Unit-11

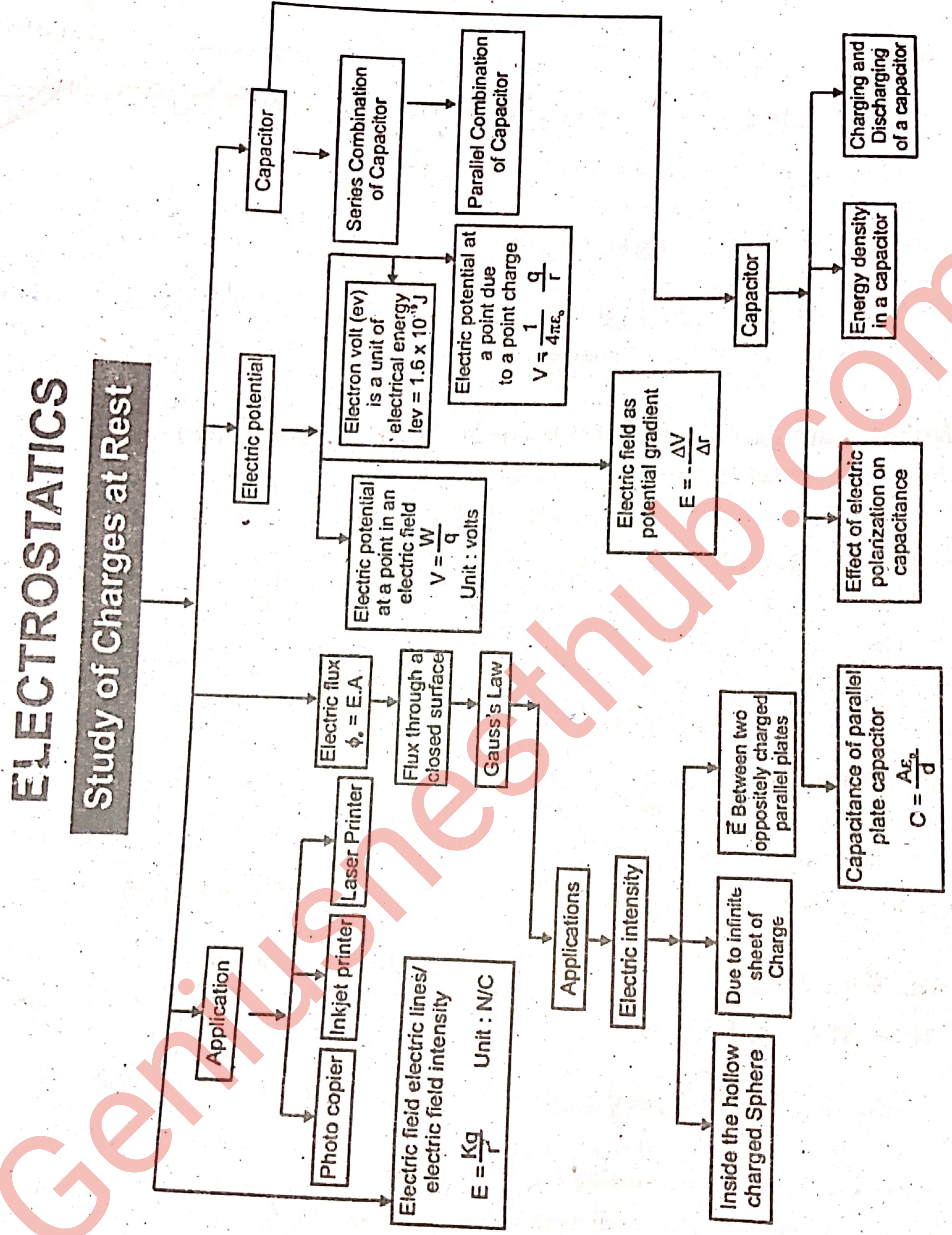
ELECTROSTATICS

Learning Objectives

After studying this chapter the students will be able to

- State Coulomb's law and explain that force between two point charges is reduced in a medium other than free space using Coulomb's law.
- Derive the expression $E = 1/4\pi\varepsilon_o\, q/r^2$ for the magnitude of the electric field at a distance 'r' from a point charge 'q'.
- Describe the concept of an electric field as an example of a field of force.
- Define electric field strength force per unit positive charge.
- Solve problems and analyze information using $E = F/q$.
- Solve problems involving the use of the expression $\mathrm{E} = 1/4\pi\varepsilon.q/r^2$.
- Calculate the magnitude and direction of the electric field at a point due two charges with the same or opposite signs.
- Sketch the electric field lines for two point charges of equal magnitude with same or opposite signs.
- Describe the concept of electric dipole
- Define and explain electric flux.
- Describe electric flux through a surface enclosing a charge.
- State and explain Gauss's law.
- Describe and draw the electric field due to an infinite size conducting plate of positive or negative charge.
- Sketch the electric field produced by a hollow spherical charged conductor.
- Sketch the electric field between and near the edges of two infinite sizes oppositely charged parallel plates.
- Define electric potential at a point in terms of the work done in bringing unit positive charge of potential.
- Solve problems by using the expression $V = W/q$.
- Describe that the electric field at a point is given by the negative of potential gradient at that point.

CONCEPT MAP


ELECTROSTATICS
Study of Charges at Rest
Capacitor
Series Combination of Capacitor
Parallel Combination of Capacitor
Electric potential
Electron volt (ev) is a unit of electrical energy $1ev = 1.6 \times 10^{-19} J$
Electric potential at a point due to a point charge $V = \frac{1}{4\pi\varepsilon_o}\frac{q}{r}$
Electric potential at a point in an electric field $V = \frac{W}{q}$ Unit : volts
Electric field as potential gradient $E = -\frac{\Delta V}{\Delta r}$
Capacitor
Charging and Discharging of a capacitor
Energy density in a capacitor
Effect of electric polarization on capacitance
Capacitance of parallel plate capacitor $C = \frac{A\varepsilon_o}{d}$
Electric flux $\phi_e = E.A$
Flux through a closed surface
Gauss's Law
Applications
Electric intensity
$\vec{E}$ Between two oppositely charged parallel plates
Due to infinite sheet of Charge
Inside the hollow charged Sphere
Application
Laser Printer
Inkjet printer
Photo copier
Electric field electric lines/ electric field intensity $E = \frac{Kq}{r^2}$ Unit : N/C

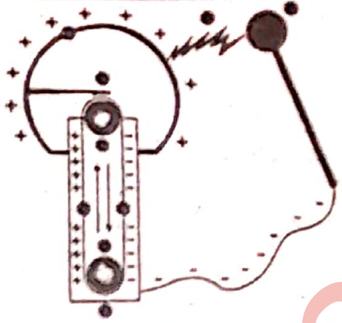
Introduction

Two fundamental processes of electrostatics are introduced: Coulomb's law for force between stationary charges and the principle of superposition for electric field configurations. The electric field at a point in space is defined and used, with Coulomb's law, to derive an expression for the electric field at a distance from a point charge. The concept of work done by an electric field on a charged particle is introduced. For practical purposes, the concept of electric field is translated into concepts of electric potential and electrical potential energy.

The principle of superposition explains the fact that a near-uniform electric field can be produced by two charged parallel conducting plates. The absence of an electric field in hollow conductors is discussed. The presence of strong electric fields in the vicinity of sharp points on charged conductors is identified and applied to corona discharges in relation to photocopiers and laser printers.

Another quantity being discussed that plays an important role in electrical circuits is capacitance and its dependence on the dielectrics.

For Your Information



A van de Graaff generator is an electrostatic generator which uses a moving belt to accumulate very high amounts of electrical potential on a hollow metal globe on the top of the stand. A Van de Graaff generator operates by transferring electric charge from a moving belt to a terminal. First invented in 1929, the Van de Graaff generator became a source of high voltage for accelerating subatomic particle to high speeds, making it a useful tool for fundamental physics research.

Electrostatics:

The branch of physics which deals with the study of charges at rest under the influence of electric forces is called electrostatics.

Electric Force:

The force which holds the negative and positive charges that make up atoms or molecules is called electric force.

Basic law of electrostatics(Law of electrostatics):

Like charges repel and unlike charges attract each other.

Properties of Charge:

Charge is the intrinsic property of fundamental particles. There are two kinds of charges, namely positive and negative charges. The charge on electron is assumed to be negative and the charge on proton is positive.

Electrons have a negative charge and protons have positive charge.

The atom is electrically neutral. In SI units, charge is measured in coulombs (symbol C). The charge carried by an elementary particle (electron or proton) is written as e, and its magnitude is

$$1e = 1.6 \times 10^{-19}\ \text{C}$$

The important characteristic of the charge is that charge is quantized. Quantization of charge means that is exists in discrete packets. Charge q is an integral multiple of minimum charge on elementary particle.

$$q = ne$$

For Your Information

When you charge up your body by touching the Van der Graaf generator your hair stands on end. The hair stands because all hair gains the same electric charge and repel each other. The force of repulsion is so great that it exceeds the weight of each hair strand. Your arms do not lift away from your body though – even they have the same charge as your body. This is because they are too heavy!

Point Charges(Localized Charges):

These are such charges whose size is very small as compared to distance between them.

Test Charge:

It is very small positive charge whose electric field is negligibly weak.

Q.1 State and Explain the Coulomb's Law.

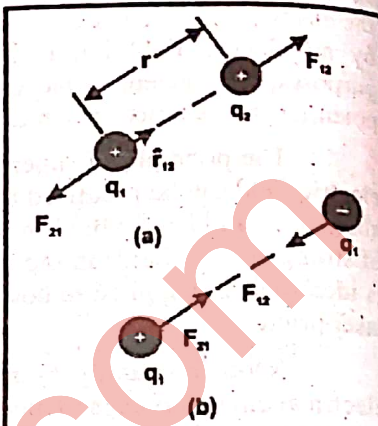
RWP – 2010, FSD- 2011, MIRPUR 2011

Coulomb's Law:

The quantitative measurement of the force between two electric charges was first made by **Coulomb (1736 – 1805)**. He carried out series of experiments to measure the force between electric charges using an apparatus known as **torsion balance.**

Statement:

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



Coulomb force between (a) similar charges, and (b) opposite charges.

The magnitude of the force $\vec{F}$ between two electric charges q_1 and q_2 separated by distance r can be expressed as:

$$F \propto q_1q_2 \qquad \text{.... (A)}$$

$$F \propto \frac{1}{r^2} \qquad \text{.... (B)}$$

Combining Eq (A) & Eq(B)

$$\Rightarrow \quad F \propto \frac{q_1q_2}{r^2}$$

$$\Rightarrow \quad F = k\frac{q_1q_2}{r^2} \qquad \text{.... (11.2)}$$

Where k is a constant of proportionality, it is called **electrostatic constant.** Its value depends upon:

- **i.** Units of the system used
- **ii.** The medium between the charges.

Coulomb's law is valid for point charges.

For free space.

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

Point Charge

A point particle with non-zero charge is called point charge.

Note: A particle with no dimensions is called point particle.

Where ε_o is known as permittivity of free space and its value is $8.85 \times 10^{-12}\ C^2N^{-1}m^{-2}$.

$$k = \frac{1}{4 \times 3.14 \times 8.85 \times 10^{-12}}$$

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

So, the electric force between the charges,

$$F = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1q_2}{r^2}\right]$$

Vector form of Coulomb's Law

In order to show the direction of the force we use unit vector along the line joining the two charges. In fig. 11.1 (a) $\hat{r}_{12}$ is unit vector, pointing from the charge q_1 towards the charge q_2 which show the force on charge q_2 due to charge q_1 i.e.,

$$\vec{F}_{21} = k\frac{q_1q_2}{r^2}\hat{r}_{12} \qquad \text{.... (11.3)a}$$

For like charges the product q_1q_2 will be positive and a force of repulsion between these two charges will be F_{21}. Similarly for unlike charges the product q_1q_2 will be negative and a force of attraction between these two charges will be F_{12}. Similarly unit vector $\hat{r}_{12}$, pointing from the charge q_2 towards the charge q_1 which show the force on charge q_1 due to charge q_2 is given by

$$\vec{F}_{12} = k\frac{q_1q_2}{r^2}\hat{r}_{21} \qquad \text{.... (11.3)b}$$

Since $\hat{r}_{12} = -\hat{r}_{21}$

So from Eq: 11.3(a) and 11.3(b) we can write

$$\vec{F}_{21} = -\vec{F}_{12} \qquad \text{.... (11.4)}$$

Where $\vec{F}_{21}$ is the force exerted by the charge q_1 on q_2 and $\vec{F}_{12}$ is the force exerted by the charge q_2 on q_1. Eq 11.4 shows that the two forces are same in magnitude but opposite in direction which is illustrated in fig 11.1(b).

It follows Newton's 3rd law of motion.

Coulomb's Law in Material Media:

$$F = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1q_2}{r^2}\right]$$

This gives the force between two charges when there is air or vacuum between them. But it is experimentally observed that that when an insulator i.e. dielectric is placed between the electric charges, it reduces the force. **Permittivity is the property of a medium which affects the magnitude of force between two point charges.** The coulomb's force can now be written as

$$F_{med} = \frac{1}{4\pi\varepsilon}\frac{q_1q_2}{r^2} \qquad \text{.... (11.5)}$$

The quantity ε is called the permittivity of the medium. The permittivity of a material medium compared with the permittivity of vacuum is called relative permittivity or dielectric constant ε_r for particular insulator. Its ratio is given by

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_o} \qquad \text{.... (11.6)}$$

Obviously the ε_r is dimensionless constant and its value is always greater than unity for various dielectrics.

The force in a medium of relative permittivity ε_r, is given by

$$F_{med} = \frac{1}{4\pi\varepsilon_o\varepsilon_r}\frac{q_1q_2}{r^2}\hat{r} \qquad \text{.... (11.7)}$$

$$\Rightarrow \quad F_{med} = \frac{1}{\varepsilon_r}\left[\frac{1}{4\pi\varepsilon_o}\frac{q_1q_2}{r^2}\right]\hat{r}$$

$$\Rightarrow \quad F_{med} = \frac{F_{vac}}{\varepsilon_r} \qquad \text{.... (11.8)}$$

$$\Rightarrow \quad F_{vac} = \varepsilon_r F_{med}$$

$$\Rightarrow \quad F_{vac} > F_{med}$$

The values of relative permittivity for various dielectrics are given in Table 11.1.

Table: The relative permittivity of various dielectrics:

Material	ε_r	Material	ε_r
Vacuum	1	Glass	4.8-10
Air	1.0006	Mica	3-7.5
Benzene	2.284	Paraffine paper	2
Germinium	16	Rubber	2.94
Water	78.5	Ammonia(liquid)	22-25

MCQ's From Past Board Papers

1. Relative permittivity for air is:
   (A) 1.06 (B) 1.006 (C) 1.0006 (D) 1.6
2. The Electrostatic force between two charges is 42 N. If we place a dielectric of $\varepsilon_r = 2.1$ between, the charges, then the force become equal to:
   (A) 42 N (B) 83.2 N (C) 20 N (D) 2N

3. **Presence of dielectric always:**
(A) Increases the electrostatic force (B) Reduces the electrostatic force
(C) Does not affect the electrostatic force (D) Doubles the electrostatic force.

4. **If the medium between the charges is not free space then electrostatic force will:**
(A) Increase (B) Decrease (C) Remain same (D) None of these

5. **The force between two point charges separated by air is 4 N. When separated by a medium of relative permittivity the force between them becomes:**
(A) $\frac{1}{2}$ N (B) 2 N (C) 4 N (D) 8 N

6. **The SI units of Coulomb's constant are**
(A) Nm^2C^2 (B) $Nm^{-2}C^2$ (C) Nm^2C^{-2} (D) $Nm^{-2}C^{-2}$

7. **The value of relative permittivity for all the dielectrics other than air or vacuum is always**
(A) Less then unity (B) Greater than unity (C) Equal to unity (D) zero

8. **If F_1 and F_2 are forces acting on α-particle and electron respectively man electric field, then**
(A) $F_1 = F_2$ (B) $F_1 > F_2$ (C) $F_1 < F_2$ (D) $F_1 = 4F_2$

9. **The constant of proportionality "K" depend upon:**
(A) Nature of medium between two charges (B) The system of units
(C) Nature of charge bodies (D) Nature of medium between two charges and system of units

10. **The value of Coulomb's constant (K) in SI units is**
(A) $9 \times 10^9 Nm^2C^{-2}$ (B) $9 \times 10^9 NC^2m^{-2}$ (C) $9 \times 10^9 N^{-1}m^2C^2$ (D) $9 \times 10^9 Nm^2C^2$

11. **The force between two similar unit charges placed one meter apart in air is:**
(A) Zero (B) One Newton (C) 9×10^9 N (D) 9×10^{-9} N

12. **The value of ε_0 permittivity for free space is:**
(A) $8.85 \times 10^{-12}C^2N^{-1}m^{-2}$ (B) $8.85 \times 10^{-12}Nm^2C^{-2}$ (C) $8.85 \times 10^{-12}NmC^{-2}$ (D) $8.85 \times 10^{-12}m^2N^{-1}C^2$

13. **The electrostatic force of repulsion between two electrons at a distance 1m is:**
(A) 2.3×10^{-24} N (B) 2.3×10^{-26} N (C) 2.3×10^{-28} N (D) 2.3×10^{-30} N

14. **Two charges 1 μc and 5 μc separated by 20 cm, the ratio of electrical forces acting on them will be:**
(A) 1 : 2 (B) 1 : 5 (C) 1 : 1 (D) 5 : 1

15. **SI unit of permittivity of free space are:**
(A) Nm^2C^{-2} (B) $N^{-1}m^2C^{-1}$ (C) $C^2N^{-1}m^{-1}$ (D) $C^2N^{-1}m^{-2}$

16. **SI unit of relative permivity is**
(A) $\frac{C^2}{Nm^2}$ (B) $\frac{C^{-2}}{Nm^2}$ (C) $Nm^{-2}C^{-1}$ (D) None of these

17. **Value of ε_r for air is;**
(A) 1.6 (B) 1.96 (C) 1.986 (D) 1.0006

18. **If the distance between the two charged bodies is halved, the force between them becomes:**
(A) Double (B) Half (C) Four time (D) One fourth

19. **If both the magnitude of charge and distance between them is doubled, then coubled, then coulomb's force will be:-**
(A) Doubled (B) Half (C) Remains same (D) One fourth

20. Presence of dielectric between two charges always:
(A) Reduces the electric force (B) Enhance the electric force
(C) Does not effect electric force (D) Doubles the electric force

21. The direction of field lines around an isolated charge "-q" is
(A) Radically inward (B) Radically outward (C) Elliptical (D) Circular

22. Closeness of the electric field lines in the measure of
(A) direction of field (B) strength of field (C) potential difference (D) uniformity of field

23. Force between two similar unit charges placed one meter apart in air is:
(A) One newton (B) 9×10^9 N (C) 9×19^9 N (D) Zero Newton

Answers Key

1. C	2. C	3. B	4. B	5. B	6. C	7. B	8. B	9. B	10. A	11. C	12. A
13. C	14. C	15. D	16. D	17. D	18. C	19. C	20. A	21. A	22. B	23. B	

Q.2 What is meant by electric field of force? Define and explain electric intensity field?

Ans.

Electric Field and its Intensity

Origin of electric force

Like gravitational field, the origin of electric force is still unknown, so they are called as "forces of nature" while the transmission of electric force is described by Michael Faraday by using the concept of electric field.

The concept of field theory was introduced by Michael Faraday. He stated that the charge q produces an electric field in the space surrounding it and when a charge q_o is brought in its field then it exerts a force F on it. The electric field around a charge is like a sphere with in which other charges are influenced by it. The existence of electric field can be proved by bringing a test q_o into its field.

Electric Field

The space or region around the charge in which it exerts electric force on other charges is called electric field.

Electric Intensity

Electric field strength or electric field intensity at any point is defined as ***the force experienced per unit charge q_o placed at that point.***

If $\vec{F}$ is the force experienced by positive test change q_o at point P, Then electric intensity at P is given by

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

Direction of electric intensity

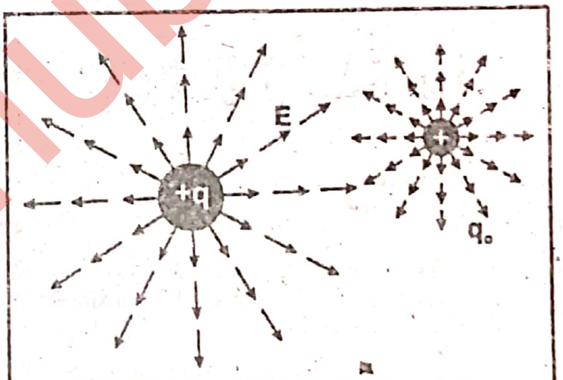
Electric intensity is a vector quantity. The direction of electric intensity is same as that of electric force.

Unit

Its SI unit is NC^{-1} or Vm^{-1}.

Electric intensity due to a point charge

According to Coulomb's law the force experienced by test charge q_o placed in the field of a charge q is given by



Electric field intensity due to a point charge.

$$F = k\left[\frac{qq_o}{r^2}\right]$$

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

Putting value of F, we get

So $$E = \frac{k\left[\frac{qq_o}{r^2}\right]}{q_o}$$

Or

$$E = k\left[\frac{q}{r^2}\right]$$

$$E = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{r^2}\right]$$

In vector form,

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{r^2}\right]\hat{r}$$

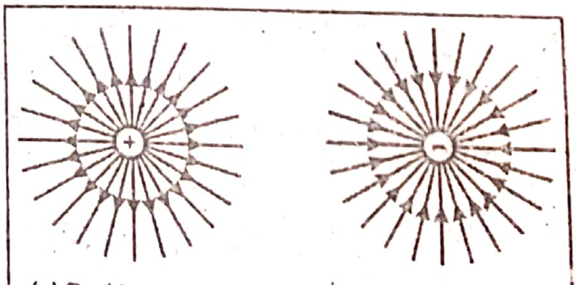
Where $\hat{r}$ is the unit vector directed from q to q_o.

Q.4 What are electric lines of forces? Sketch field lines in different cases. Also write down characteristics of electric field lines.

Representation of Electric Field Lines

The electric field in the vicinity of a charge body can be represented by imaginary lines called electric lines of force.

The electric lines of force are the path followed by a unit positive test charge in the field of source charge. These lines are called electric field lines. These electric field lines give properties of electric field due to charges.



