9} \times (1.6 \times 10^{-19})^2}{2 \times 5.29 \times 10^{-11}} = -2.1777 \times 10^{-18} \text{ J}$$

Since $(1 \text{ eV} = 1.6 \times 10^{-19} \text{ J})$

$$E = \frac{-2.177 \times 10^{-18}}{1.6 \times 10^{-19}}$$

Total Energy $= E = -13.61$ eV

(c) The ionization energy for the atom in eV.

Since electron possesses -13.6 eV in the ground state of a hydrogen atom, therefore if we want to ionize a hydrogen atom then we must supply 13.6 eV energy by some external source or it must be accelerated through a potential difference of 13.6 V. Hence

Ionization energy = energy required by electron

Ionization energy $= E_I = 13.6$ eV.

12.12 The electron flash attachment for a camera contains a capacitor for storing the energy used to produce the flash. In one such unit, the potential difference between the plates of a 750μF capacitor is 330V. Determine the energy that is used to produce the flash.

Solution:

$C = 750\mu F = 750 \times 10^{-6} F$

$V = 330$ volts

Energy Stored in Capacitor $= E = ?$

Energy stored in a capacitor $= E = \frac{1}{2} CV^2$

$$E = \frac{1}{2} \times 750 \times 10^{-6} \times (330)^2 J = 40.83 J$$

12.13 A capacitor has a capacitance of 2.5×10^{-8} F. In the charging process, electrons are removed from one plate and placed on the other one. When the potential difference between the plates is 450V, how many electrons have been transferred? ($e = 1.60\times10^{-19}C$)

Solution:

$C = 2.5 \times 10^{-8} F$

$V = 450$ volts

$e = 1.6 \times 10^{-19} C$

$n = ?$

Since $Q = CV$

Also $Q = ne$

By comparing above two formulae,

$$ne = CV$$

$$n = \frac{CV}{e}$$

$$n = \frac{2.5\times10^{-8}\times450}{1.6\times10^{-19}} = 7.0 \times 10^{13} \text{ electrons}$$