(a) Positive Charge (b) Negative Charge

Electric lines of force around a charge

Electric field patterns

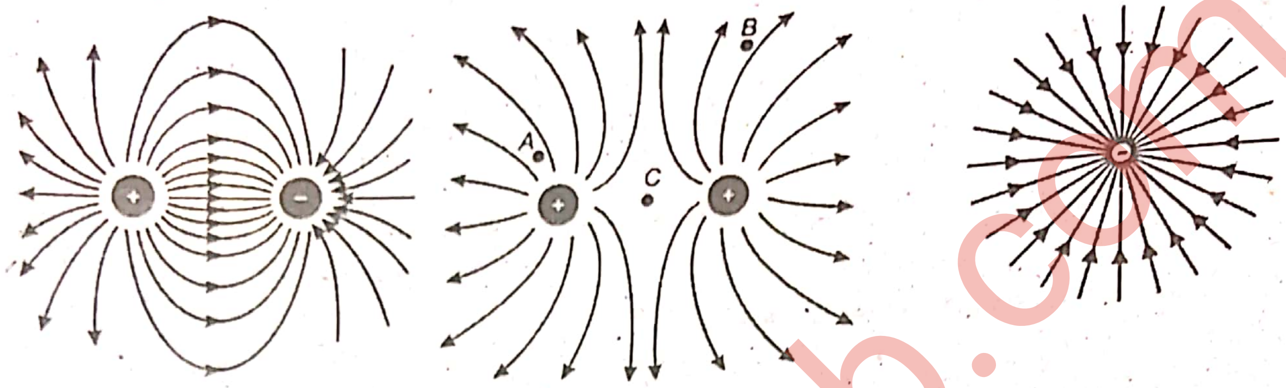
In order to draw the electric field lines, we place positive test charges q_o at equal distances from field charge q at different places.

(1) Electric field lines due to a positive point charge

The electric field created by positive point charge +q repels the positive test charge q_o. The electric lines of forces are directed **radially outward.**

(2) Electric field lines due to a negative point charge

The electric field created by negative charge -q attracts the positive test charge q_o. The electric lines of forces are directed **radially inward.**



Electric lines of force

(3) Electric field lines for like charges

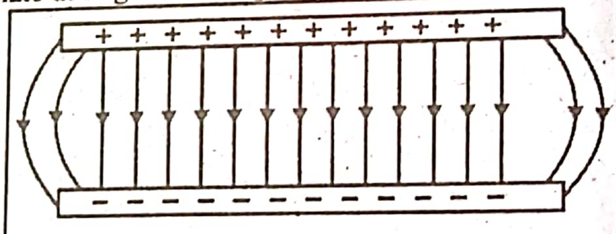
For two similar positive charges of equal magnitudes, the field lines are curved as shown in figure. The lines in region between the two charges seem to repel each other. The middle region shows the presence of a zero field spot or neutral zone.

(4) Electric field lines for unlike charges

Fig. (11.5) shows the field lines due to positive and negative charges which are placed at a certain distance from each other. The field lines starts from positive charge and terminate at negative charge. There are some points in the field where the resultant intensity is equal to the sum of the intensities due to positive charge and negative charge and its direction is along the tangent to the field.

Note:

For uniform electric field, field lines are parallel, equally spaced and lines passing per unit area is same.



Uniform electric field between charged plates.

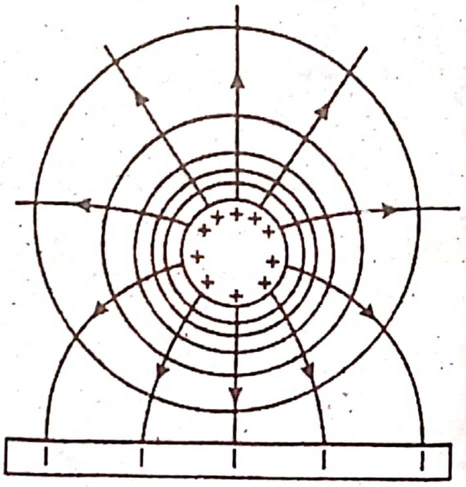
5) Field lines for two oppositely charged parallel plates

In this case, the field is uniform in the middle region where field lines are equally spaced as shown in figure.

If the plates are not of infinite length, the field lines at the ends of plates will be a little bulging out, showing that field is not uniform at the ends. The field such as at the ends of plates is called "fringing field". Another interesting property of field lines can be explained with the help of fig.

6) Field lines due to positive charge placed near metal plate

Suppose that a charge +q is placed near a metal plate. The positive charge will attract the negative charges (electrons) in the metal plate, resulting in the motion of these charges until some of them reach that surface of the metal which is near to +q charge where they will be at rest. Thus, the field lines starting from +q charge will end on the



Electric lines of force on the surface of metal plate negative charges of the metal plate. Furthermore, these lines are always perpendicular to the metal surface. The electric lines of force cannot pass through a conductor. Therefore electric field is zero inside a conductor. The electric lines of force have the tendency to contract in length. This explains attraction between oppositely charged bodies.

Properties of Electric Field Lines

1. Electric field lines start from positive charge and end on the negative charge.
2. The tangent to the field line at any point gives direction electric field at that point.
3. Number of electric field lines per unit area passing perpendicularly through an area give the magnitude of electric field.
4. No two electric filed lines intersect each other.

   This is because $\vec{E}$ has only one direction at any given point. If the lines cross, $\vec{E}$ could have more than one direction, which is physically not possible.
5. Electric field lines are parallel and equally spaced where the electric field is uniform and non-parallel where the electric field is non-uniform.
6. The lines are closer where field is stronger and are farther apart where field is weaker.
7. Electric field lines cannot pass through conductors

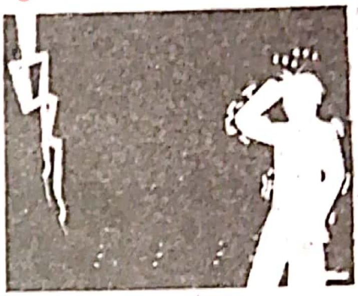
QUIZ

Q 1: Explain why it is possible for an air passenger to get an electrical shock when he touches the knob of the toilet door in a high altitude flying airplane.

Ans. Any person may have charges due friction with flour or with anything like seat in the plane. When the person will touch the metallic knob of the toilet door, charges will flow through the body of the person to hand, that's why person can get electric shock.

Q 2: What would you do if you are caught on thunder storm?

Ans. Thundering lightning will not affect inside the plane due to shielding effect. As external electric field cannot enter or interfere inside the charged closed surface like flying aeroplane.



MCQ's From Past Board Papers

1. **Which one of the following can be taken as measure of electric field intensity:**
   (A) $\frac{F}{A}$ (B) $\frac{\varphi_e}{A}$ (C) $\frac{qA}{\varepsilon_o}$ (D) $\frac{\phi\varepsilon_o}{A}$
2. **Concept of electric field was given by**
   (A) Michelson (B) Henry (C) Michel Faraday (D) Orested
3. **The fact that Electric Field exists in space around an electrical charge is ______.**
   (A) Electrical property (B) Gravitational Field (C) Intrinsic property of nature (D) All of these
4. **The force experience by unit positive charge placed at a point in an electric field is called:**
   (A) Coulomb's force (B) Faraday's force (C) Electric field intensity (D) None of these
5. **The force on Neutron due to a field of 10^2 N/C is:**
   (A) 1.6×10^{-17} N (B) 1.6×10^{-19} N (C) Zero (D) 1.6×10^{-21} N
6. **Special organ called Ampullae of lorenzini that are very sensitive to electric field are found in:**
   (A) Bats (B) Cats (C) Doges (D) Sharks
7. **An ECG records the ——— between points on human skin generated by electric process in the heart:**
   (A) Heart Beat (B) Pulse Rate (C) Pressure (D) Voltage
8. **The electric field lines are closer where the field is:**
   (A) Strong (B) Weak (C) Uniform (D) Variable
9. **The electric field created by positive charge is:**
   (A) Radially inward (B) Zero (C) Circular (D) Radially outward

10. The unit of Electric Intensity other than NC^{-1} is:-

(A) $\frac{V}{A}$ (B) $\frac{V}{m}$ (C) $\frac{V}{C}$ (D) $\frac{N}{V}$

11. S.I unit of strength of electric field is:

(A) J/C (B) C/V (C) N/C (D) J/N

12. NC^{-1} is the SI unit of:

(A) Force (B) Charge (C) Current (D) Electric intensity

13. The direction of field lines due to a charge "+q" is

(A) Radially outward (B) Radially inward (C) Circular (D) Curve

14. The unit of electric intensity other than NC^{-1}.

(A) VA^{-1} (B) Vm^{-1} (C) VC^{-1} (D) NC

15. The electric field intensity due to an infinite sheet of charge is

(A) $\bar{E} = \frac{\sigma}{2E_o}\hat{r}$ (B) $\bar{E} = \frac{2\sigma}{E_o}\hat{r}$ (C) $\bar{E} = \frac{1}{2\sigma E_o}\hat{r}$ (D) $\bar{E} = \frac{\sigma}{E_o}\hat{r}$

16. If an electron of charge "e" is accelerated through a potential difference V, it will acquire energy:

(A) Ve (B) $\frac{V}{2}$ (C) $\frac{E}{V}$ (D) Ve^2

Answers Key

1. B	2. C	3. C	4. C	5. C	6. D	7. D	8. A	9. D	10. B	11. C	12. D
13. A	14. B	15. A	16. A								

Q.5 Describe the Principle, Construction and Working of Photocopier (Xerography).

Ans.

Applications of electrostatics:

a) Photocopiers

A photocopier is a machine that makes quickly and easily copies of documents.

The heart of a copier is the drum, an aluminum cylinder coated with a layer of selenium (as shown in Figure 11.8

a) Aluminum is an excellent electrical conductor. Selenium, on the other hand, is a photoconductor; it is an insulator in the dark but becomes as conductor when exposed to light.

When the paper to be copied is laid on the glass plate, then the photocopier perform the following function.

- First, an electrode called a corotron gives the entire selenium surface a positive charge in the dark.
- Second, a series of lenses and mirrors focuses an image of a document onto the revolving drum. The dark and light areas of the document produce corresponding areas on the drum. The dark areas retain their positive charge, but the light areas become conducting and lose their positive charge, ending up neutralized. Thus, a positive-charge image of the document remains on the selenium surface.
- In the third step, a special dry black powder, called the toner, is given a negative charge and then spread onto the drum, where it adheres selectively to the positively charge areas.
- The fourth step involves transferring the toner onto a blank piece of paper. However, the attraction of the positive-charge image holds the toner to the drum. To transfer the toner, the paper is given a greater positive charge than that of the image, with the aid of another corotron.
- Last, the paper and adhering toner pass through heated pressure rollers, which melt the toner into the fibers of the paper and produce the finished copy.

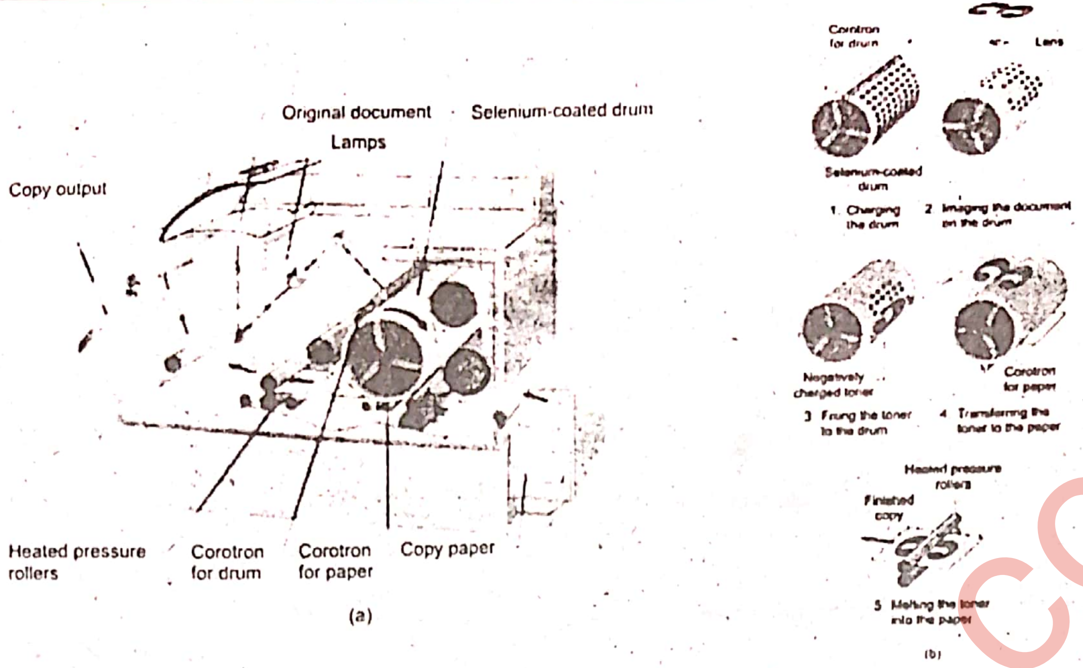
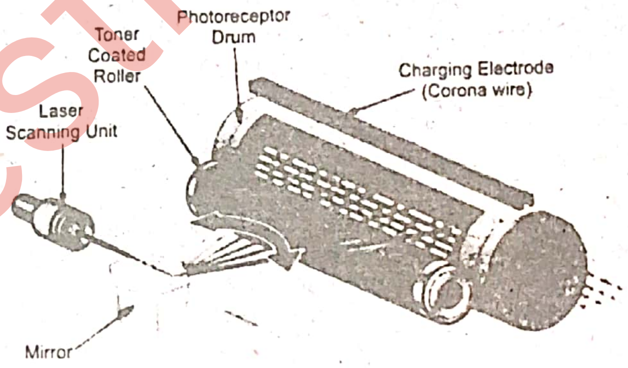


Fig: 11.8 (a) The dry copying process is based on electrostatics. The major steps in the process are the charging of the photo conducting drum, transfer of an image creating a positive charge duplicate, attraction of toner to the charged parts of the drum, and transfer of toner to the paper.

Q.6 Explain the Construction and Working of laser printer and Inkjet Printer

Ans.

Laser Printer



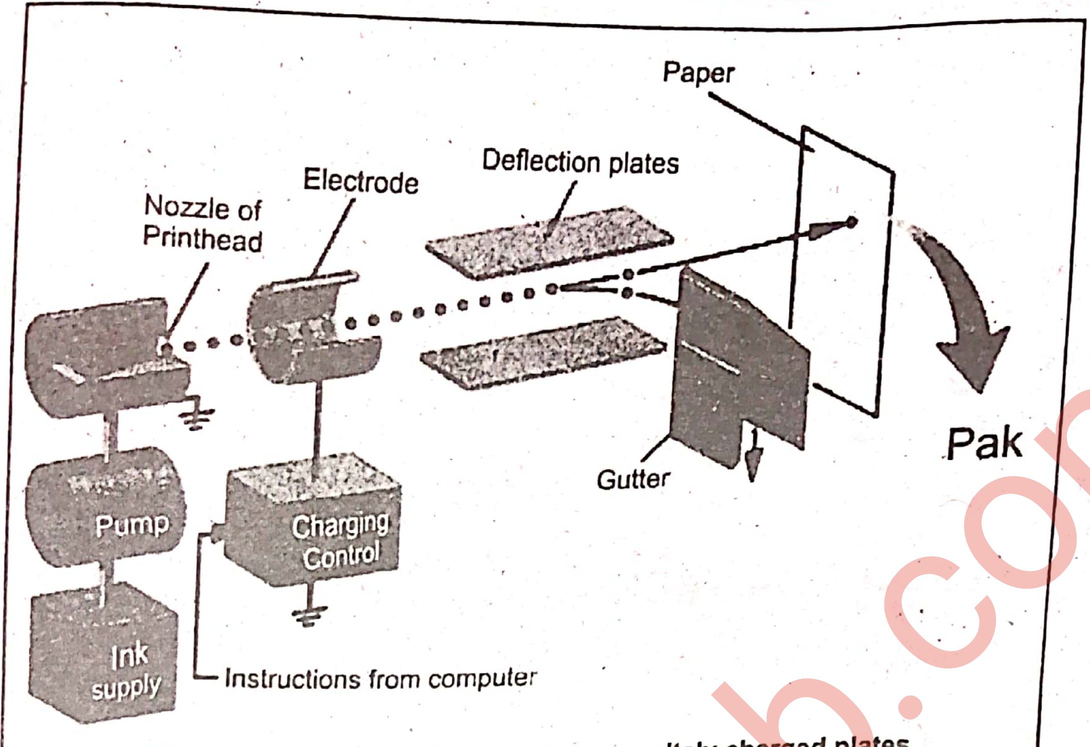
Laser printer with a static laser scanning unit, but movable mirror.

Laser printer work is largely due to the process called xerography. Initially, the photo-receptor drum is charged positively by corona wire by applying an electrical current on it as shown in fig 11.8 (b).

When the light of the laser beam hits the drum, whatever areas that are exposed to the light are rid of these electric charges. The areas that are not exposed to light eventually make up the printed image, these areas, which remain electrostatic, then pick up the particles from the ink toner. The heat generated by the printer melts the dry ink and then gets fused on the paper to create the printed image.

c) Inkjet Printers

An inkjet printer is another type of printer that uses electric charges in its operation. While shuttling back and forth across the paper, the inkjet printhead ejects a thin stream of ink. The elements of one type of inject printed is shown in fig: 11.9. During their flight, the droplets pass through two electrical components, an electrode and the deflection plates (a parallel plate capacitor). When the printhead moves over moves over regions of the paper that are not to be inked, the charging control is turned on and an electric field is established between the printhead and the electrode. As the drop pass through the electric field, they acquire a net charge by the process of induction. The deflection plates divert the charged droplets into a gutter and thus prevent them from reaching the paper.



charging of ink droplets between two oppositely charged plates.

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

QUIZ

Q. **What are the basic differences between laser printer and photocopier?**

Ans. Copier uses a bright light and lens to focus an image of the original (actually, a strip at a time which is scanned in most modern low to medium performance copiers) onto the drum. Adjusting the lens-to-original and lens-to-drum distance is used to vary the reduction or magnification.

A laser printer uses a low power sharply focused laser beam to scan one line at a time on the drum. Modern laser printers use infra-red solid state laser diodes similar to those used in CD players and optical disk drives while older ones used helium neon lasers.

Q. **State any two other applications of electrostatic**

Ans. **Following are few applications of the electrostatics:**

- The Van de Graaff Generator.
- Xerography.
- Laser Printers.
- Ink Jet Printers and Electrostatic Painting.
- Smoke Precipitators and Electrostatic Air Cleaning.

Q. **State any two hazards of electrostatic.**

Ans. Following are some examples of dangers associated with static electricity:

- It is dangerous when there are flammable gases or a high concentration of oxygen. A spark could ignite the gases and cause an explosion.
- It is dangerous when you touch something with a large electric charge on it. The charge will flow through your body causing an electric shock. This could cause burns or even stop your heart. A person could die from an electric shock.

MCQ's From Past Board Papers

1. **Selenium is a:**
   (A) Insulator (B) Photoconductor (C) Conductor (D) First insulator then conductor
2. **The toner of the printer is given**
   (A) Positive charge (B) Negative charge (C) Neutral (D) First positive then negative

3. **The word "Xerography" means:**
(A) Writing by left hand (B) Writing by children (C) Dry writing (D) Writing by water colours

4. **Which one is a photo conductor?**
(A) Copper (B) Selenium (C) Mercury (D) Aluminum

5. **Photo copier and inkjet printer are the application of:**
(A) Magnetism (B) Electricity (C) Electro magnetism (D) Electro statics

6. **The toner of the printer is given**
(A) Positive charge (B) Negative charge (C) Neutral (D) First positive then negative

7. **Photocopier and inkjet printer are the applications of:**
(A) Electrostatics (B) Magnetism (C) Electricity (D) Electro-magnetism

8. **The drum in a photocopier is coated with a layer of:**
(A) Aluminium (B) Silver (C) Gold (D) Selenium

9. **The photo copying process is called:**
(A) Photography (B) Scanning (C) Xerography (D) Holography

Answers Key

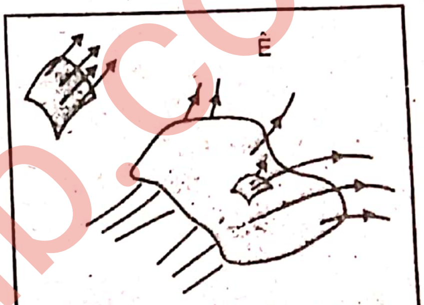
1. B	2. B	3. C	4. B	5. D	6. B	7. A	8. D	9. C

Q.7 What is Electric Flux? Explain. Give its unit.

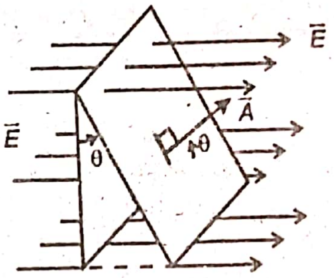
Ans.

Electric Flux:

Flux is a Latin word, which means to flow. In electrostatics, it can be defined as,



Electric flux through a unit area and curved surface



Electric flux at angle

Definition (physical)

The number of field lines passing through certain area perpendicularly, is called electric flux through that area.

OR

Definition (quantitative)

Electric flux through an area is defined as *the scalar product of electric field intensity* $\vec{E}$ *and vector area* $\vec{A}$

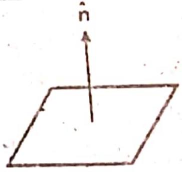
Mathematically

$$\Phi = \vec{E}.\vec{A}$$

OR $$\Phi = EA\cos\theta$$

Where θ in the angle between $\vec{E}$ and $\vec{A}$.

(Area Vector: *A is a vector whose magnitude is equal to the surface area and whose direction is normal to the surface area.*)



Area Vector

Thus flux Φ is the scalar product of the electric field E and area vector A.

Dependence of Electric flux

Electric flux depends upon

i) Number of electric lines of forces per unit area.
ii) Area of surface.
iii) Orientation of the surface.

Flux at any angle:

When the area $\vec{A}$ is tilted such that it is making an angle θ with the electric field lines as shown in Fig 11.11 (b) in this case the electric flux is:

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

The number of lines passing through the area will be E (A cosθ) depending upon angle θ.

Maximum Flux:

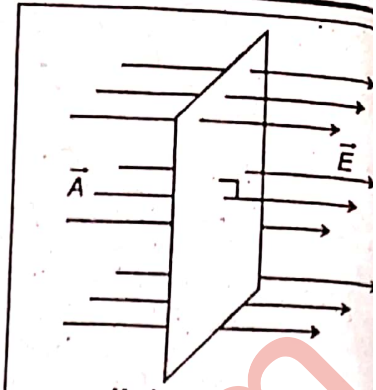
If the surface is placed perpendicular to the electric field such that surface area then $\vec{A}$ is parallel to electric field $\vec{E}$

i.e. (θ = 0) (Fig 11.11 b)

then electric flux will be maximum.

$$\Phi_{max} = EA\cos 0$$
$$\Phi_{max} = EA\,(1)$$
$$\Phi_{max} = EA$$

Therefore maximum number of lines passes through the surface area.



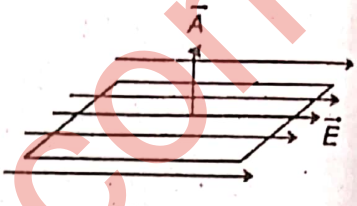
Maximum electric flux

Zero Flux:

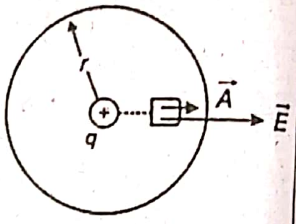
If the surface is placed parallel to the electric field Fig. 11.11 (d) such that surface area $\vec{A}$ is perpendicular to electric field $\vec{E}$ (θ = 90°) then no electric lines of force will pass through the surface. Consequently no electric flux will pass through the surface.

Then flux is

$$\Phi_{min} = EA\cos 90$$
$$\Phi_{min} = EA\,(0)$$
$$\Phi_{min} = 0$$



Electric flux



Electric flux

.8 Describe the method to evaluate the electric flux through the closed surface.

ectric flux through close surface:

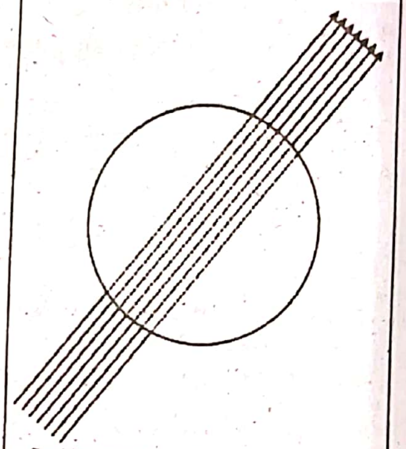
We will follow these steps

- If the case is such that either field is non-uniform or the surface is curved, then we divide the surfaces into very small patches of area ΔA called differential area and assume that these are approximately flat and they are so small that electric field E is almost uniform over it.
- Calculate the electric flux through each of these small patches, using the formula:

$$\Phi_E = \vec{E}.\Delta\vec{A}$$

- To calculate total flux through the whole surface we add flux from each patch such that

$$\Phi_E = \Sigma\,\vec{E}.\Delta\vec{A}$$



Positive, negative and zero flux through a close surface

Also remember these points,

For an arbitrary closed surface, then area vector of its any differential area is $\Delta\vec{A} = \Delta A\hat{n}$, where ΔA is the magnitude of the differential area and $\hat{n}$ is the unit vector (direction) normal to the surface in positive direction.

In case of closed surface, the electric flux may be positive or negative or zero depending upon the number of lines entering or leaving the surface:

The electric flux is positive if net numbers of electric field lines are leaving the surface, that is, there is source of field lines in the closed surface.

The electric flux is negative if net numbers of electric field lines are entering the closed surface or more field lines are entering than leaving the surface; there is a sink of field lines in the closed surface.

i. The electric flux is zero if numbers of field lines entering are equal to field line leaving the surface or no field line intercepting the surface.

Q.9 Derive an expression for electric flux through a surface enclosing a charge.

Consider a spherical closed surface of radius r having a point charge q at its center as shown in fig. 11.13.

Gauss was a German mathematician and scientist who contributed significantly to many fields, including number theory, statistics, analysis, differential geometry, geophysics, electrostatics, astronomy and optics.

To calculate the electric flux through the whole surface, it is divided into n-number of small pieces having area ΔA_1, ΔA_2, ΔA_3, ΔA_4..... ΔA_n. The intensity of electric field is same at every point as they are at equidistant from the charge.

The electric flux through the small elements ΔA_1 is

$$\Phi_1 = \vec{E}_1 . \Delta\vec{A}_1 = E_1 \, \Delta A_1 \cos 0 = E_1 \Delta A_1$$

The electric flux through the other small elements ΔA_2 is

$$\Phi_2 = \vec{E}_2 . \Delta\vec{A}_2 = E_2 \, \Delta A_2 \cos 0 = E_2 \Delta A_2$$

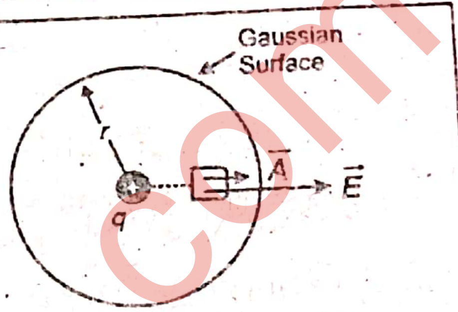
Similarly the electric flux through ΔA_n is

$$\Phi_n = \vec{E}_n . \Delta\vec{A}_n = E_n \, \Delta A_n \cos 0 = E_n \Delta A_n$$

The total flux through the entire surface is

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

$$\Phi = \sum_{surface} E\Delta A \qquad \dots (11.12)$$



Flux through a close surface

But as electric field intensity E is constant over the sphere

Therefore

$$\Phi = E \sum_{surface} \Delta A$$

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

Thus the above equation can be written as

$$\Phi_E = \frac{q}{4\pi\varepsilon_o}\frac{1}{r^2} \text{(total area enclosed by spherical surface)}$$

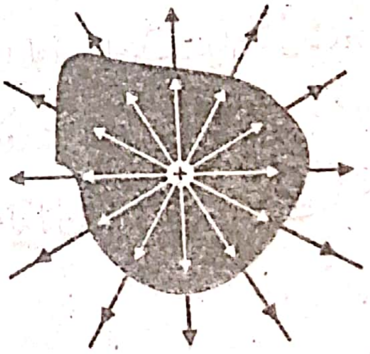
$$= \frac{q}{4\pi\varepsilon_o}\frac{1}{r^2}(4\pi r^2)$$

$$= \frac{q}{\varepsilon_o} \qquad \dots (11.13)$$

Conclusion

- The electric flux through a closed surface does not depend upon the shape or geometry of closed surface.
- The flux through the surface depends upon the medium and charge enclosed.

Q.10 State and prove Gauss's Law.



Flux through an irregular close

Gauss's Law

Statement: Gauss's law states that *"the net electric flux through a closed surface is equal to the total charge q enclosed by the surface divided by the permittivity of free space ε_o."*

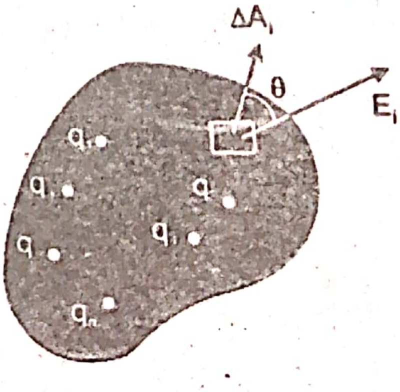
Proof:

Let us consider an irregular closed surface S, enclosing a point charges q_1, q_2, q_3 .... q_n as shown in fig 11.15.

Then the total electric flux through that closed surface is:

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

$$\Rightarrow \quad \Phi_e = \frac{q_1}{\varepsilon_o} + \frac{q_2}{\varepsilon_o} + \frac{q_3}{\varepsilon_o} \dots\dots \frac{q_n}{\varepsilon_o}$$



Number of charges in a closed

$$\Rightarrow \quad \Phi_E = \frac{1}{\varepsilon_o}(q_1 + q_2 + q_3 + \dots\dots\dots q_n)$$

$$\Rightarrow \quad \Phi_E = \frac{1}{\varepsilon_o}\sum_{i=1}^{n} q_i$$

$$\Rightarrow \quad \Phi_E = \frac{1}{\varepsilon_o}(\text{total charge enclosed in surface})$$

$$\Rightarrow \quad \Phi_E = \frac{Q}{\varepsilon_o}$$

Thus gauss's law shows that the electric flux through any closed surface is $1/\varepsilon_o$ times the total charge enclosed in it.

Q.11 What is Gaussian surface? How can you apply the Gauss's law to calculate the electric field?

Ans. Gaussian surface

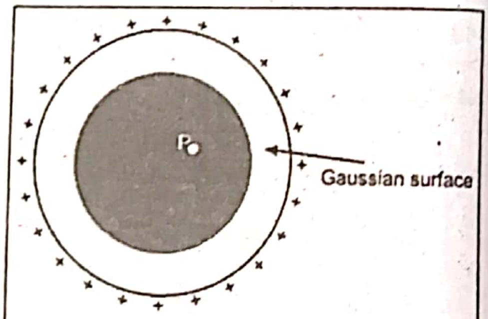
A Gaussian surface is **an imaginary closed surface of arbitrary shape** which passes through the point where we want to calculate electric intensity.

Applications of Gauss's Law:

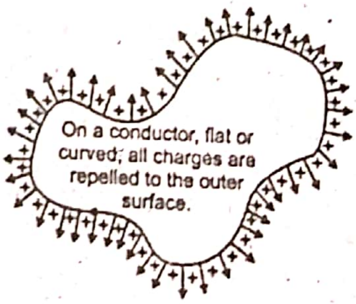
Gauss's law provides a convenient method to calculate E in the case of sufficiently symmetrical charge distribution. Some of examples are now presented.

Q.12 What is location of charges on a hollow closed surface? Also calculate the Electric Intensity for Hollow Charged Sphere?

Intensity of Field inside a Hollow Charged Sphere



Gaussian surface inside a conductor



Excess of charge on the surface of a conductor

Gaussian surface

In order to calculate the electric intensity inside the sphere, we imagine a Gaussian sphere of radius R' inside the sphere, where radius of Gaussian sphere R' is less than R (i.e. $R' < R$)

Charge enclosed

It can be seen in figure that the charge enclosed by Gaussian sphere is zero. i.e.

$$q = 0 \quad \_\_\_\_\_\_\_\_ \quad (1)$$

Flux through the surface

The electric flux through the closed surface is

$$\Phi_e = \vec{E} \cdot \vec{A} \quad \_\_\_\_\_\_\_\_ \quad (2)$$

Calculation of Electric Intensity

By Gauss's law

$$\Phi_e = \frac{q}{\varepsilon_o} \quad \_\_\_\_\_\_\_\_ \quad (3)$$

Using equations (1) and (2) in equation (3), we have

$$\vec{E} \cdot \vec{A} = \vec{O}$$

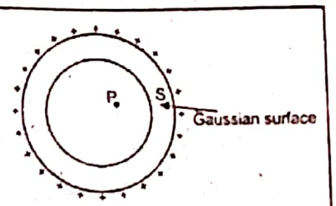
Since vector area can never be zero. So

$$\vec{E} = \vec{O}$$

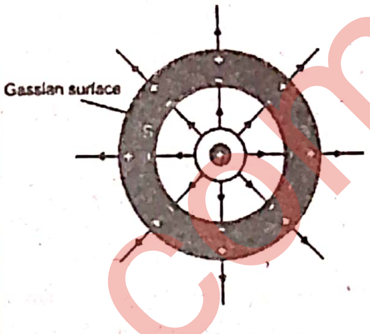
Thus, the interior of a hollow conducting charged metallic sphere is field free region.

Location of Excess Charge on a Conductor:

We know that the electric field E = 0 at all points due to electrostatic equilibrium in a conductor (the charges will reside on the outer surface of the hollow closed body).



An excess of charge on the outer surface of a hollow conductor



Charge *q* inside the hollow conductor having a Gaussian surface S

Case 1:

We can make an imaginary Gaussian surface S, in the interior of a conductor, as shown in fig:. Because E = 0 everywhere in this surface, the net charge inside the surface has to be zero. Since E = 0 everywhere on the Gaussian surface S, the net charge inside that point is zero. That also mean that there cannot be a net charge at any point within the conductor, because that tiny point could be put anywhere in the conductor. if that's so, that means all the charge must be on the outer surface of the conductor, as shown in fig 11.16.

Case 2:

Now let's consider a hollow conductor as shown in the illustration 11.18. Since the conductor is hollow so there is no net charge at any point within the conductor. The cavity is surrounded by a Gaussian surface S which encloses no net charge and so there is no charge on the internal cavity. Again all the charge is deposited on the outer surface of the conductor.

Case 3:

In the third case as shown in the fig: 11.19. Let's put a charge q inside the hollow conductor. We insulate it so no charges can jump from one surface to another. Now if we use Gauss's Law with Gaussian surface S again, the net charge of what it encloses has to be zero because there was no charge transfer between the charge and the conductor. Initially the conductor was uncharged but when charge q is inserted, then there will be negative charge on the inside cavity in order to maintain its neutral status.

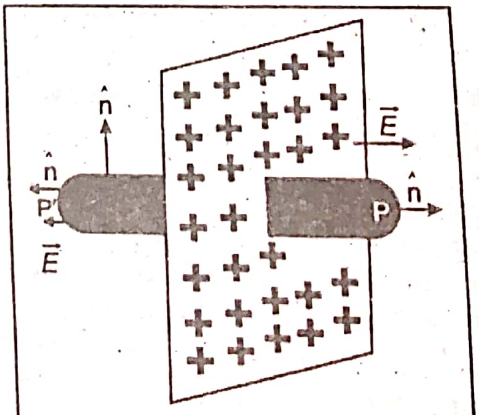
So the other surface must have a charge equal but opposite the charge of the internal cavity, or the outer surface's charge is equal to that of charge q.

For your Information

Airlines Airbus A380 flew through a storm. when 500 peoples were on the board but none of them were injured. As there is no electric field, no potential difference inside a metal shell, so one of the safest way to be inside a metal shell. during thunderstorm.

Q.13 Calculate the Electric Intensity Due to an Infinite Sheet of Charge. FSD – 17, GRW – 15, 16, LHR 2017

Electric field Intensity Due To an Infinite Sheet of Charge:



Gaussian surface in the form of a cylinder perpendicular to the sheet of charge

Consider an infinite plane sheet of charge density σ. Let P be the point at a distance r from the sheet. E be the electric field at point P due to positive sheet of charges. Consider Gaussian surface in the form of a cylinder of cross-sectional area A perpendicular to the sheet of charge. The direction of E is perpendicular to face containing P and parallel to the curved surface.

Since we know by Gauss's law

$$\text{Total electric flux} = \frac{1}{\varepsilon_0} \times \text{(Charge enclosed by the closed surface)}$$

$$\Rightarrow \quad \Phi_E = \frac{1}{\varepsilon_0} \times (Q)$$

As surface charge density σ = Q/A or,

$$\Rightarrow \quad \sigma A = Q$$

So above equation becomes:

$$\Rightarrow \quad \Phi_E = \frac{\sigma A}{\ } \qquad \text{-------(1)}$$

Flux through the surfaces of Gaussian surface

Now we calculate the electric flux through each of the three surfaces of Gaussian cylinder.

i) Flux through right end flat surface

$$\Phi_{e_1} = \vec{E} \cdot \vec{A}$$
$$\Phi_{e_1} = E A \cos 0^\circ \qquad (\because \theta = 0^\circ)$$
$$\Phi_{e_1} = E A (1)$$
$$\Phi_{e_1} = EA$$

ii) Flux through left end flat surface

$$\Phi_{e_2} = \vec{E} \cdot \vec{A}$$
$$\Phi_{e_2} = E A \cos 0^\circ \qquad (\because \theta = 0^\circ)$$
$$\Phi_{e_2} = E A (1)$$
$$\Phi_{e_2} = EA$$

iii) Flux through curved surface

As no field lines pass through the curved surface, so

$$\Phi_{e_3} = 0$$

Hence, the total flux through the cylinder is,

$$\Phi_e = \Phi_{e_1} + \Phi_{e_2} + \Phi_{e_3}$$
$$\Phi_e = EA + EA + 0$$
$$\Phi_e = 2\,EA \quad \underline{\qquad\qquad} \ (2)$$

Comparing equation (1) and (2),

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

$$\Rightarrow \quad E = \frac{\sigma}{2\varepsilon_0} \qquad \ldots. (11.15)$$

In vector form

$$\text{and} \quad \vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{r} \qquad \ldots. (11.16)$$

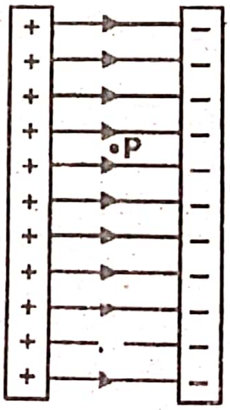
Where $\hat{r}$ is the unit vector normal to the sheet and directed away from sheet.

Q.14 Evaluate the electric intensity between two oppositely charged parallel plates.

Ans.

Electric field intensity between two oppositely charged parallel plates.

Consider two parallel and closely spaced metal plates of infinite extent separated by vacuum. Let the plates have opposite charge. The charges are uniformly distributed and are concentrated over the inner surface of plate. Electric field starts from inner surface of positively charged metal plate and end on negative charges on the inner face of the other plate.



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

Gaussian Surface

Consider a Gaussian surface in form of hollow box, whose top is inside the upper metal plate and the bottom is in space between the plates, as shown in figure.

Charge enclosed

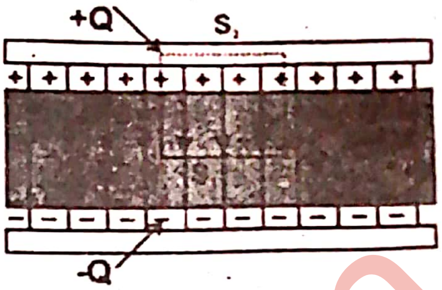
Let

A = surface area of the top / lower surface of the hollow box.

σ = uniform surface charge density.

Then, the charge enclosed by the Gaussian surface is

$$q = \sigma A \quad \text{\_\_\_\_\_\_\_\_} (1)$$



Dotted rectangle represents the cross section of Gaussion box with its lop inside the upper metal plate and its bottom in the dielectric between the plates.

Flux through the surface

Now we calculate the electric flux through each surface of hollow box.

i) Flux through sides of the box

As the field lines are parallel to the sides of the box. So flux through the sides is **zero**.

ii) Flux through upper surface of the box

As there is no field inside the metal plate. So flux through the upper end of the box is also **zero.**

iii) Flux through lower surface of the box

The flux through the lower surface of the box is given by,

$$\Phi_e = \vec{E} \cdot \vec{A}$$

$$\Phi_e = E A \cos 0^\circ \qquad (\because \theta = 0^\circ)$$

$$\Phi_e = E A (1)$$

$$\Phi_e = EA$$

Total flux through the box

Hence net flux through the box is,

$$\Phi_e = EA \quad \text{\_\_\_\_\_\_\_\_} (2)$$

Calculation of electric intensity

According to Gauss's Law:

$$\Phi_e = \frac{1}{\varepsilon_o}(q) \quad \text{\_\_\_\_\_\_\_\_} (3)$$

Using equations (1) and (2) in equation (3), we have

$$EA = \frac{1}{\varepsilon_o}(\sigma A)$$

or

$$\boxed{E = \frac{\sigma}{\varepsilon_o}}$$

In vector form, $\vec{E} = [\frac{\sigma}{\varepsilon_o}]\hat{r}$

This shows that electric field is same at all the points between the plates and $\hat{r}$ is the unit vector directed from positive to negative plate.

MCQ's From Past Board Papers

1. **SI unit of Electric flux is:**
(A) NmC^{-1} (B) $Nm^{-1}C^{-1}$ (C) Nm^2C^{-1} (D) Nm^3C^{-2}

2. **Total Flux through a closed surface depends on:**
(A) Shape of Surface (B) Charge enclosed only (C) Medium Only (D) Both b & c

3. **Equation $\phi = \vec{E} \cdot \vec{A}$ is applicable to a surface:**
(A) Spherical (B) Cylindrical (C) Conical (D) Flat

4. **The Electric Intensity near an Infinite plate of positive charge will be ________.**
(A) $\frac{q}{\varepsilon_o}$ (B) $\frac{\sigma}{2\varepsilon_o}$ (C) $\frac{q}{A}$ (D) None of these

5. **Electric intensity inside the hollow sphere is:**
(A) $\frac{\sigma}{\varepsilon_0}$ (B) $\frac{\sigma}{2\varepsilon_0}$ (C) $\frac{1}{\varepsilon_0}$ (D) Zero

6. **Which one of the following can be taken as measure of electric field intensity:**
(A) $\frac{F}{A}$ (B) $\frac{\phi e}{A}$ (C) $\frac{qA}{\varepsilon_o}$ (D) $\frac{\phi\varepsilon_o}{A}$

7. **A charged conductor has charge on its:**
(A) Inner-surface (B) Outer-surface (C) Middle point (D) Surrounding space

8. **For computation of electric flux, the surface area should be**
(A) Parallel (B) Flat (C) Curved (D) Spherical

9. **The electric flux through closed surface depends upon.**
(A) Charge (B) Medium (C) Geometry (D) Charge and medium

10. **Electro Encephalo Graphy (EEG) is the diagnostic test for the working of**
(A) eyes (B) heart (C) brain (D) lungs

11. **Unit of electric flux is;**
(A) $\frac{N}{C}$ (B) $\frac{N.m}{C}$ (C) $\frac{N.m^2}{C}$ (D) $\frac{m^2}{C}$

12. **The SI unit of electric flux is:**
(A) $N\ mc^{-2}$ (B) $N\ m^2C^{-1}$ (C) $N\ C\ m^{-2}$ (D) $N\ m\ c^2$

13. **Total Flux through a closed surface depends on:**
(A) Shape of Surface (B) Charge enclosed only (C) Medium Only (D) charge and Medium

Answers Key

1. C	2. D	3. D	4. B	5. D	6. B	7. B	8. B	9. D	10. B	11. C	12. B	13. D

Q.15 Define Electric Potential Difference and Absolute Electric Potential.

Potential Difference:

"Potential difference between two points is the work done in moving a unit positive charge from one point to another keeping the charge from one point to another keeping the charge in electrostatic equilibrium."

Explanation:

P.E. And K.E. Of The Charge In Electric Field: Let us consider a positive charge +q placed in oppositely charged parallel plates. A charge experienced a force in an electric field. If the charge is allowed to move freely in an electric field it will move from plate A to plate B and acquire kinetic energy as shown in Fig: 11.23 (a). On the other hand external force is required to move the charge against electric field. In order to move the charge q_o, with uniform velocity from B to A an external force F must be applied which is equal and opposite to q_oE as shown in Fig 11.23(b). This force will maintain the equilibrium by preventing the charge q_o from acceleration while moving from A to B.

Let W_{BA} be the work done by the force in carrying a positive charge q_o from point B to point A without disturbing the equilibrium state of the charge. The change in potential energy ΔU of charge q_o is defined to be equal to the work done by the force in carrying the charge q_o from one point to the other against the electrical field, i.e.

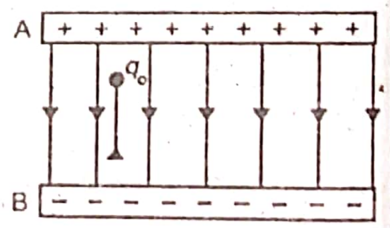
$$\Delta U = W_{BA}$$

$$U_A - U_B = W_{BA} \qquad \text{.... (11.18)}$$

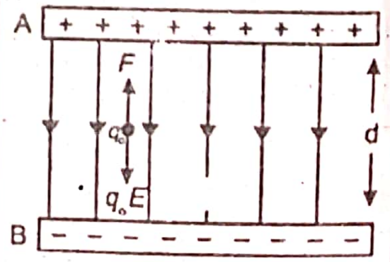
Where U_A and U_B represent the potential energies at point A and B respectively.

If this charge is released from point A, it will move from A to B and will gain an equivalent amount of K.E.

Potential Difference: Potential difference between two points is the work done in moving a unit positive charge from one point to another keeping the charge from one point to another keeping the charge in electrostatic equilibrium. It implies that.



Potential difference between point A & B in electric field.



Potential difference between point A & B in electric field.

$$\frac{\Delta U}{q_o} = \frac{W_{BA}}{q_o} \qquad \text{.... (11.19)}$$

$$\Rightarrow \frac{\Delta U}{q_o} = \frac{U_A}{q_o} - \frac{U_B}{q_o} = V_A - V_B = \Delta V \quad \text{.... (1)}$$

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

The defining equations give $U_A = q_oV_A$ and $U_B = q_oV_B$

Thus $\Delta U = q_o \Delta V = W_{BA}$ .... (11.20)

Where ΔV is potential difference between A and B.

Volt: Its SI unit is volt.

$$1 \text{ volt} = \frac{1 \text{ Joule}}{1 \text{ Coulomb}}$$

One volt is the potential difference between two points in an electric field if one joule of work is done in moving one coulomb of charge from the one point to the other.

Other multiples and sub-multiples of volt are

1 milli volt (mV) = 10^{-3} V, 1 micro volt (μV) = 10^{-6} V

1 kilo volt (mV) = 10^{3} V, 1 mega volt (MV) = 10^{6} V

1 giga volt (GV) = 10^{9} V

It is scalar.

ELECTRIC POTENTIAL:

"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."

Its SI unit is also volt. It is scalar.

As $\Delta V = \frac{W_{BA}}{q_o}$

Or $V_A - V_B = \frac{W_{BA}}{q_o}$

If point A is at infinity, then $V_B = V_\infty = 0$

So $V_A - 0 = \frac{W_{\infty A}}{q_o}$

In general,

$$V = \frac{W}{q_o}$$

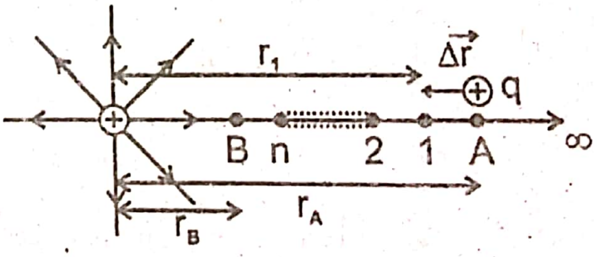
Where V is the absolute potential

Q.16 Derive a relation for the electric potential (or absolute potential) at a certain point due to a point charge.

Ans.

Electric potential due to a point charge consider an isolated charge +Q fixed in space as shown.

Let a test charge q_o is moved from point A to point B against the electric field of charge Q keeping the electrostatic equilibrium. Let r_A and r_B be distances of point A and point B from charge Q. We divide the distance between A and B into infinite simally small displacements (as shown) so that the field intensity E over each displacement remains same.



Since $E = \frac{1}{4\pi\epsilon_o}\frac{Q}{r^2}$ ⇒ $E \propto \frac{1}{r^2}$

Let the test charge q is moved from A to 1 in first step,

So $\frac{1}{<r^2>} = \frac{1}{<r\,r>} = \frac{1}{r_A r_1}$

So, $E = \frac{1}{4\pi\epsilon_o}\left(\frac{Q}{r_A r_1}\right)$ ... (1)

Work done in moving the test charge q from A to 1 is:

$$\Delta W_{A\to 1} = \vec{F}\cdot\vec{d}$$

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

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

Since $\quad Q = 180^\circ$ because q is moved against electric field E.

$$\Rightarrow \Delta W_{A\to 1} = qE\,\Delta r \cos 180$$

$$\Delta W_{A\to 1} = qE\,\Delta r\,(-1)$$

Put value of E from eq (1)

$$\Delta W_{A\to 1} = -q\,E\,\Delta r$$

$$= -q\left(\frac{1}{4\pi\epsilon_o}\frac{Q}{r_A r_1}\right)(r_1 - r_A)$$

$$= \frac{1}{4\pi\epsilon_o}\frac{Qr}{r_A r_1}(r_1 - r_A)$$

$$= \frac{Qq}{4\pi\epsilon_o}\left(\frac{r_A - r_1}{r_A - r_1}\right)$$

$$\Delta W_{A\to 1} = \frac{Qq}{4\pi\epsilon_o}\left(\frac{r_A}{r_A r_1} - \frac{r_1}{r_A r_1}\right)$$

$$\Delta W_{A\to 1} = \frac{Qq}{4\pi\epsilon_o}\left(\frac{1}{r_1} - \frac{1}{r_A}\right)$$

Similarly

$$\Delta W_{1\to 2} = \frac{Qq}{4\pi\epsilon_o}\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$$

....

....

$$\Delta W_{n\to B} = \frac{Qq}{4\pi\epsilon_o}\left(\frac{1}{r_B} - \frac{1}{r_n}\right)$$

So total work done in moving the test charge q from A to B is:

$$\Delta W_{A\to B} = \Delta W_{A\to 1} + \Delta W_{1\to 2} + \ldots\ldots\ldots\ldots\ldots\ldots \Delta W_{n\to B}$$

$$= \frac{Qq}{4\pi\epsilon_o}\left(\frac{1}{r_1} - \frac{1}{r_A}\right) + \frac{Qq}{4\pi\epsilon_o}\left(\frac{1}{r_2} - \frac{1}{r_1}\right) + \ldots\ldots + \frac{Qq}{4\pi\epsilon_o}\left(\frac{1}{r_B} - \frac{1}{r_n}\right)$$

$$= \frac{Qq}{4\pi\epsilon_o}\left(-\frac{1}{r_A} + \cancel{\frac{1}{r_1}} - \cancel{\frac{1}{r_1}} + \cancel{\frac{1}{r_2}} \ldots\ldots\ldots\ldots + \cancel{\frac{1}{r_n}} - \cancel{\frac{1}{r_n}} + \frac{1}{r_B}\right)$$

$$\Delta W_{A\to B} = \frac{Qq}{4\pi\epsilon_o}\left(-\frac{1}{r_A} + \frac{1}{r_B}\right) = \frac{Qq}{4\pi\epsilon_o}\left(\frac{1}{r_B} - \frac{1}{r_A}\right)$$

Let point A lies at infinity i.e., $r_A = \infty$ then

$$\Delta W_{\infty\to B} = \frac{Qq}{4\pi\epsilon_o}\left(-\frac{1}{r_B} - \frac{1}{\infty}\right) = \frac{Qq}{4\pi\epsilon_o}\left(\frac{1}{r_B} - 0\right)$$

$$\Rightarrow \Delta W_{\infty\to B} = \frac{Qq}{4\pi\epsilon_o}\left(\frac{1}{r_B}\right) \quad \ldots.(2)$$

This work done on charge q is stored as electric P.E. U

$$\Rightarrow u = \frac{Qq}{4\pi\epsilon_o}\left(\frac{1}{r}\right)$$

From eq (2)

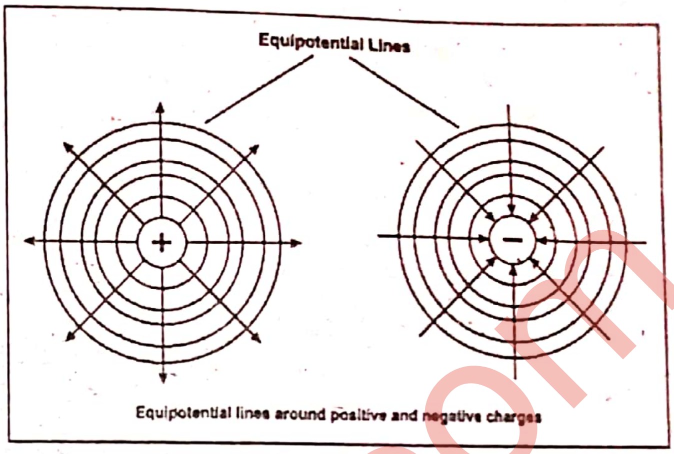
$$\frac{\Delta W_{\infty\to B}}{q} = \frac{Q}{4\pi\epsilon_o}\left(\frac{1}{r_B}\right), \text{ so}$$

$$\boxed{V = \frac{1}{4\pi\epsilon_o}\frac{Q}{r}}$$

Q.17 What are equipotential lines or equipotential surfaces? DG KHAN 2018

Field and Potential Gradient:

"These are such surfaces on which all the points are on the same potential and electric field along these surfaces is zero."



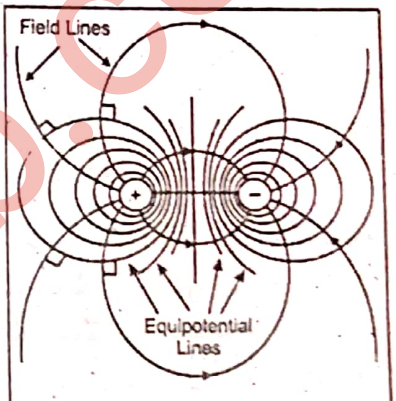
Equipotential lines around positive and negative charges

Explanation:

Electric fields is very difficult to represent in a diagram. Both strength and direction can be indicated at every point in the field. As an alternative to field-line diagrams, 'contour maps' of the electric field can be drawn using equipotential lines. An equipotential line connects points in space where the potential of an electric field is the same as shown in fig (11.26).

Equipotential Surfaces around A Point Charge:

Electric potential due to a point charge at distance r is given by formula: $V = \frac{q_o}{4\pi\varepsilon_o r}$



Equipotential lines due to two chages

So all points at the same distance r from the charge will have the same potential – the equipotential lines form circle centered on the charge.

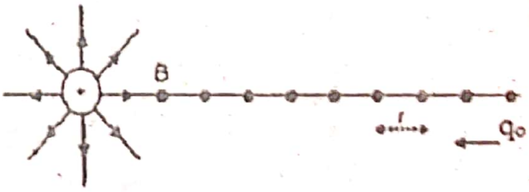
Equipotential Surfaces due to two or more Point Charge:

If there are two or more charges present, then the potential due to each charge. Potential is a scalar quantity. However; potential can be either positive or negative, depending upon the sign of the charge.

The same basic idea is true on equipotential map, the closer the lines are together; the stronger the field is at that point if the equipotential lines are close together, the electric potential energy must be changing by large amounts in small distances, and there must be a large force acting.

Q.18 Derive the relation between electric field and electric potential gradient.

OR Show that, $\vec{E} = -\frac{\Delta V}{\Delta r}$



Let a test charge q_o is moved with uniform velocity (in equilibrium) against the electric field through displacement Δr, then work done by the electric force is:

$$W = F\, d \cos\theta$$

$$\Rightarrow \quad W = q_oE\,\Delta r \cos 180^\circ$$

$$\Rightarrow \quad W = q_oE\,\Delta r\,(-1)$$

$$\Rightarrow \quad W = -q_oE\,\Delta r \qquad \text{----------(i)}$$

As the charge q_o is moved between two points having potential difference ΔV then work done on the charge can be calculated by formula:

$$W = q_o\,\Delta V \qquad \text{----------(ii)}$$

Comparing equation (i) and (ii),

$$\Rightarrow \quad q_o\,\Delta V = -q_oE\,\Delta r$$

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

So,

$$\Rightarrow \quad E = -\frac{\Delta V}{\Delta r} \qquad \text{.... (11.28)}$$

Potential gradient

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

The strength of the field is equal to the potential gradient.

We may also define the electric field strength as, ***the negative of potential gradient.***

OR *"The rate of change of electric potential ΔV with respect to displacement. Δr is known as potential gradient."*

The negative sign indicates that the direction of the field is opposite to the direction in which the potential is increasing i.e. electric field is in the direction of decreasing potential.

This relationship between field strength and potential gradient is analogous to gravitational fields.

Q.19 Define electron volt (eV).

The Electron Volt (eV):

"One electron volt is the amount of energy acquired or lost by an electron when it is displaced across two points in the electric field between which potential difference is one volt."

By definition

$\Delta(KE) = 1\ \text{eV}$, when $q = e = 1.602\times10^{-19}$ C and $\Delta V = 1$ V.

Thus $\Delta(KE) = W = q\,\Delta V$

$$1\ \text{eV} = 1.602\times10^{-19}\ \text{C}\times1\ \text{V}$$
$$= 1.602\times10^{-19}\ \text{J}$$

The electron volt (eV) is just another unit of energy like the joule.

This is the smaller unit of energy. Its bigger units are multiples of 1 eV that are in frequent use are given below.

1 Million electron volt = 1 Mev = 10^6 eV

1 Giga electron volt = 1 GeV = 10^9 eV

Q.20 Show that $\frac{\text{volt}}{\text{meter}} = \frac{\text{newton}}{\text{coulomb}}$

Ans. **Proof**

$$\text{L.H.S.} = \frac{\text{volt}}{\text{meter}}$$
$$= \frac{\text{joule}/\text{coulomb}}{\text{meter}}$$
$$= \frac{\text{joule}}{\text{coulomb meter}}$$
$$= \frac{\text{newton meter}}{\text{coulomb meter}}$$
$$= \frac{\text{newton}}{\text{coulomb}}$$
$$= \text{R.H.S.}$$

Hence, $\frac{\text{volt}}{\text{meter}} = \frac{\text{newton}}{\text{coulomb}}$

MCQ's From Past Board Papers

1. A Particle carrying a charge of 2e falls through potential difference of 3V. The energy acquired by it will be
(A) 1.5 eV (B) 0.66 eV (C) 6 eV (D) 3 eV
2. Two opposite point charge of same magnitude separated by distance 2d, electric potential mid-way between them is:
(A) 1V (B) 2V (C) Zero (D) $\frac{V}{2}$
3. The work done in moving a positive charge on an equipotential surface is:
(A) Finite and Positive (B) Infinite (C) Finite and Negative (D) Zero

4. **Electric field inside a hollow charge conducting sphere are ______.**
(A) 0 (B) $\frac{1}{4\pi\varepsilon_0}\frac{q}{r}$ (C) $\frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$ (D) None of these

5. **One Electron Volt is equal to ______.**
(A) 6.25×10^{18} Joule (B) 6.25×10^{-18} Joule (C) 1.6×10^{-19} Joule (D) 1.6×10^{19} Joule

6. **A particle having 2 e charge falls through a potential difference of 5 V. Energy acquired by it is___**
(A) 2.5 e V (B) 20 e V (C) 0.4 e V (D) 10 e V

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

8. **A particle carrying a charge of 2e falls through potential difference of 3V. Energy acquired by it is:**
(A) 9.6×10^{-18}J (B) 9.6×10^{-20}J (C) 9.6×10^{-15}J (D) 9.6×10^{-19}J

9. **The amount of energy acquired or lost by an alpha particle as it moves through p.d. of 1 V is:**
(A) 3.2×10^{-19} J (B) 6.4×10^{-19} J (C) 1.6×10^{-19} J (D) Zero

10. **A particle having 2e charge falls through a potential difference of 5V. Energy acquired by it is**
(A) 2.5 eV (B) 20 eV (C) 0.4 eV (D) 10 eV

11. **Special organs called Ampullae of Lorenzini that are very sensitive to electric field are found in**
(A) Cats (B) Dogs (C) Bats (D) Sharks

12. **If a charged body is moved against the electric field, it will gain:**
(A) P.E (B) K.E
(C) Mechanical energy (D) Electrical potential energy

13. **One Joule is equal to:**
(A) 1.6×10^{-19} eV (B) 1.6×10^{19} eV (C) 6.25×10^{-18} eV (D) 6.25×10^{18} eV

14. **The electron volt is the unit of**
(A) electric current (B) electric energy (C) potential (D) potential difference

15. **The relation "$\frac{-\Delta V}{\Delta r}$" represents**
(A) Gauss's Law (B) Electrical flux (C) Electric intensity (D) Potential difference

16. **Two opposite point charge of same magnitude separated by distance 2d, electric potential mid-way between them is:**
(A) 1V (B) 2V (C) Zero (D) $\frac{V}{2}$

17. **The quantity $\frac{\Delta V}{\Delta r}$ is called:**
(A) Electric potential (B) Electric energy (C) Potential barrier (D) Potential gradient

18. **The work done in bringing a unit positive charge from infinity to that point in an electric field is called.**
(A) Potential (B) Potential difference (C) Absolute potential (D) All of these

19. **The absolute Electric potential at a point distance 20cm from a charge of 2 μc is**
(A) 9×10^2 V (B) 9×10^3 V (C) 9×10^4 V (D) 9×10^5 V

20. **The amount of energy is equal to 1.6×10^{-19} J is called**
(A) One volt (B) one milli volt (C) One electron volt (D) One mega electron volt

Answers Key

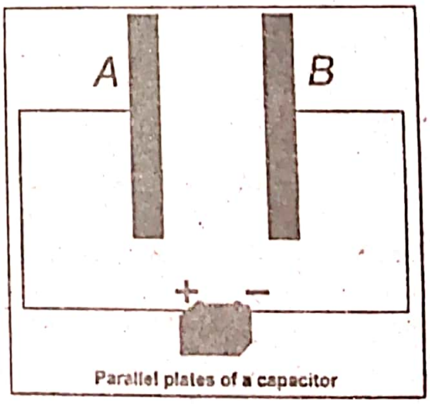
1. C	2. C	3. C	4. A	5. C	6. D	7. A	8. D	9. A	10. D	11. D	12. D
13. D	14. B	15. C	16. C	17. D	18. C	19. C	20. C				

Q.22 What is a capacitor and capacitance of a capacitor? Give SI Unit of Capacitance.

Ans.

Capacitor:

A device which is used for storing electric charges for long period of time, is called capacitor.



Parallel plates of a capacitor

Parallel Plate Capacitor:

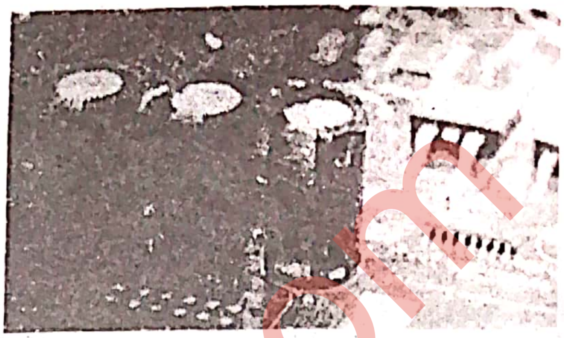
It consists of two parallel metal plates, separated by small distance. The medium between the two plates is air or a sheet of some insulator. This medium is known as dielectric.

Charging of Parallel Plate Capacitor:

When a charge is transferred to one of the plate say (A), then due to electrostatic induction, it would induce charge Q on the inner surface of the other plate B.

The capacitor is commonly charged by connecting its plate for a while to the opposite terminals of a battery. this way some electrons are transferred through the battery from the positive plate to the negative plate. Charge +Q and Q appear on the plates. Mutual attraction between the charges keeps them bound on the inner surface of two plates an thus the charge remains stored in the capacitor even after removal of the battery.

Capacitance of a capacitor and its unit:



Capacitors use in different electronic devices

The capability of a capacitor to store charges is called its capacitance.

Capacitor Equation:

When a charge Q is transferred on one of the plates of a capacitor, the potential difference V between the plates also increases. In other words, the charge 'Q' on the plate of a capacitor is directly proportional to the electric potential difference V between them i.e.

$$Q \propto V$$

$$Q = CV \qquad \ldots (11.29)$$

$$\Rightarrow \quad C = \frac{Q}{V}$$

Where C is a constant of proportionality, called the **capacitance of capacitor**.

Dependence of Capacitance

Capacitance depends upon the following factors;

1) **Geometry** of the capacitor i.e. area of the plates and separation between the plates.
2) The **medium** between the plates.

Definition of capacitance

The capacitance can be defined as the amount of charge on plates which produces a potential difference of one volt between the plates.

Unit of Capacitance

SI unit of capacitance is farad.

$$1 \text{ farad} = \frac{1\,\text{coulomb}}{1\,\text{volt}}$$

OR

$$1\,\text{F} = \frac{1\,\text{C}}{1\,\text{V}}$$

Definition of farad

The capacitance of a capacitor is said to be 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.

Convenient sub-multiples of farad are:

1 μF (micro Farad) = 10^{-6} F & 1μμF (Pico Farad) = 10^{-12} F

Q.23 Derive an expression for capacitance of a parallel plate capacitor.

D.G.Khan – 2017, Rwp – 2017, SGD – 2017

Ans.

Capacitance of a Parallel Plate Capacitor:

Consider a parallel plate capacitor as shown in figure. Let A is the area of each plate, d is the distance between the plates, Q is the charge stored on each plate, V is the potential difference between the plates, E is the electric field betweer the plates and σ is the surface charge density on plates.

i) Capacitance when air or vacuum between the plates

Let there is air or vacuum between the plates of the capacitor. Then

$$C_{vac} = \frac{Q}{V} \qquad \text{\_\_\_\_\_\_\_\_} (1)$$

We know that

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

OR $$V = E\,d \quad \text{——————} (2)$$

As electric intensity between two oppositely charged plates is given by

$$E = \frac{\sigma}{\varepsilon_o} \quad \text{——————} (3)$$

Putting this value of E in equation (2), we get

$$V = \frac{\sigma d}{\varepsilon_o} \quad \text{——————} (4)$$

Also, the surface density of charge on the plates is given by

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

OR $$Q = \sigma A \quad \text{——————} (5)$$

Using equations (4) and (5) in Equation (1), we get

$$C_{vac} = \frac{\sigma A}{\left(\frac{\sigma d}{\varepsilon_o}\right)}$$

OR $$C_{vac} = \frac{A\varepsilon_o}{d} \quad \text{——————} (6)$$

ii) With dielectric as the medium

When a dielectric is inserted between the plates of a capacitor, then it is seen that the charge storing capacity of a capacitor is enhanced by the dielectric which permits it to store ε_r times more charge for the same potential difference. *ε_r is a dimensionless quantity which is always greater than unity for dielectric and is independent of the size and shape of the dielectrics. It is called dielectric constant or relative permittivity.*

In case of a parallel plate capacitor completely filled with a dielectric the capacitance is

$$C_{med} = \frac{\varepsilon_o\varepsilon_r A}{d} \quad \ldots.. (11.32)$$

Dependance:

Eq 11.32: shows the dependence of capacitance upon the area of the plates, the separation between the plates and the medium between them. The larger the plates, the closer they are and higher the dielectric constant of the separating medium the greater will be the capacitance of the capacitor.

Relative Permittivity or Dielectric Constant or Specific Inductive Capacity (ε_r)

$$\varepsilon_r = \frac{C_{med}}{C_{vac}} \quad \ldots. (11.33)$$

"The ratio of the capacitance of a capacitor with a given material filling the space between the conductors to the capacitance of the same capacitor when the space is evacuated is the relative permittivity ε_r of the material."

Q.24 Describe series and parallel combination of capacitors. D.G.Khan – 2017, Rwp – 2017, SGD – 2017

Ans.

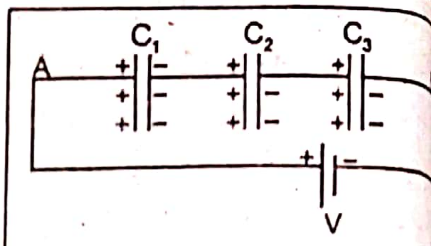
Combination of Capacitor:

We know that the capacitors can be connected either in series or in parallel. We want to find out an equivalent capacitor that has the same capacitance as that of the combination of capacitors.

Series Combination of Capacitors:

Definition:

When the capacitors are connected plate to plate i.e. the right plate of one capacitor is connected to the left plate of the next capacitor so on as shown in fig: 11.30 (a) it is called series combination.



Series combination of capacitors

Properties:

i. Charge on each capacitor in combination will be same.

A battery of voltage V is connected between points A and B. Then it supplies +Q charge to the left plates of the capacitor C and –Q charge is induced on its right plates. As a result of this charging each capacitor gets an equal amount of charge Q on each of its plates.

$$Q_1 = Q_2 = Q_3 = Q$$

ii. Potential difference on each capacitor will be different.

$$V_1 = \frac{Q}{C_1},\ V_2 = \frac{Q}{C_2},\ \&\ V_3 = \frac{Q}{C_3}$$

iii. The potential difference V must be equal to the sum of potential difference, V_1, V_2 & V_3 across the capacitors i.e

$$V = V_1 + V_2 + V_3 \qquad \text{(i)}$$

We have $V = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$

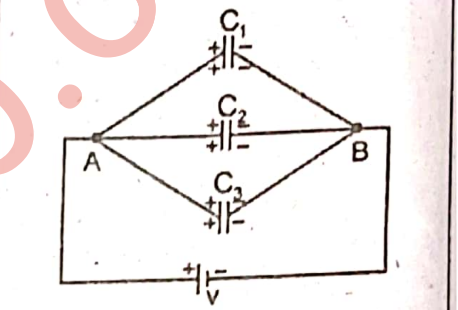
or $V = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$

Let Ce be the capacitance of equivalent capacitor, which would hold the same charge when the potential difference V is applied. That is

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

Therefore $\frac{Q}{C_e} = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$

$$\text{Or } \frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \qquad \text{.... (11.34)}$$



Parallel combination of capacitors

- ➤ *The equivalent capacitance of a series combination is always less than any individual capacitance in the combination.*
- ➤ *By connecting more capacitors in series combination, equivalent capacitance decreases.*

Parallel Combination of capacitors:

Definition:

When two or more capacitors are connected between the same two points in a circuit, as shown in fig: 11.30(b), then it is called parallel combination of capacitors.

Properties:

i. The potential difference between the plates of each capacitor is the same and its equal to the applied potential difference V

i.e. $V = V_1 = V_2 = V_3$.

ii. The charge on each capacitor will be different, depending upon their capacitance.

$$Q_1 = C_1V,\ Q_2 = C_2V,\ Q_3 = C_3V$$

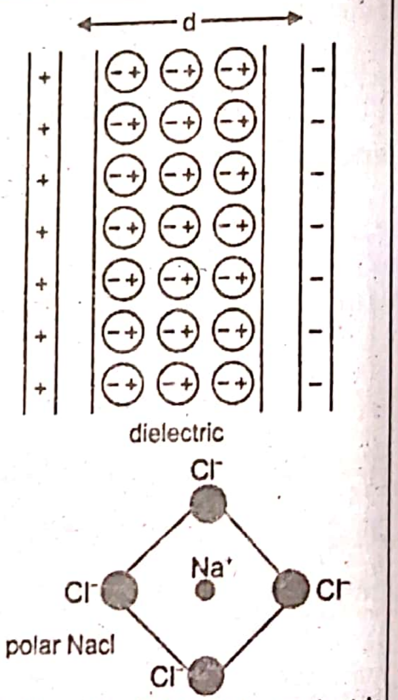
iii. Sum of the charges on different capacitors is equal to the total charge Q supplied to the parallel combination.

$$Q = Q_1 + Q_2 + Q_3$$

$$\Rightarrow C_eV = C_1V + C_2V + C_3V = (C_1 + C_2 + C_3)V$$

$$Ce = C_1 + C_2 + C_3$$

- ➤ *Thus the equivalent capacitance of a parallel combination is always larger than any individual capacitance in the combination.*
- ➤ *By connecting more capacitors in parallel combination, equivalent capacitance increases.*



Polarization of a dielectric in an electric field gives rise to thin layers of bound charges on the surfaces, creating positive and negative surface charge densities.

Q.25 Explain the phenomenon of electric polarization of dielectrics. What is the effect of polarization of dielectrics on the capacitance of a capacitor.

Ans.

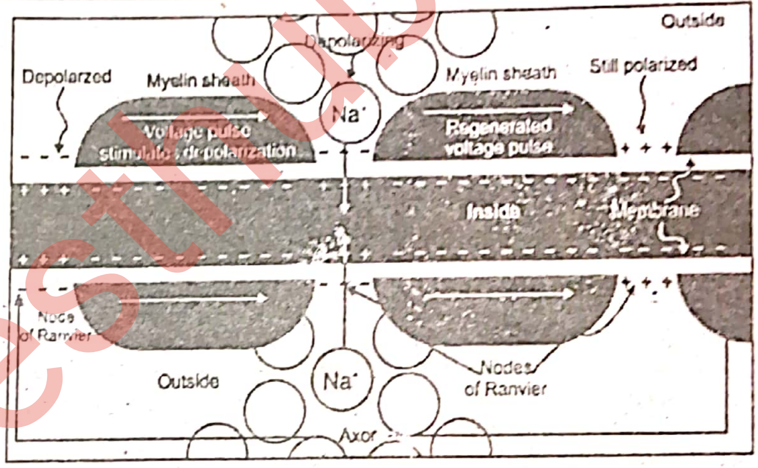
Electric Polarization:

When a dielectric material is placed in an electric field, the negative and positive charges of atoms/molecules of dielectric are slightly displaced, this phenomenon is called polarization and the dielectric is said to be polarized.

Explanation

When insulating material with relative permittivity (or dielectric constant) ε_r is inserted into an initially charged parallel plates of a capacitor. Then negative charges appear on the left face and positive charges on the right face of the dielectric as shown in fig11.31. The phenomenon is known as electric polarization and dielectric is said to be polarized under such condition. The charges on the dielectric faces are called induced charges; they are induced by the external field and appear on the dielectric face only. The electric field from the free charges is left to right whereas the electric field due to induced charges is right to left.

Molecules in the dielectric material have their positive and negative charges separated slightly due to electric field of the charged capacitor (Eo) , causing the molecules to be oriented slightly. As electric field due to induced charges is opposite to the external electric field so it reduces the intensity of external field due to oppositely charges plates of the capacitor.



An axon membrane acts as a capacitor. Axon of a resting human nerve cell has a potential difference of 65mV. Current enters the axon (or dendrite) through ion channels (e.g. Na+ channels) in a region of membrane, depolarizing that region. The intracellular + charge is attracted to adjacent negatively charged region of membrane.

Dipole:

"The system in which two charges of equal magnitude but of opposite sign separated by the distance d, are present is termed as a dipole."

OR

Two opposite point charge separated by a finite distance d constitutes a dipole."

Electric dipole moment is represented by P, which is equal to the product of the charge q present in the dipole and the distance d between the two charges of the dipole.

$$P = |q \times d|$$

It is a vector quantity.

Types of Dielectric Materials

We know that dielectric materials are made up of the two types of molecules; polar and non polar molecules.

Polar Molecules: A polar molecule behaves like a permanent dipole; although electrically neutral as a whole. For example in NaCl the end with Sodium ion is positive while the end with Chlorine ion is negative. Other examples are HF, HCl etc.

Non-Polar Molecule:

A non-polar molecule has no electric dipole moment in the absence of an external field. The center of positive and negative charges coincide in the absence of an external electric field. When a non-polar dielectric material is placed in an external field, it gets polarized, that is, it displaces the electrons to the opposite of electric field E as shown in fig. Under the action of external field the center of negative and positive charges shift and form dipoles

Q.26 Derive an Expression for Energy stored by the Capacitor.

Ans.

Energy Stored in A Capacitor

Capacitor is a device which is used to store the charge. In other words, it is a device for storing electric P.E. Because work is to be done to deposit charge on the plates against the repulsion of already existing charges. It increases the potential difference between plates and a large amount of work is needed to bring up next increment of charge. This work done on charges is stored as electric potential energy.

Energy Stored in a Capacitor:

Let us suppose that initially the capacitor is uncharged when voltage is zero. When it is connected to source of potential difference V, it is charged. Initially, when the capacitor is uncharged, the potential difference between the plates is zero ($V_i = 0$). Finally when charge +Q and (–Q) are deposited on the plates, the potential difference between the plates becomes V ($V_f = V$).

So, average potential difference V_{av} between plates of capacitor is:

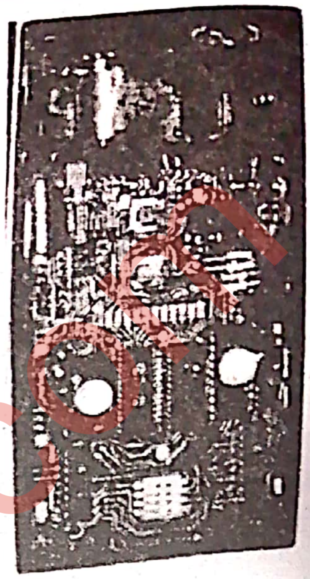
$$V_{av} = \frac{0+V}{2} = \frac{1}{2}V$$

Thus the energy stored in a capacitor, is

$$\text{Electric P.E.} = W = Q\,V_{av}$$

$$= Q\left(\frac{1}{2}V\right)$$

$$\text{Electric P.E. } (U_E) = \frac{QV}{2} \qquad \text{.... (11.37)}$$



Energy stored in the large capacitor is used to preserve the memory of an electronic calculator when its batteries are charged.

Where Q is the charge on a capacitor with a voltage V applied. Charge and voltage are related to the capacitance C of a capacitor by Q = CV and so the expression for U can be written in three equivalent expression as:

$$U_E = \frac{QV}{2}$$

$$= \frac{(CV)V}{2}$$

$$U_E = \frac{CV^2}{2} \qquad \text{.... (11.38)}$$

Put $Q = CV \Rightarrow V = \frac{Q}{C}$ in equation (11.37) , we get:

$$\Rightarrow U_E = \frac{Q^2}{2C}$$

Electric P.E. in the Form of Electric Field

It is also possible to regard the energy as being stored in the electric field between the plates rather than the potential energy of the charges on the plates. Such a view point is useful when the Electric field between the plates is considered rather than the charges on the plates causing the field is to be considered.

We know that

$$V = E\,d$$

and

$$C = \frac{A\varepsilon_r\varepsilon_0}{d}$$

Substituting these values in Eq. (11.38). We get

$$U_E = \frac{1}{2} \times \frac{A\,\varepsilon_r\varepsilon_0}{d} \times (Ed)^2$$

$$U = \frac{1}{2}\varepsilon_r\varepsilon_o\,E^2 \times (Ad) \qquad \text{.... (11.39)}$$

Energy Density:

The energy contained in a unit volume of the field is called energy density.

Let u denote the energy density that is, Then

$$u = \frac{\text{Energy}}{\text{Volume}} = \frac{U}{Ad}$$

$$u = \frac{1}{2}\varepsilon_r\varepsilon_o\,E^2 \qquad \text{.... (11.40)}$$

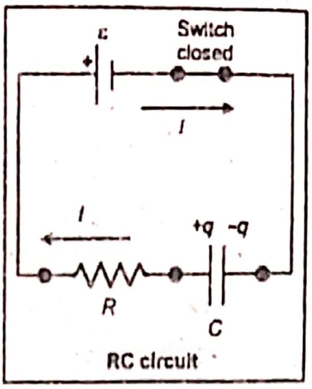
Q.27 Describe the charging and discharging of a capacitor. What is time constant?

Charging and Discharging a Capacitor:

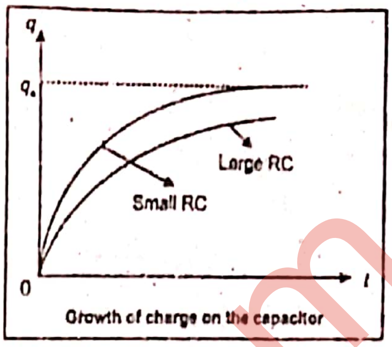
Electronic flashguns for cameras have to be left for a short period of time between flashes.

There is a capacitor inside that stores energy, it needs to be charged up again by the battery in the flashgun. The time taken for this depends on the rate at which the charge is flowing, which in turn is determined by the resistance of the circuit. It can take a couple of seconds before the capacitor is fully charged.

Fig (11.35) shows a resistor capacitor circuit called RC circuit.



RC circuit



Growth of charge on the capacitor

When the switch S is closed to connect the upper circuit, a battery of voltage V, starts charging the capacitor through the resistor R.

The charge builds up gradually on the plates to the maximum value of q_o. Suppose at $t = 0$ charge on a capacitor is zero i.e. $q = 0$.

It can be shown that after time t, as charge builds up on the plates, it repels more charge than is arriving, and the current drops as the charge on the plates increases. Charging will stop when the P.D. between the capacitor plates is equal to the e.m.f. of the battery.

maximum charge on capacitor = capacitance × e.m.f of battery

Experiments shows that the charging process of a capacitor exhibits the exponential behavior therefore we can write its Eq: as

$$q = q_o(1 - e^{-t/RC}) \qquad \text{.... (11.41)}$$

Where e is a constant. Its value is 2.7182 Fig (11.37) shows a graph between time t and charge q According to this graph, $q = 0$ at $t = 0$ and increases gradually to its maximum value q_o.

For Your Information

In principle, a capacitor can never charge up fully, because the rate of charging decreases as the charge increases. In practice, after a finite time the charging current becomes too small to measure, and the capacitor is effectively fully charged.

Time constant:

The time taken to charge a capacitor in a given circuit is determined by the time constant of the circuit. The bigger the capacitance, the longer it takes to charge the capacitor. The larger the resistance, the smaller the current, which also increases the charging time. The factor RC is called 'time constant. The time constant is the duration of time for the capacitor in which 63.2% of' its maximum value charge is deposited on the plates.

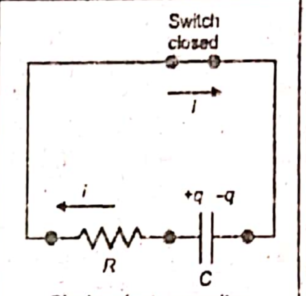
This can be seen by putting $t = RC$ in Eq (11.41)

$$q = q_o(1 - e^{-1}) = q_o\left(1 - \frac{1}{2.718}\right)$$

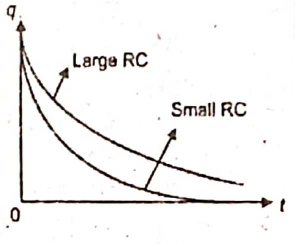
$$q = q_o(0.632)$$

$$\Rightarrow \frac{q}{q_o} = 0.632 = 0.632 \times \frac{100}{100}$$

$$\frac{q}{q_o} = 63.2\% \qquad \text{.... (11.42)}$$



Discharging a capacitor



Decay of charge of capacitor

The graph also shows that the charge reaches its maximum value sooner when the time constant is small.

Fig. 11.37: Illustrates the discharging of a charged capacitor through a resistor. When the switch S is closed the charge +q on the right plate can now flow clockwise through the resistance and neutralize the charge –q on the left plate. Assuming the fully charged capacitor beings discharging at time $t = 0$, it can be shown that charge left on either plate at time t is

$$q = q_o e^{-t/RC} \qquad \text{.... (11.43)}$$

The corresponding graph in fig. 11.38 shows that discharging begins at $t = 0$ when $q = q_o$, and decreases gradually.

Smaller values of time constant RC lead to a some rapid discharge. When t = RC, the magnitude of charge remaining each plate is,

$$q = q_o\,(0.367)$$

Thus,

$$\frac{q}{q_o} = 36.7\% \qquad \ldots.\ (11.44)$$

Q.27 What are applications of charging and discharging of capacitors?

Applications of Charging and Discharging of Capacitors

The charging and discharging of a capacitor has many applications.

- Capacitor discharge ignition (CDI) is a type of automotive electronic ignition system which is widely used in motorcycles, lawn mowers, chain saws, small engines, turbine powered aircraft, and some cars, it was originally developed to overcome the long charging times associated with high inductance coils used in inductive ignition systems, making the ignition system more suitable for high engine speeds (for small engines, racing engines and rotary piston engines). It can enhance the capability of power supply and make the spark much stronger.
- This is used as wind shield wipers of the automobiles.
- It is used in electronic flashguns in cameras.

Electronic Ignition Cdl

MCQ's From Past Board Papers

1. Energy stored in Capacitor is given by the relation.

(A) $\frac{1}{2}\varepsilon_o\varepsilon_r r^2$
(B) $\frac{1}{2}\varepsilon_o\varepsilon_r E^2 Ad$
(c) $\frac{1}{2}\frac{\varepsilon_o\varepsilon_r E^2}{Ad}$
(D) $\frac{1}{2}\varepsilon_o\varepsilon_r \frac{Ad}{E^{-2}}$

2. The product of resistance and capacitance is called:

(A) Force
(B) Time
(c) Velocity
(D) Current

3. Electron volt is the unit of:

(A) Potential
(B) Potential difference
(C) Electric current
(D) Electric energy

4. Due to polarization, electric field E

(A) Increases
(B) Decreases
(C) First increases then decreases
(D) Remains same

5. If Potential difference across two plates of a parallel plates capacitor is doubled then energy stored in it will be:

(A) Two times
(B) Eight times
(C) Four times
(D) Remain same

6. The energy stored per unit volume in the electric field between the plates of charged capacitor with dielectric is ________.

(A) $U = \frac{1}{2}\frac{\varepsilon_o}{\varepsilon_r}E^2$
(B) $U = \frac{1}{2}\frac{\varepsilon_r}{\varepsilon_o}E^2$
(C) $U = \frac{1}{2}\varepsilon_o\varepsilon_r E^2$
(D) $U = \frac{1}{2}\frac{E^2}{2\varepsilon_o\varepsilon_r}$

7. Presence of dielectric always:

(A) Increases the electrostatic force
(B) Decreases the electrostatic force
(C) Does not effect the electrostatic force
(D) Doubles the electrostatic force

8. The increase in capacitance of a capacitor due to presence of dielectric is due to ____ of dielectric.

(A) electric polarization
(B) electrification
(C) ionization
(D) electrolysis

9. Energy density in case of a capacitor is always proportional to:

(A) E^2
(B) ε_o
(C) V^2
(D) C

10. In a capacitor, energy is stored in the:

(A) magnetic field
(B) electric field
(C) gravitational field
(D) nuclear field

11. A capacitor stores energy in the form of:

(A) Magnetic field
(B) Heat energy
(C) Electrical energy
(D) Mechanical energy

12. A capacitor of 50 μF capacitance has P.D of 8 volt across its plates then charge on each plate of capacitor is:

(A) 4×10^{-10} C
(B) 4×10^{-6} C
(C) 400 C
(D) 4×10^{-4} C

13. When some dielectric is inserted between the plates of a capacitor, then capacitance.

(A) Increased
(B) Decreased
(C) Zero
(D) Infinity

14. A capacitor is perfect insulator for:
(A) Alternating current (B) Direct current (C) Both a & b (D) None of these

15. If medium of relative permittivity ε_r is present between plates of a capacitor, the capacitance is given by:
(A) $\frac{A\varepsilon_0\varepsilon_r}{d}$ (B) $A\varepsilon_0\varepsilon_r d$ (C) $\frac{A\varepsilon_0}{\varepsilon_r d}$ (D) $\frac{Ad\varepsilon_0}{\varepsilon_r}$

16. A dielectric material is placed between plates of parallel plate capacitor. Its capacitance increases due to:
(A) polarization (B) rectification (C) magnification (D)increased electric field

17. In the time constant of RC circuit, how much charge is stored, out of maximum charge q_o?
(A) 0.37 q_o (B) 0.51 q_o (C) 0.63 q_o (D) 0.90 q_o

18. farad is defined as:
(A) $\frac{\text{Coulomb}}{\text{Volt}}$ (B) $\frac{\text{Ampere}}{\text{Volt}}$ (C) $\frac{\text{Coulomb}}{\text{Joule}}$ (D) $\frac{\text{Joule}}{\text{Coulomb}}$

19. The increase in capacitance of a capacitor due to presence of dielectric is due to _____ of dielectric.
(A) Electric polarization (B) Electrification (C) Ionization (D) Electrolysis

20. Capacitance of a capacitor does not depend upon:
(A) Distance between plates (B) Area of plates
(C) Electric field between plates (D) Medium between plates

21: If the separation between the plates of a capacitor is doubled then its capacitance become
(A) Double (B) Half (C) One fourth (D) Three times

22. When dielectric is placed between the plates of capacitor, The value of E between the plates
(A) Increase (B) Zero (C) Decrease (D) infinite

23. Capacitance of a Capacitor in Vacuum is given by
(A) $\frac{A\varepsilon_0}{d}$ (B) $\frac{A\varepsilon_r}{d}$ (C) $\frac{Ad}{\varepsilon_0}$ (D) $\frac{A}{\varepsilon_0 d}$

24. The product of resistance and capacitance is equal to:
(A) Velocity (B) Force (C) Acceleration (D)Time

25. Coulomb/volt is called:-
(A) farad (B) ampere (C) joule (D) henry

26. A capacitor of capacitance 'C' has a charge 'Q' and stored energy is 'W'. If the charge is increased to '2Q'. The stored energy will be:
(A) $\frac{W}{4}$ (B) $\frac{W}{2}$ (C) 2W (D) 4W

Answers Key

1. B	2. B	3. D	4. B	5. C	6. C	7. B	8. A	9. A	10. B	11. A	12. D
13. A	14. B	15. A	16. A	17. C	18. A	19. A	20. C	21. B	22. C	23. A	24. D
25. A	26. C										

FORMULAE

1	Coulomb's Law	$F_{vac} = \frac{1}{4\pi\varepsilon_o}\frac{q_1q_2}{r^2}$	$F_{med} = \frac{1}{4\pi\varepsilon_o\varepsilon_r}\frac{q_1q_2}{r^2}$	
2	Electrostatics constant	$k = \frac{1}{4\pi\varepsilon_o}$		
3	Electric intensity	$E = \frac{F}{q}$	$\vec{E} = \frac{\vec{F}}{q}$	
4	Electric intensity due to point charge	$E = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}$	$\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}\hat{r}$	

5	Electric flux	$\phi=\vec{E}\cdot\vec{A}$	$\phi=EA\cos\theta$	
6	Electric flux through closed surface	$\phi=\frac{q}{\varepsilon_0}$		
7	Gauss's Law for electrostatics	$\phi=\frac{1}{\varepsilon_0}\times(Q)$		
8	Surface charge density	$\sigma=\frac{q}{A}$		
9	Electric field intensity inside a hollow conducting sphere	$E=0$		
10	Electric field intensity due to infinite sheet of charge	$E=\frac{\sigma}{2\varepsilon_0}$	$\vec{E}=\frac{\sigma}{2\varepsilon_0}\hat{r}$	
11	Electric field intensity between two oppositely charged parallel plates	$E=\frac{\sigma}{\varepsilon_0}$	$\vec{E}=\frac{\sigma}{\varepsilon_0}\hat{r}$	
12	Electric potential difference	$\Delta V=\frac{W}{q}$	$\Delta V=\frac{\Delta U}{q}$	
13	Relation between electric potential energy and electric potential difference	$\Delta U=q\Delta V$		
14	Relation between electric intensity and electric potential difference	$E=-\frac{\Delta V}{\Delta r}$	$V=Ed$	
15	Absolute electric potential difference	$V=\frac{W}{q}$		
16	Capacitance of capacitor	$q=CV$	$C=\frac{q}{V}$	
17	Capacitance of parallel plate capacitor	$C_{vac}=\frac{A\varepsilon_0}{d}$	$C_{med}=\frac{A\varepsilon_0\varepsilon_r}{d}$	
18	Dielectric constant,	$\varepsilon_r=\frac{C_{med}}{C_{vac}}$	$\varepsilon_r=\frac{\varepsilon_{med}}{\varepsilon_0}$	$\varepsilon_r=\frac{F_{vac}}{F_{med}}$
19	Energy stored in capacitor	$E=\frac{1}{2}qV$	$E=\frac{1}{2}CV^2$	$E=\frac{1}{2}q^2/C$
20	Energy density of electric field	$=\frac{1}{2}\varepsilon_0\varepsilon_r E^2$		
21	RC-time constant	t=RC		

UNITS

1	Electrostatics constant (k)	Nm^2C^{-2}	
2	Permittivity of free space	$C^2 N^{-1}m^{-2}$	
3	Relative permittivity	no unit	
4	Electric intensity	N/C	V/m
5	Electric flux	Nm^2C^{-1}	
6	Surface charge density	C/m^2	
7	Electric potential difference	J/C	volt
8	Electrical energy	eV	
9	Capacitance	C/V	farad
10	Dielectric constant	no unit	
11	Energy density	J/m^3	
12	RC-time constant	second	

CONSTANTS

1	Electrostatics constant(k)	$9\times10^9\,Nm^2C^{-2}$
2	Permittivity of free space	$8.85\times10^{-12}\,N^{-1}m^{-2}C^2$
3	Relative permittivity of air	1.0006
4	Relative permittivity of free space	1
5	Charge on electron	$1.6\times10^{-19}\,C$

Key Points

- ❖ According to Coulomb law the electric force between two point charges is directly proportional to the product of magnitudes of the charges and inversely proportional to the square of the distance between them.
- ❖ An electric field is a region around a charge in which an electric test charge would experience an electric force. The existence of electric field can be proved by bringing a test charge $q_{\circ}$ into its field.
- ❖ The applications of electrostatics are photocopier and inkject printer.
- ❖ For electric flux area is considered as vector quantity.
- ❖ The electric flux Φ is defined as the number of lines of force that pass through the area placed in the electric field. $\Phi = E.A = EA\cos\theta$.
- ❖ When area A is normal to the electric field E then electric flux is maximum.
- ❖ The electric flux through any closed surface is $1/\varepsilon_{\circ}$ times the total charge enclosed in it.
- ❖ A device which is used for storing electric charges is called capacitor. The SI unit of capacitance is called fared.
- ❖ The electron volt (eV) is another unit of energy and is related to joule as 1 eV = 1.602×10^{-19} J.
- ❖ The dielectric materials are made up of the two types of molecules; polar and nonpolar molecules.
- ❖ The system in which two charges of equal magnitude but of opposite sign separated by the distance are present is termed as a dipole.
- ❖ The energy stored between the plates of a capacitor is in the form of electric field. $U = \frac{1}{2}\varepsilon r\varepsilon_{\circ}E^2 \times (Ad)$
- ❖ The charging process of a capacitor exhibits the exponential behavior so we can write its Eq: As $q = q_{\circ}(1 - e^{-t/RC})$
- ❖ The time constant is the duration of time for the capacitor in which 63.2% of its maximum value charge is deposited on the plates.

Solved Examples

Example 11.1:

Find electric field at a distance of 30cm from a 3μC point charge?

Solution:

$r = 30\text{cm} = 30 \times 10^{-2} = 0.3$ m.

$q = 3\mu\text{C} = 3 \times 10^{-6}$ C

Using electric field intensity formulae

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

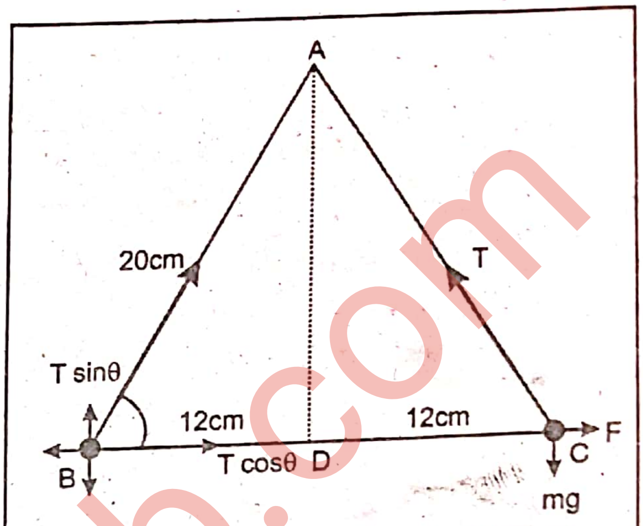
$$= (9\times10^{9}\,\text{N}\,\text{m}^2C^{-2}(\frac{3\times10^{-6}C}{(0.3m)^2}$$

$$= 3 \times 10^{5}\,\text{N}\,\text{C}^{-1}$$

Example 11.2:

Two small spheres, each having a mass of 0.1g is suspended from a point with the help of threads 20cm long. They are equally charged and they repel each other to a distance of 24cm. What is the charge on each sphere?

Solution:



force between two charge spheres

Fig: 11.3. shows that two charged spheres B and C which are separated by distance r due to force of repulsion F i.e., Since two spheres are equally charged so let charge on each sphere = q

Separation between spheres is $r = 0.24$ m

Mass of spheres in $m = 0.1\text{g} = 1\times10^{-4}$ kg.

Length of threads $= \ell = 20cm = 0.2m$

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

Putting values $$F = 9\times10^9\frac{q^2}{(0.24)^2}$$

$$F = 156.25\times10^9 q^2 \qquad \text{.... (1)}$$

Each sphere is under the action of three forces:

(1) Weight mg is acting vertically downward, (2) tension T, and (3) electrostatic force F. Considering the sphere B and resolving T into rectangular component, we have,

$m\,g = T\sin\theta$ ... (2) ; $F = T\cos\theta$ ... (3)

Dividing Eq; (2) by (3) we get

$$\tan\theta = \frac{mg}{F} \qquad \text{... (4)}$$

By Pythagorean Theorem $AD^2 = AB^2 - BD^2$

or $$AD = \sqrt{AB^2 - BD^2} = \sqrt{(20)^2 - (12)^2} = 16cm$$

from fig $$\tan\theta = \frac{AD}{BD} = \frac{16}{12} \qquad \text{.....(5)}$$

Comparing Eq: (4) & (5) we get

$$\frac{16}{12} = \frac{mg}{F}$$

or $$F = \frac{12}{16}mg = 0.75mg = 0.75\times10^{-4}\times9.8 = 7.4\times10^{-4}N$$

Putting F = 7.4 × 10^{-4} N in Eq: (1) we get

$$\therefore \quad 156.25\times10^9 q^2 = 7.4\times10^{-4} \quad or \quad q^2 = \frac{7.4\times10^{-4}}{156.25\times10^9} = 4.8\times10^{-15}$$

$$q = 6.9\times10^{-8}C$$

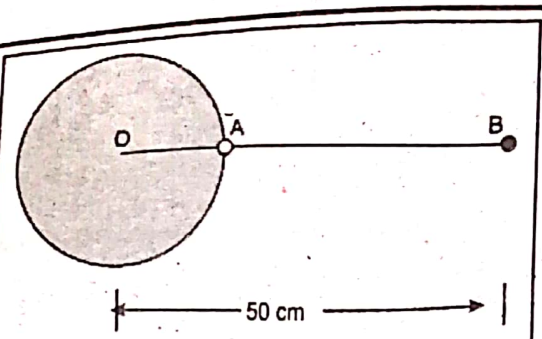
Example 11.3:

A metallic sphere of diameter 30 cm carries a charge of 600 μ C. Find the electric field intensity (a) at a distance of 50 cm from the centre of the sphere and (b) at the surface of sphere.

Solution:

The electric field due to a charged sphere has spherical symmetry.

Therefore, a charged sphere behaves for external points as if the whole charge is placed at its centre.



Field intensity due to a charge sphere

(a) Distance f charge from the sphere r = OB = 50cm

Charge on sphere q = 600 µC = 600 × 10^{-6} C

Electric field intensity from the centre of the sphere is $E = k\frac{q}{r^2}$

$$= 9\times10^9\times\frac{600\times10^{-6}}{\left(50\times10^{-2}\right)^2}$$

$$= 21.6\times106\ N/C$$

(b) $r = \frac{d}{2} = \frac{OA}{2} = \frac{30cm}{2} = 0.15m$

Electric field intensity from the surface of a sphere $E = k\frac{q}{r^2}$

$$= 9\times10^9\times\frac{600\times10^{-6}}{\left(0\times15\right)^2}$$

$$= 24\times10^7\ N/C$$

Example 11.4:

What is the electric potential energy of a 7n C charge that is 2 cm from a 20 n C charge?

Solution:

We will use the equation: $U = k\frac{q_1q_2}{r}$

Putting values

$$U = 9.0\times10^9\,\frac{\left(7\times10^{-9}\right)\left(20\times10^{-9}\right)}{0.02\text{m}}$$

$$U = 6.3\times10^{-5}\text{J}$$

Example 11.5:

What is the potential difference between two points in an electric field if it takes 600 J of energy to move a charge of 2 C between these two points?

Solution:

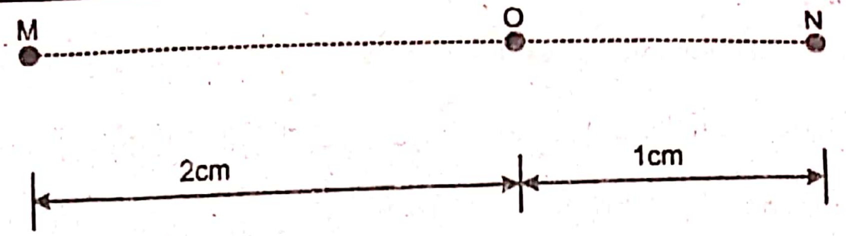
We will use the equation: $V = \frac{W}{q}$

$$= \frac{600}{2}$$

$$= 300\text{V}$$

Example 11.6:

A point charge of $3\,\mu C$ is placed at point O between M and N, 3cm apart. Point M is 2cm from the charge and N is 1cm from the charge. What is the potential difference $V_M - V_N$?



Potential due to a point charge

Solution:

Potential at M due to the charge is $V_m = k\dfrac{q}{r}$

$$V_M = 9\times10^9 \times \frac{3\times10^{-6}}{2\times10^{-2}} = 13.5\times10^5\,\text{V}$$

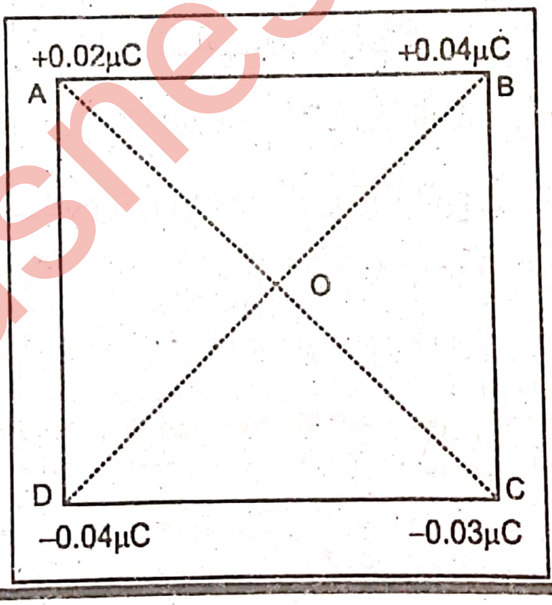
Potential N due to the charge is

$$V_N = 9\times10^9 \times \frac{3\times10^{-6}}{1\times10^{-2}} = 27\times10^5\,\text{V}$$

$$\therefore \quad V_M - V_N = 13.5\times10^5 - 27\times10^5 = -13.5\times10^5\,\text{V}$$

Example 11.7:

Four point charges of $+0.02\,\mu C$, $-$ 0.0.3 μC and $+0.04\,\mu C$ are placed at the corner A, B, C and D of a square ABCD respectively. Find the potential at the centre of the square if each side of the square is 1.5m apart.



Solution:

Fig: Shows the square ABCD with charges placed at its corners. The diagonals of the square intersect at poin O. Clearly, point O is the centre of the square. The distance of each charge from point O is

$$= \frac{1}{2}\sqrt{(1.5)^2 + (1.5)^2} = 1.0606\text{m}$$

The potential at point O due to all charges is equal to the algebraic sum of potentials due to each charge.

Potential at O due to all charges.

$$\therefore \quad V = k\left[\frac{q_A}{r_A}+\frac{q_B}{r_B}+\frac{q_C}{r_C}+\frac{q_D}{r_D}\right]$$

Putting the values we get

$$=9\times10^9\left[\frac{0.02\times10^{-6}}{1.0606}+\frac{0.4\times10^{-6}}{1.0606}+\frac{-0.03\times10^{-6}}{1.0606}+\frac{0.04\times10^{-6}}{1.0606}\right]$$

$$=\frac{9-10^9}{1.0606}\left[(0.02+0.04-0.03+0.04)10^{-6}\right]$$

$$=\frac{9-10^9}{1.0606}\times0.07\times10^{-6}=593.9\text{V}$$

Example 11.8:

A particle carrying a charge (3e) falls through a potential difference of 5V. Calculate in joules the energy acquired by the particle.

Solution:

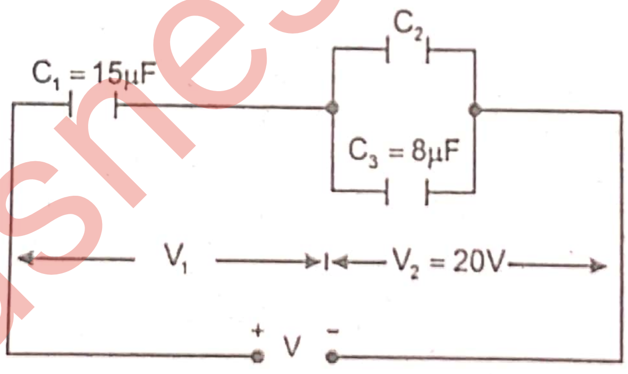
The energy acquired by the charged particle is

$$\Delta(\text{KE}) = q\,\Delta V = (3e)(5\,\text{V}) = 15\text{eV}$$

$$=15\times1.602\times10^{-19}\text{J}=2.4\times10^{-18}\text{J}$$

Example 11.9:

Shows a different combination of capacitors, if the total charge is $600\,\mu$C. Then determine the values of V_1, and C_2.



Capacitors, C_1, C_2, & C_3 connected to potential V

Solution:

$$\text{P.D. across capacitor } C_1 : V_1 = \frac{Q}{C_1} = \frac{600\times10^{-6}}{15\times10^{-6}} = 40\text{V}$$

$$\text{Total p.d.: } V = V_1 + V_2 = 40 + 20 = 60\text{V}$$

Charge on capacitor C_3 is: $Q_3 = C_3 \times V_2$

$$=\left(8\times10^{-6}\right)\times20$$

$$=160-\times10^{-6}C=160\mu C$$

∴ Charge on capacitor C_2 is: $Q_2 = 600 - 160 = 440\,\mu C$

$$\therefore \text{ Capacitance of capacitor } C_2 = \frac{400\times10^{-6}}{20}$$

$$= 22\times10^{-6} F = 22\mu F$$

Example 11.10:

A 6μF capacitor is charged to a P.D. of 200V and then connected in parallel with an un-charged 3μF capacitor. Calculate the P.D. across the parallel plate capacitors.

Solution:

Capacitance of charged capacitor $= C_1 = 6\mu F$

Capacitance of un-charged capacitor $= C_2 = 3\mu F$

Charge on capacitor, C_1 is: $Q = C_1 V = (6\times10^{-6}) \times 200 = 0.0012C$

The equivalent capacitance of parallel combination of capacitors is

$C_{eq} = C_1 + C_2 = 6 + 3 = 9\mu F$.

The charge 0.0012C is distributed between the two capacitors to have a common P.D.

$$\therefore \text{ P.D. across Parallel plate capacitors: } V = \frac{Q}{C_{eq}} = \frac{0.0012}{9\times10^{-6}} = 133.3V$$

* * *

Text Book Exercises

Q.1 Select the correct answer of the following questions.

(i) A charge Q is divided into two parts q and Q-q and separated by a distance R. The force of repulsion between them will be maximum when:

(a) $q = Q/4$ (b) $q = Q/2$ (c) $q = Q$ (d) None of these

(ii) Some charge is being given to a conductor. Then its potential:

(a) Is maximum at surface

(b) Is maximum at centre

(c) Is remain same throughout the conductor

(d) Is maximum somewhere between surface and centre

(iii) Electric potential of earth is taken to be zero because the earth is good:

(a) Semiconductor (b) Conductor (c) Insulator (d) Dielectric

(iv) A proton is about 1840 time heavier than an electron. When it is accelerated by a potential difference if 1 kV, its kinetic energy will be:

(a) 1840 keV (b) 1/1840 keV (c) 1 keV (d) 920 keV

(v) A capacitor is charged with a battery and then it is disconnected. A slab of dielectric is now inserted between the plates, then:

(a) The charge in the plates reduces and potential difference increase

(b) Potential difference between the plates increase, stored energy decreases and charge remains the same

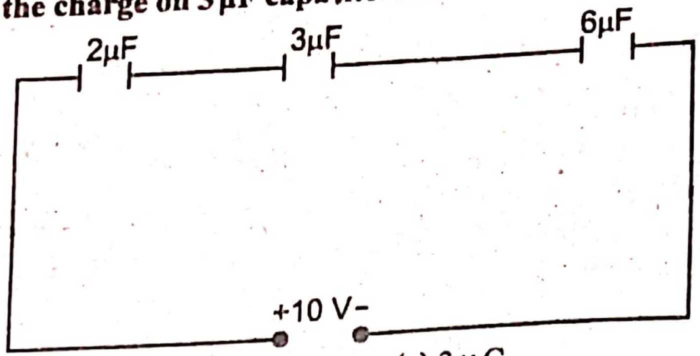
(c) Potential difference between the plates decreases, stored energy decreases and charge remains the same

(d) Potential difference between the plates decreases, stored energy decrease and charge remains unchanged

(vi) **A one microfarad capacitor of a TV is subjected to 400 V potential difference. The energy stored in capacitor is:**

(a) 8 J (b) 16 J (c) 4×10^{-3} J (d) 2×10^{-3} J

(vii) **In the figure below, the charge on 3 μF capacitor is:**



(a) 5 μC (b) 10 μC (c) 3 μC (d) 6 μC

(viii) **The electric potential between two points A and B is ΔV. The work done W by the field in moving a charge q from A to B is:**

(a) $W = -q\ \Delta V$ (b) $W = q\ \Delta V$ (c) $W = -\Delta V/q$ (d) $W = \Delta V/q$

(ix) **The electric flux through the surface of a sphere due to a charge q placed at its centre depends upon:**

(a) the radius of the sphere (b) the quantity of charge outside the sphere

(c) the surface area of the sphere (d) the quantity of charge inside the sphere

(x) **Two parallel, metal plates are a distance 8.00 m apart the electric field between the plates is uniform, directed toward the right, and has a magnitude of 4.00 N/C. If an ion of charge+ 2e is released at rest at the left-hand plate, what is its kinetic energy when it reaches the right-hand plate.**

(a) 4 eV (b) 64 eV (c) 32 eV (d) 16 eV

No.	Option	ANSWER	EXPLANATION
(i)	(b)	$q = Q/2$	As $F = k\frac{q_1 q_2}{r^2}$ As Q is divided into $q_1 = \frac{Q}{2}$ and $q_2 = \frac{Q}{2}$ then the product of q_1 and q_2 will become maximum. So F will also become maximum. (i.e. $q_1 : q_2 = 1:1$)
(ii)	(c)	Is same through out the conductor	As the charge will uniformly distributed over the surface, so potential become constant through out the surface.
(iii)	(b)	Conductor	The Earth's potential is zero because it is large storehouse of charges and addition or subtraction of charges will not matter significantly.
(iv)	(c)	1 keV	As $K.E = q\Delta V$ $= (1e)(1kV)$ $= 1$ keV
(v)	(c)	Potential difference between the plates decrease, stored energy decreases and charge remains the same	By placing dielectric between plates of charged capacitor, ● q = constant even thought its effective value decreases. ● V will decrease, as E decreases by ε_r.

			• U will also decreases as energy stores in it electric field (i.e. $U = \frac{1}{2}\varepsilon_0\varepsilon_r E^2 Ad$)
(vi)	(a)	8 J	$U = \frac{1}{2}CV^2 = \frac{1}{2}(10^{-6} F)(4000\ V)^2 = 8J$
(vii)	(b)	10 μC	$\frac{1}{C_e} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} = \frac{3+2+1}{6}$ $C_e = 1\mu C$ $Q = C_eV$ $= (1 \times 10^{-6}C)(10)(1)$ $= 10\ \mu C$ In series $q_1 = q_2 = q_3 = q = 10\mu C$
(viii)	(b)	$W = q\ \Delta V$	As $\Delta V = \frac{W}{q}$ $W = q\Delta V$
(ix)	(d)	the quantity of charge inside the sphere	As $\phi = \frac{q}{\epsilon_0}$ (for a closed surface) So $\phi \propto q$ (when q is amount of change enclosed)
(x)	(b)	64 eV	As $K.E = q\Delta V$ $= q(E\Delta r)$ $= (2e)(4 \times 8V)$ $= 64\ eV$

Comprehensive Questions

Q.2 Write short answers of the following questions.

1. State and explain coulombs law. Do include the case when the charges are placed in dielectrics. Discuss how the unit of charge coulomb is defined?

Ans. See Theory Question No. 1

2. Explain the concept of electric field and hence define electric field intensity. Discuss the direction as well as the unit of $\vec{E}$.

Ans: See Theory Question No. 2

3. Explain the concept of electric flux. Using mathematical expressions of electric flux to how electric flux is maximum and minimum.

Ans. See Theory Question No. 7

4. State and prove the Gauss law for electrostatics. Also discuss its applications with daily life example.

Ans: See Theory Question No. 10

5. Explain the concept of electric potential. Derive an expression for electric potential at a field point due to source charge.

Ans. See Theory Question No. 15

6. Describe the Construction of capacitor and derive an expression for the energy stored in a capacitor.

Ans. See Theory Question No. 26

7. Describe the concept equipotential surfaces and derive an expression for electric field as a negative of potential gradient.

Ans: See Theory Question No. 17

8. Explain the phenomenon of electric polarization. Discuss how the phenomenon of polarization account for the increase in capacitance of a capacitor when instead of air, dielectric is inserted between its plates?

Ans: See Theory Question No. 25

9. Derive an expression for the capacitance of a parallel plate capacitor when a dielectric is inserted between the plates of a capacitor.

Ans: See Theory Question No. 23

10. Describe the process of charging and discharging a capacitor. Give the diagram and mathematical expressions for the growth and decay of charge on the capacitor.

Ans: See Theory Question No. 27

Conceptual Questions

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

Ans: Yes Electric field is zero in this region.

Reason:

As electric field strength can be defined as the negative of potential gradient.

$$\vec{E} = \frac{-\Delta V}{\Delta r} \longrightarrow (1)$$

Since the potential is constant in given region

i.e. $V = \text{constant}$

so $\Delta V = 0$

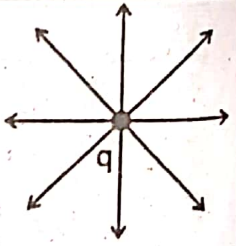
and eq (1) becomes

$$E = \frac{\Delta V}{\Delta r} = \frac{0}{\Delta r} = 0$$

So $\boxed{E = 0}$

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

Ans: Yes, the charged particle will make a rectilinear motion.



Reason:

When a charged particle is placed in an electric field, it will experiences the force at that point. So

$$E = \frac{F}{q}$$

$$F = qE$$

As the field is non-uniform (field lines are not parallel and not equally spaced) but pointing in the same direction. So it must be only due to point charge (+ve or -ve) which is a radial field. So the path must be rectilinear.

3. What is the relationship between voltage and energy? More precisely, what is the relationship between potential difference and electric potential energy?

Ans: Both of them are closely related with each other.

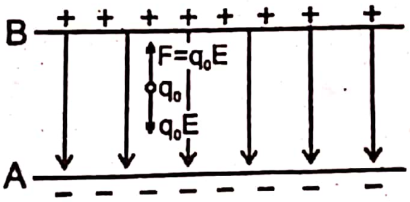
Explanation:

Let two plates A and B are oppositely charged. A positive test charge of very small magnitude and dimension is displaced from A to B. So the work is done in bringing it from A to B, which is stored in form of **potential energy**. This work done per unit charge is called potential difference

So $\Delta V = \frac{W_{AB}}{q_o}$

Since $W_{AB} = \Delta U$

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



Hence change in potential energy per unit test charge in called **potential difference.** Electric potential energy is possessed by the charge where as the potential difference is the property associated with electric field.

4. Voltages are always measured between two points. Why?

Ans: Voltage is always measured between two points because it is a relative quantity.

Explanation:

As we can define the potential difference between two points as the work done in bringing a unit positive charge from one point to another point against the direction of electric field by keeping electrostatic equilibrium. Thus work done is stored in form of potential energy. Which is a relative quantity. So this change in potential energy per unit test charge is called potential difference.

So potential difference between two points is given as $V_B - V_A = \frac{W_{AB}}{q_o}$

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

5. How are units of volts and electron volts related? How do they differ?

Ans: Volt is the unit of potential difference where as electron volt is the unit of energy.

Explanation:

- **Volt:** Potential difference of one volt exists between two points is work done in moving unit positive charge from one point to another, keeping electrostatic equilibrium is one joule.

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}} \qquad \left(\because \Delta V = \frac{W}{q_o}\right)$$

- **Electron Volt:** One electron volt energy is define as the amount of energy acquired or lost by an electron as it traverses a potential difference of one volt.

$$1 \text{ eV} = (1 \text{ e})(1 \text{ V}) \qquad (\because \Delta U = q\Delta V)$$
$$1 \text{ eV} = (1.6 \times 10^{-19} \text{ C})(1 \text{ V})$$
$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

Difference

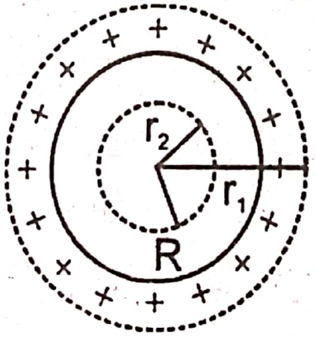
Electron volt is the unit of energy, where as volt is the unit of change in energy per unit test charge (p.d).

6. In what region of space is the potential due to a uniformly charged sphere the same as that of a point charge? In what region does it differ from that of a point charge?

Ans: Electric potential due to uniformly charged sphere at point outside the sphere is like electric potential due to a point charge whereas at a point inside the charged sphere is constant but similar to a point charge.

Explanation:

Consider a charged sphere for which charge is uniformly distributed over its surface.



Out side the charged sphere

As $E = \frac{1}{4\pi\epsilon 0}\frac{q}{r_2}$

$$E = \frac{1}{4\pi\epsilon_0}\frac{q}{r_1^2}$$

Also $\Delta V = E\Delta r$

$$E = \frac{1}{4\pi\epsilon_0}\frac{q}{r_1^2} r_1$$

$$V = \frac{1}{4\pi\epsilon_0}\frac{q}{r_1}$$

Which is same as due to a point charge.

Inside the charged sphere

$$E = \frac{1}{4\pi\epsilon_0}\frac{q}{r_2^2}$$

$$E = 0 \qquad (\because q = 0)$$

$$\Delta V = (0)\,\Delta r$$

$$\Delta V = 0$$

$$V = \text{Constant}$$

So $V = \frac{1}{4\pi\epsilon_0}\frac{q}{r_2}$

Which is not same as due to a point charge.

7. Can the potential of a non-uniformly charged sphere be the same as that of a point charge? Explain.

Ans: Yes, the potential of non-uniformly charged sphere is same as that of point charge.

Explanation: (outside the charged sphere)

In general, electric potential due to non-informly charged sphere can not be same but in special cases like our point is far from the sphere then we can take it equal to the potential due to a point charge.

Inside the charged speed.

Where as at a point inside the non-uniform distribution on sphere. The charge has different amount in different parts of the sphere and there would be a resultant electron field in the interior of sphere so the electric potential is same as that of a point charge.

8. What is an equipotential line and equipotential surface?

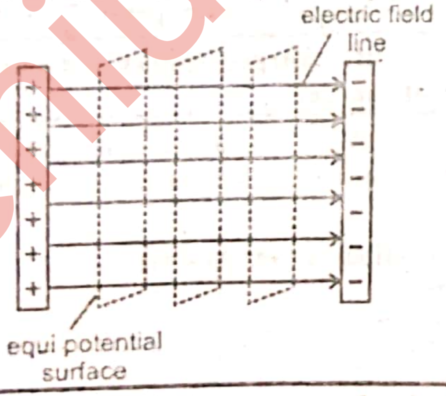
Ans: **Equipotential Line:**

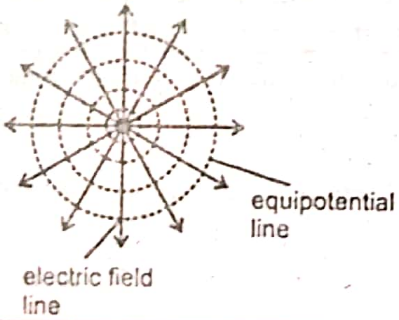
An equipotential line is a line joining points having the same potential.

There will be no work done in moving a charge along the equipotential line between two points Equipotential lines are always perpendicular to the electric field lines due to charges.

Equipotential Surface:

Any surface with same electric potential at every point is called equipotential surface. Electric field lines are always perpendicular the equipotential surface and hence the work done in moving a charge between two points on an equipotential surface is zero. (due to a point change)





9. Can different equipotential lines cross each other? Explain.

Ans: No, different equipotential lines will never cross each other.

Explanation

If equipotential surfaces intersect then their corresponding electric field lines also intersect which is not possible. Otherwise, electric field (a vector quantity) will have more than one direction at a point which is not possible.

10. Water has a large dielectric constant, but it is rarely used in capacitors. Explain why?

Ans: (i) Pure water is a non-polar dielectric. Water molecules are moving randomly. They are not tightly bound to each other. In an electric field the water molecules are polarized. But they are not at rest and cannot induce charges to produce electric field like solid dielectric. The motion of water molecules varies the capacity of a capacitor continuously. Therefore water cannot be used as dielectric in a capacitor.

(ii) Water can produce corrosion to plates.

(iii) It can ionize the plates or any salts within capacitor.

11. A capacitor is connected in series with a resistor and charged. Explain why the potential difference across the resistor decreases with time during the charging.

Ans: Potential difference across the resistor decreases to conserve the energy.

Explanation

For an RC circuit connected with a battery (source). According to conservation of energy, the source voltage must be equal to voltage drop across the capacitor and voltage drop across the resistor. So by KVL,

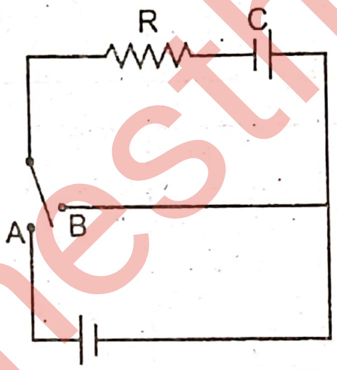
i.e. $V_S = V_C + V_R$

$$V_S = \frac{q}{C} + IR$$

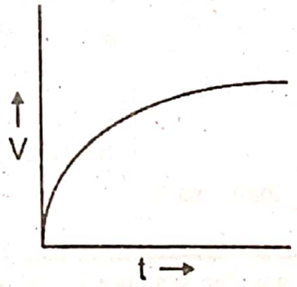
As the charge stored q will increase then voltage across capacitor $V_C \left(= \frac{q}{c}\right)$ will also increase. So V_R (= IR) will decrease in order to conserve the energy in series combination.

12. Sketch the graphs of potential difference against time for (a) a discharging capacitor (b) a charging capacitor.

Ans: **Charging of capacitor:**



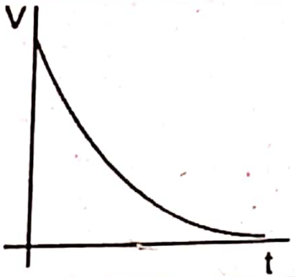
When switch S is connected with terminal A, the capacitor will start to charge. The value of charge 'q' in any instant '*t*' in terms of equilibrium value of charge 'q_0' can be expressed as $q = q_0(1-e^{-t/RC})$. So increase in charge with time *t* is exponential. As q = CV ($q \propto V$). So $V = V_0(1-e^{-t/RC})$.



Discharging of capacitor:

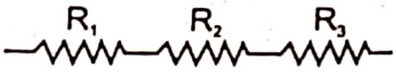
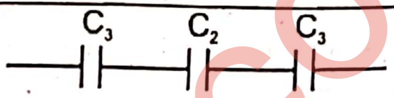
When the switch S is connected with terminal *B*, the capacitor will start to discharge. The charge q at any instant '*t*' interms of equilibrium values can be expressed $q = q_0 e^{-\frac{t}{RC}}$.

Decreases exponentially with time. As $q \propto V$, So $V = V_o e^{-t/RC}$

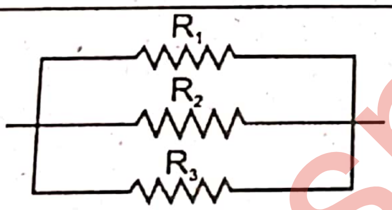
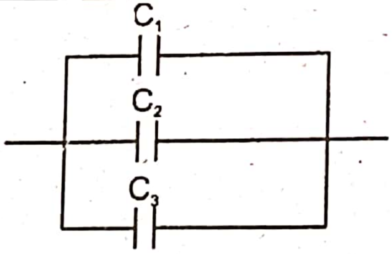


13. Compare the formula for capacitors in series and parallel with those for resistors in series and parallel explain why the pattern is different.

Ans: **For Series combination:**

Resistor in series	Capacitor in series
	
• $I_1 = I_2 = I_3$	• $q_1 = q_2 = q_3$
• $V_1 \neq V_2 \neq V_3$	• $V_1 \neq V_2 \neq V_3$
• $V = V_1 + V_2 + V_3$	• $V = V_1 + V_2 + V_3$
• $IR = IR_1 + IR_2 + IR_3$	• $\frac{q}{C} = \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3}$
• $R = R_1 + R_2 = R_3$	• $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$
• equivalent resistance is greater than each individual resistance.	• equivalent capacitance is smaller than individual capacitance.

For parallel combination.

Resistors in Parallel	Capacitor in Parallel
	
• $V_1 = V_2 = V_3$	• $V_1 = V_2 = V_3$
• $I_1 \neq I_2 \neq I_3$	• $q_1 \neq q_2 \neq q_3$
• $I = I_1 + I_2 + I_3$	• $q = q_1 + q_2 + q_3$
• $\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$	• $CV = CV_1 + CV_2 + CV_3$
• $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$	• $C = C_1 + C_2 + C_3$
• Equivalent resistances is smaller than each individual resistance	• Equivalent capacitance is greater than each individud capacitance

14. Explain why capacitors are of little use for storage of energy for normal domestic purposes of lighting, heating and so on.

Ans: Capacitors are of little use for storage of energy for normal domestic purposes due to following reasons.

- There is a limit of charge which can be stored on the plates of capacitor during it charging.
- As the charged capacitor is connected to a load, these potential difference can not remains constant across ends of a capacitor for a longer time.

Numerical Problems

1. What is the magnitude of the force of attraction between an iron nucleus bearing charge $q = 26e$ and its innermost electron, if the distance between them is 1×10^{-12}m.

Given Data:

Charge on electron $q_1 = 1.6 \times 10^{-19}$ C

Charge of nucleus $q_2 = 26e = 26 \times 1.6 \times 10^{-19}\ C = 41.6 \times 10^{-19}$ C

Separation $= r = 1 \times 10^{-12}$ m

Coulomb's constant $= k = 9 \times 10^9\ Nm^2\ C^{-2}$

To find:

Coulomb force F = ?

Solution:

By Coulomb's law $F = \frac{kq_1q_2}{r^2}$

Putting values: $\Rightarrow F = \frac{(9 \times 10^9)(1.6 \times 10^{-19})(41.6 \times 10^{-19})}{(1 \times 10^{-12})^2}$

$\Rightarrow F = 5.99 \times 10^{-3}$ N

$$\boxed{F = 6 \times 10^{-3}\ N}$$

2. Charges $2\mu C$, $-3\mu C$, and $4\mu C$ are placed in air at the vertices of an equilateral triangle of sides 10 cm. what is the magnitude of resultant force acting on $4\mu C$ charge?

Given dada:

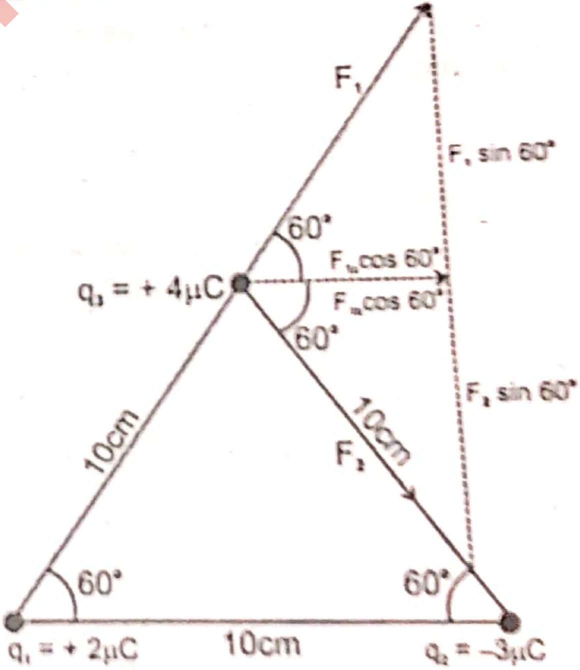
$q_1 = +2\mu C = 2 \times 10^{-6}$ C

$q_2 = -3\mu C = -3 \times 10^{-6}$ C

$q_3 = +4\mu C = 4 \times 10^{-6}$ C

$r = 10cm = 0.1m$

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



To Find: Coulumb force F = ?

Solution:

Now, the repulsive force on charge 4μC due to q_1 is given by

$F_1 = \frac{1}{4\pi\varepsilon_o}\frac{q_1q_3}{r^2}$

$F_1 = \frac{9 \times 10^9 \times 2 \times 10^{-6} \times 4 \times 10^{-6}}{(0.1)^2} = 7200 \times 10^{-3}$

$F_1 = 7.2N \ \dots (1)$

Similarly, the repulsive force on 4 μC due to q_2 is:

$F_2 = \frac{1}{4\pi\varepsilon_o}\frac{q_2q_3}{r^2} = \frac{9 \times 10^9 \times 2 \times 10^{-6} \times 4 \times 10^{-6}}{(0.1)^2} = 10800 \times 10^{-3}N$

$F_2 = 10.8\ N \ \dots (2)$

Since, the triangle is equilateral triangles, so each force F_1 and F_2 making angles θ_1 and [illegible] x-ax are 60°. The x-component of the resultant force F on 4 μC is:

$$F_x = F_{1x} + F_{2x} = F_1 \cos\theta_1 + F_2 \cos\theta_2$$
$$F_x = F_1 \cos 60^\circ + F_2 \cos 60^\circ$$
$$F_x = 7.2 \times 0.5 + 10.8 \times 0.5$$
$$F_x = 3.6 + 5.4 = 9N \quad \dots (3)$$

Similarly, y-component of the resultant force is:

$$F_y = F_{1y} + F_{2y} = F_1 \sin\theta_1 - F_2 \sin\theta_2$$
$$F_y = 7.2 \times \sin 60^\circ - 10.8 \times \sin 60^\circ$$
$$F_y = 7.2 \times 0.866 - 10.8 \times 0.866$$
$$F_y = 6.2 - 9.4 = -3.2 \quad \dots (4)$$

Magnitude of the resultant force is,

$$F = \sqrt{F_x^2 + F_y^2} = \sqrt{9^2 + (-3.2)^2} = \sqrt{91.24} = 9.55\text{ N}$$

To find the direction, we have $\phi = \tan^{-1}\dfrac{F_y}{F_x} = \tan^{-1}\left(-\dfrac{3.2}{9}\right) = 379^\circ$

Note:

If you want to get answer of the book, then take all charge positive.

i.e. $q_1 = 2\ \mu C$

$q_2 = 3\ \mu C$

$q_3 = 4\ \mu C$

---

3. A charge *q* is placed at the centre of the line joining the two charges, each of magnitude *Q*. Prove that the system of three charges will be in equilibrium if *q* = –*Q*/4.

Given Data:

Separation between charge q and Q = r

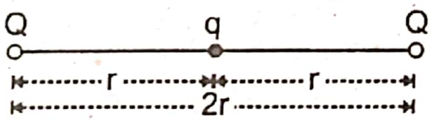
Separation between charge Q and Q = 2r

To Find:

Prove $q = \dfrac{-Q}{4} = ?$

Solution:

From coulomb's law, the system will be in equilibrium when;



$$F_{(qQ)} + F_{(Q,Q)} = 0$$
$$\Rightarrow \quad \frac{kqQ}{r^2} + \frac{kQ.Q}{(2r)^2} = 0 \quad \Rightarrow \quad \frac{kqQ}{r_2^2} + \frac{kQ^2}{4r^2} = 0$$
$$\Rightarrow \quad k\frac{Q}{r^2}\left[q + \frac{Q}{4}\right] = 0$$
$$\Rightarrow \quad q + \frac{Q}{4} = 0$$
$$\Rightarrow \quad \boxed{q = -\frac{Q}{4}}$$

---

4. Two equal and opposite charges of magnitude 2 ×10^{-7} C are placed 15cm apart. What is the magnitude and direction of electric intensity (*E*) at a point mid-way between the charges? What force would act on a proton (charge = + 1.6×10^{-19} C) placed there?

Given Data:

Charge = $Q = 2 \times 10^{-7}$ C

Charge = $-Q = -2 \times 10^{-7}$ C

Separation $r = 15cm = 0.15m$

At mid-way $d_1 = d_2 = d = \frac{r}{2} = \frac{0.15}{2} = 0.075m$

Coulomb's constant $k = 9 \times 10^9\ Nm^2C^{-2}$

o Find:

Net electric field $E_{net} = ?$

Force on proton $F_P = ?$

olution:

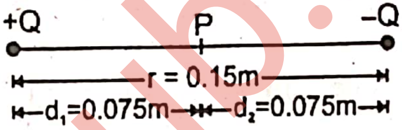
Since at point P $\vec{E}_{+Q}$ and $\vec{E}_{-Q}$ has same direction i.e. from A to B. therefore,

$$\vec{E}_{net} = \vec{E}_{+Q} + \vec{E}_{-Q} \rightarrow \text{(i)}$$

The electric field intensity due to positive charge at point 'P' is

$$\vec{E}_{+Q} = k\frac{Q}{d_1^2}\hat{d}_1 \longrightarrow \text{(ii)}$$

The electric field intensity due to negative charge at point 'P' is



$$\vec{E}_{-Q} = k\frac{-Q}{d_2^2}\hat{d}_1$$

$$\hat{d}_2 = -\hat{d}_1 \text{ therefore,}$$

$$\vec{E}_{-Q} = k - \frac{Q}{d_2^2}(\hat{d}_1)$$

$$\vec{E}_{-Q} = k\frac{Q}{d_2^2}(\hat{d}_1) \longrightarrow \text{(iii)}$$

Putting equation (ii) and equation (iii) in equation (i), we get

$$\vec{E}_{net} = k\frac{Q}{d_1^2}\hat{d}_1 + k\frac{Q}{d_2^2}\hat{d}_1 \quad (\text{as } d_1 = d_2 = d)$$

Hence, $\vec{E}_{net} = k\frac{Q}{d_2}\hat{d}_1 + k\frac{Q}{d_2}\hat{d}_1$

OR $\vec{E}_{net} = 2k\frac{Q}{d_2}\hat{d}_1$

OR in magnitude: $E = 2k\frac{Q}{d_2}$

Putting values

$$\vec{E}_{net} = 2 \times 9 \times 10^9 \times \frac{2 \times 10^{-7}}{(0.075)^2}\hat{d}_1$$

$$\vec{E}_{net} = 6400 \times 10^2\,\hat{d}_1$$

$$= 0.64 \times 10^6\,\hat{d}_1\ NC^{-1}$$

As the direction of d_1 is along AB therefore the direction of electric field at point 'P' will also be along AB.

$$\vec{F}_P = \vec{E}_{net} \times q_p$$

Putting values:

$$\vec{F}_P = 0.64 \times 10^6\,\hat{d}_1 \times 1.6 \times 10^{-19}$$

$$\vec{F}_P = 1.024 \times 10^{-13}\,\hat{d}_1\ N$$

5. Two positive point charges of 15×10^{-10} C and 13×10^{-10}C are placed 12cm apart. Find the work done in bringing the two charges 4cm closer.

Given Data:

Charge $q_1 = 15 \times 10^{-10}$ C

Charge $q_2 = 13 \times 10^{-10}$ C

Initial: Separation $r = 12\text{cm} = 0.12\text{m}$

Change in distance $\Delta r = 4\text{cm} = 0.04\text{m}$

Final: Separation $R = 0.12\text{m} - 0.04\text{m} = 0.08\text{m}$

Coulomb's constant $k = 9 \times 10^9\ \text{Nm}^2\text{C}^{-2}$

To find:

Work W = ?

Solution:

The work done in moving the charge is

$$W = kq_1q_2\left[\frac{1}{r} - \frac{1}{R}\right]$$

putting values

$$W = 9 \times 10^9 \times 15 \times 10^{-10} \times 13 \times 10^{-10}\left[\frac{1}{0.12} - \frac{1}{0.08}\right]$$

$$\boxed{W = 7.318 \times 10^{-8}\ \text{J}}$$

6. A hollow sphere is charged to 14μC. Find the potential (a) at its surface (b) inside the sphere (c) at a distance of 0.2m from the surface. The radius of the sphere is 0.3m.

Given Data:

Charge $q = 14\mu\text{C} = 14 \times 10^{-16}$ C

Radius $r = 0.3\text{m}$

Distance $D = 0.2\text{m}$

Coulomb's constant $= k = 9 \times 10^9\ \text{Nm}^2\text{C}^{-2}$

To find:

(a) Electric potential at surface $V_{sur} = ?$

(b) Electric potential inside $V_{in} = ?$

(c) Electric potential at 0.2m $V_{0.2m} = ?$

Solution:

(a) Electric potential at surface $V_{sur} = k\frac{q}{r}$

Putting values $V_{sur} = 9 \times 10^9 \times \frac{14 \times 10^{-6}}{0.3}$

$$\boxed{V_{sur} = 42 \times 10^4\ \text{V}}$$

(b) An excess charge placed on an isolated conductor will distribute itself on the surface conductor, whether on the surface or inside come to the same potential. This is true even if the conductor has an internal cavity and even if that cavity contains a net charge. Therefore, the electric potential inside the hollow sphere will be the same as that on the surface.

$$\boxed{V_{in} = V_{sur} = 42 \times 10^4\ \text{V}}$$

(c) The electric potential at 0.2m from surface of hollow sphere is $V_{0.2m} = k\frac{q}{r'}$

Where $r' = r + D$ therefore,

$$V_{0.2m} = k\frac{q}{r + D}$$

Putting values $V_{sur} = 9 \times 10^9\ Nm^2\ C^{-2} \times \frac{14 \times 10^{-6}\ C}{0.3m + 0.2m}$

$$\boxed{V_{sur} = 25.2 \times 10^4\ V}$$

---

7. If 280 J of work is done in carrying a charge of 2C from a place where the potential is –12V to another place where potential is V, calculate the value of V.

Given Data:

Work W = 280J

Charge q = 2C

Potential V_A = –12V

To find:

Potential V_B = ?

Solution:

By definition of electric potential $\Delta V = \frac{W}{q}$

OR $V_B - V_A = \frac{W}{q}$

OR $V_B = \frac{W}{q} + V_A$

Putting values: $V_B = \frac{280J}{2C} + (-12V)$

$$\boxed{V_B = 128\ V}$$

---

8. Calculate the electric potential at the surface of a silver nucleus having radius 3.4×10^{-14} m. The atomic number of silver is 47 and charge on a proton = $1.6 \times 10 \times 10^{-19}$C.

Given Data:

Charge of nucleus $q = 47q_P = 47e = 47 \times 1.6 \times 10^{-19}\ C = 75.2 \times 10^{-19}\ C$

Radius = r = 3.4×10^{-5} m

Coulomb's constant $k = 9 \times 10^9\ Nm^2\ C^{-2}$

To find:

Electric potential (v) = ?

Solution:

The electric potential is

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

Putting values:

$$V = 9 \times 10^9 \times \frac{75.2 \times 10^{-19}}{3.4 \times 10^{-14}}$$

OR $V = 199.058 \times 10^4$

OR $V = 1.99058 \times 10^4$

Therefore, $\boxed{V = 1.99 \times 10^6\ V}$

9. The electric field at a point due to a point charge is 26 N/C and the electric potential at that p is 13 J/C. Calculate the distance of the point from the charge and magnitude of charge.

Given Data:

Electric field $E = 26N/C$

Electric potential $V = 13J/C$

To find:

Distance $d = ?$, charge $q = ?$

Solution:

Electric potential at a point 'P' is related to magnitude of electric field intensity by the relation

$$V = Ed$$

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

putting values $$d = \frac{13V}{26NC^{-1}}$$

$$\boxed{d = 0.5m}$$

10. Two point charge of $8\mu C$ and $-4\mu C$ are separated by a distance of 10cm in air. At what point the line joining the two charges is the electric potential zero?

Given Data:

Charge $q_1 = 8\mu C = 8 \times 10^{-6} C$

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

Separation $r = 10cm = 0.1m$

To find:

Distance $x = ?$

Solution:

Let there is a point 'P' which the electric potential is zero. Such that let, the point 'P' is at a distance from charge q_1 let the electric potential is

$$V_{q_1} = V_{q_2} \longrightarrow (i)$$

$$V_{q_1} = k\frac{q_1}{x} \longrightarrow (ii)$$

Let the point 'P' is a distance $r - x$ from charge q_2, then the electric potential is

$$V_{q_2} = \frac{kq_2}{r-x} \longrightarrow (iii)$$

Putting equation (ii) and (iii) in equation (i), we get

$$k\frac{q_1}{x} = k\frac{q_2}{r-x}$$

or $$\frac{q_1}{x} = \frac{q_2}{r-x}$$

$$\frac{r-x}{x} = \frac{q_2}{q_1}$$

Or $$\frac{r}{x} - 1 = \frac{q_2}{q_1}$$

Or $$\frac{r}{x} = \frac{q_1}{q_1} + 1$$

Putting values: $\frac{0.1}{x} = \frac{4\times10^{-6}}{8\times10^{-6}} + 1$

Or $\frac{0.1}{x} = \frac{1}{2} + 1$

Or $\frac{0.1}{x} = \frac{1+2}{2}$

$\frac{0.1}{x} = \frac{3}{2}$

Or $x = \frac{2}{3}\times 0.1\text{m}$

Hence, $\boxed{x = 0.00666\text{ m}}$

Since the point 'P' is at a distance 'x' from 8μC point charges therefore the distance of zero potential from 8μC charge is 0.066m or 6.66cm.

Whereas the point 'P' is at distance r – x from 4μC point charge therefore the distance of zero potential from 4μC charge is 0.10m − 0.0666m.

$\boxed{\Rightarrow \quad 0.0333\text{m} \quad \text{or} \quad 3.33\text{cm}}$

---

1. An electron with an initial speed of 29×10^5 ms^{-1} is fired in the same direction as a uniform electric with a magnitude of 80 NC^{-1}. How far does the electron travel being brought to rest momentarily and turned back?

---

iven Data:

Initial speed $v_i = 29\times10^{-5}$ m/s

Final speed $v_f = 0$m/s

Electric field intensity $\varepsilon = 80$N/C

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

Mass of electron $m_e = 9.11\times10^{-31}$ C

o find:

Distance S = ?

olution:

The third equation of motion is

$$2aS = v_f^2 - v_i^2$$

or $$S = \frac{v_f^2 - v_i^2}{2a} \longrightarrow \text{(i)}$$

By Newton's second law:

$$a = \frac{F}{m_e} \longrightarrow \text{(ii)}$$

By definition of electric field intensity

$$E = \frac{F}{q_e}$$

Or $$F = q_eE \longrightarrow \text{(iii)}$$

Putting equation (iii) in equation (ii), we get

$$a = \frac{q_eE}{m_e} \longrightarrow \text{(iv)}$$

Putting equation (iv) in equation (i), we get

$$S = \frac{v_f^2 - v_i^2}{2\left(\frac{q_eE}{m_e}\right)}$$

Or $$S = m_e \frac{v_f^2 - v_i^2}{2 \times q_eE}$$

Putting values: $$S = 9.11 \times 10^{-31} \times \frac{(0)2 - (29 \times 10^5)^2}{2 \times (-1.6 \times 10^{-19}) \times 80}$$

$$S = 29.9277 \times 10^{-2}\ \text{m}$$

$$\boxed{S \ = \ 0.9927\ \text{m}}$$

12. Two capacitors of capacitance $4\mu F$ and $8\mu F$ are first connected (a) in series and then (b) in parallel. In each case external source of voltage is 200 V. Calculate in each case the total capacitance, the potential drop across each capacitor, and the charge on each capacitor.

Given Data:

Capacitor $C_1 = 4\mu F = 4 \times 10^{-6}$ F

Capacitor $C_2 = 8\mu F = 8 \times 10^{-6}$ F

Voltage $V = 200V$

To find:

Equivalent capacitance $(C_{eq}) = ?$

Potential drop V_1 and V_2, charges Q_1 and $Q_2 = ?$

Solution:

The equivalent capacitance is $$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2}$$

Or $$\frac{1}{C_e} = \frac{C_2 - C_1}{C_1C_2}$$

$$C_e = \frac{C_1C_2}{C_2 + C_1}$$

Putting values:

$$C_e = \frac{4 \times 10^{-6} \times 8 \times 10^{-6}}{8 \times 10^{-6} + 4 \times 10^{-6}}$$

$$C_e = \frac{32 \times 10^{-12}}{12 \times 10^{-6}}$$

$$C_e = 2.666 \times 10^{-6}\ \text{F}$$

$$\boxed{C_e \ = \ 2.666\ \mu F}$$

In series combination the charge remains the same $q_1 = q_2 = Q$

The charge on each capacitor is $Q = C_eV$

Putting values:

$$Q = 2.66 \times 10^{-6}\ \text{F} \times 200\text{V}$$

Hence, $Q = 5.33 \times 10^{-4}$ C therefore

$$\boxed{q_1 = q_2 = Q = 5.33 \times 10^{-4}\ \text{C}}$$

In series combination the voltage splits

$$V_1 = \frac{Q}{C_1}$$

Putting values

$$V_1 = \frac{5.33 \times 10^{-4}\,C}{4 \times 10^{-6}\,F}$$

$$\boxed{V_1 = 133.2V}$$

$$V_2 = \frac{Q}{C_2}$$

Putting values

$$V_2 = \frac{5.33 \times 10^{-4}\,C}{8 \times 10^{-6}\,F}$$

$$\boxed{V_2 = 66.6V}$$

For parallel combination:

The equivalent capacitance is $C_e = C_1 + C_2$

Putting values:

$$C_e = 4 \times 10^{-6} + 8 \times 10^{-6}$$

Therefore, $\boxed{C_e = 12 \times 10^{-6}\,F = 12\,\mu F}$

In parallel combination the voltage remains the same, $V_1 = V_2 = V$

Since the applied voltage V = 200V, therefore $\boxed{V_1 = V_2 = 200\,V}$

In parallel combination the charge divides whereas in series combination the voltage splits

$$q_1 = C_1V$$

Putting values:-

$$q_1 = 4 \times 10^{-6}\,C \times 200V$$

$$\boxed{q_1 = 800 \times 10^{-6}\,C = 800\,\mu C}$$

$$q_2 = C_2V$$

Putting values:

$$q_2 = 8 \times 10^{-6}\,C \times 200V$$

$$\boxed{q_2 = 1600 \times 10^{-6}\,C = 1600\,\mu C}$$

---

13. Three capacitors of capacitance $4\mu F$, $6\mu F$ and $8\mu F$ respectively are connected in series to a 250V DC supply. Find (i) the total capacitance (ii) charge on each capacitor and (iii) P.D. across each capacitor.

Given Data:

Capacitor $C_1 = 4\mu F = 4 \times 10^{-6}\,F$

Capacitor $C_2 = 6\mu F = 6 \times 10^{-6}\,F$

Capacitor $C_3 = 8\mu F = 8 \times 10^{-6}\,F$

Voltage $V = 250V$

To find:

Potential drop $V_1 = ?$, potential drop $V_2 = ?$

Potential drop $V_3 = ?$, series equivalent capacitance $C_{eq} = ?$

Solution:

For series combination:

The equivalent capacitance is $\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

Or

$$\frac{1}{C_e} = \frac{1}{4 \times 10^{-6}} + \frac{1}{6 \times 10^{-6}} + \frac{1}{8 \times 10^{-6}}$$

or

$$\frac{1}{C_e} = \frac{6+4+3}{(24 \times 10^{-6})}$$

or
$$\frac{1}{C_e} = \frac{30+21+35}{(420\times10^{-6})}$$

$$\frac{1}{C_e} = \frac{86}{420\times10^{-6}}$$

$$C_e = \frac{(420\times10^{-6})}{86}$$

$$C_e = 4.883\times10^{-6}\ \text{F}$$

$$\boxed{C_e = 4.883\times10^{-6}\ \text{F} = 4.883\ \mu\text{F}}$$

In series combination the charge remains the same, $q_1 = q_2 = q_3 = Q$

The charge on each capacitor is $Q = C_eV$

Putting values:
$$Q = 4.883\times10^{-6}\times100$$

$$Q = 488.3\times10^{-6}\ \text{C}$$

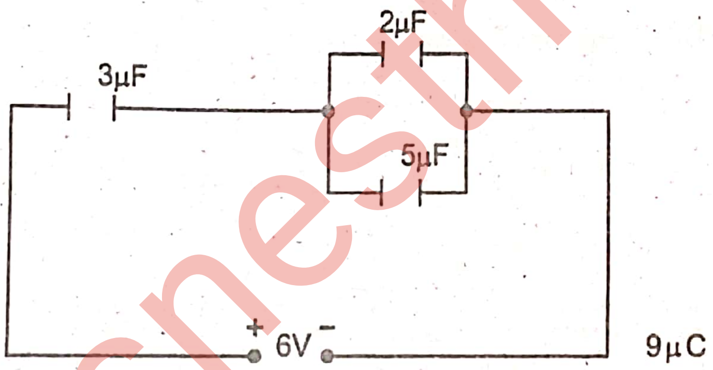
In series combination the voltage divides so the voltage across capacitor C_2 is

$$V_2 = \frac{Q}{C_2}$$

Putting values:
$$V_2 = \frac{488.3\times10^{-6}}{20\times10^{-6}}$$

$$\boxed{V_2 = 24.4\text{V}}$$

15. Find the charge on 5μF capacitor in the circuit shown in Fig.



Given Data:

Capacitor $C_1 = 3\mu F = 3\times10^{-6}$ F

Capacitor $C_2 = 2\mu F = 2\times10^{-6}$ F

Capacitor $C_3 = 5\mu F = 5\times10^{-6}$ F

Voltage $V = 6V$

To find:

Charge $q_1 = ?$

Solution:

The capacitors C_2 and C_3 are parallel connected with C_1 in series therefore, the equivalent capacitance is for parallel capacitors C_1' is $C_e' = C_2 + C_3$

or $C_e' = 2\times10^{-6}\ \text{F} + 5\times10^{-6}\ \text{F}$

or $C_e' = 7\times10^{-6}\ \text{F} = 7\mu\text{F}$

The equivalent capacitance is for series capacitors C_e is:

$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C'_e}$$

or $$\frac{1}{C_e} = \frac{C'_e + C_1}{C_1\, C'_e}$$

or $$C_e = \frac{C_1\, C'_e}{C'_e + C_1}$$

Putting values: $$C_e = \frac{3 \times 10^{-6} + 7 \times 10^{-6}}{(7 \times 10^{-6} + 3 \times 10^{-6})}$$

$$C_e = \frac{21 \times 10^{-12}}{10 \times 10^{-6}}$$

$$C_e = 2.1 \times 10^{-6}\, F = 2.1\, \mu F$$

The charge on each capacitor is

$$Q = C_e V$$

Putting values: $$Q = 2.1 \times 10^{-6}\, F \times 6V$$

Hence, $$Q = 12.6 \times 10^{-6}\, C$$

In parallel combination this charge splits between the two capacitors C_2 and C_3.

$$q_3 = C_3 \times V_{23} \longrightarrow \text{(i)}$$

Where V_{23} is the voltage for the capacitors C_2 and C_3 connected in parallel.

$$V_{23} = \frac{Q}{C'_e} \longrightarrow \text{(ii)}$$

Putting equation (ii) in equation (i), we get

$$q_3 = C_3 \times \frac{Q}{C'_e}$$

$$q_3 = 5 \times 10^{-6}\, F \times \frac{12.6 \times 10^{-6}\, C}{7 \times 10^{-6}\, F}$$

or $$\boxed{q_3 = 9 \times 10^{-6}\, C} = 9\, \mu C$$

---

16. Two parallel plate capacitors A and B having capacitance of 2µF and 6µF are charged separately to the same potential of 120v. Now positive plate of A is connected to the negative plate of B and negative plate of A is connected to the positive of B. Find the final charge on each capacitor

Given Data:

Capacitor $C_A = 2\mu F = 2 \times 10^{-6}\, F$

Capacitor $C_B = 6\mu F = 6 \times 10^{-6}\, F$

Voltage $v_A = 120V$

Voltage $v_B = 120V$

To find:

Find charge $q_A = ?$, final charge $q_B = ?$

Solution:

Let the initial charges on the capacitors before connecting are Q_A and Q_B

$$Q_A = C_A V$$

$$Q_A = 2 \times 10^{-6} \times 120$$

$$Q_A = 240 \times 10^{-6} = 240\, \mu C$$

$$Q_A = C_BV$$

$$Q_B = 6 \times 10^{-6} \times 120$$

$$Q_B = 720 \times 10^{-6}\ C = 720\ \mu C$$

Since the capacitors are connected in opposing therefore the total charges Q will be:

$$Q = Q_B - Q_A = 720 \times 10^{-6}\ C - 240 \times 10^{-6}\ C = 480 \times 10^{-6}\ C = 480\mu C$$

After reaching equilibrium the total voltage across the capacitors will be:

$$V = \frac{Q}{C_A + C_B}$$

After reaching equilibrium the voltage across the capacitor C_A will be:

$$V_A = \frac{q_A}{C_A}$$

After reaching equilibrium the voltage across the capacitor C_B will be:

$$V_B = \frac{q_B}{C_B}$$

After reaching equilibrium the total voltage will be same as voltage across each capacitor.

$$V = V_A$$

$$\frac{Q}{C_A + C_B} = \frac{q_A}{C_A}$$

$$q_A = C_A \times \frac{Q}{C_A + C_B}$$

$$q_A = 2 \times 10^{-6} \times \frac{480 \times 10^{-6}}{2 \times 10^{-6} + 6 \times 10^{-6}}$$

$$\boxed{q_A = 120 \times 10^{-6}\ C = 120\mu C}$$

$$V = V_B$$

$$\frac{Q}{C_A + C_B} = \frac{q_B}{C_B}$$

$$q_B = C_B \times \frac{Q}{C_A + C_B}$$

$$q_A = 6 \times 10^{-6} \times \frac{480 \times 10^{-6}}{2 \times 10^{-6} + 6 \times 10^{-6}}$$

$$\boxed{\begin{aligned} q_A &= 360 \times 10^{-6}\ C \\ q_A &= 360\ \mu C \end{aligned}}$$

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7. A 6μF capacitor is charged to a P.D. of 120V and then connected to an un-charged 4μF capacitor. Calculate the P.D. across the capacitors.

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iven Data:

Capacitor $C_1 = 6\mu F = 6 \times 10^{-6}\ F$

Capacitor $C_2 = 4\mu F = 4 \times 10^{-6}\ F$

Voltage $V_1 = 12V$

o find:

Final voltage = V = ?

olution:

The total charge in the circuit is the charge on capacitor C_1, therefore, $Q_1 = V_1, C_1 = Q$ this charge wil be distributed in capacitor as $Q = q_1 + q_2$

If 'V' is the voltage of the capacitors after reaching equilibrium, then $q_1 = VC_1$ and $q_2 = vC_2$. Therefore,

$$V_1C_1 = VC_1 + VC_2$$

or $$V_1C_1 = V(C_1 + C_2)$$

and $$V = \frac{v_1C_1}{(C_1 + C_2)}$$

Putting values: $$V = \frac{120 \times 6 \times 10^{-6}}{(6 \times 10^{-6} + 4 \times 10^{-6})}$$

therefore, $$\boxed{V = 72\ V}$$

18. Two capacitor of capacitance 8μF and 10μF respectively are connected in series across a P.D of 180 V. The capacitors are disconnected from the supply and are reconnected in the paralle with each other. Calculate the new P.D. and charge on each capacitor.

Given Data:

Capacitor $C_1 = 8\mu F = 8 \times 10^{-6} F$

Capacitor $C_2 = 10\mu F = 10 \times 10^{-6} F$

Voltage $v = 180V$

To find:

Potential drops v_1 and v_2 = ?, Charges q_1 and q_2 = ?

Solution:

For series combination the equivalent capacitance is:

$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2}$$

or $$\frac{1}{C_e} = \frac{C_2 + C_1}{C_1 C_2}$$

or $$C_e = \frac{C_1 C_2}{C_2 + C_1}$$

Putting values:

$$C_e = \frac{8 \times 10^{-6} \times 10 \times 10^{-6}}{10 \times 10^{-6} + 8 \times 10^{-6}}$$

or $$C_e = \frac{80 \times 10^{-12}}{18 \times 10^{-6}}$$

$$C_e = 4.444 \times 10^{-6} F = 4.444\mu F$$

In series combination the charge remains the same, $q_1 = q_2 = Q$

The charge on each capacitor is

$$Q = C_e V$$

Putting values: $Q = 4.444 \times 10^{-6} F \times 180V$

Hence, $Q = 800 \times 10^{-6} C$

When the capacitors are connected in parallel the total charge will become

$$Q_T = q_1 + q_2$$

Or $Q_T = Q + Q$

or $Q_T = 2Q$

Putting values: $Q_T = 2 \times 800 \times 10^{-6} C$

Hence, $Q_T = 1600 \times 10^{6} C = 1600 \mu C$

For parallel combination the equivalent capacitance is

$$C_e = C_1 + C_2$$

Putting values: $C_e = 8 \times 10^{-6} F + 10 \times 10^{-6} F$

Therefore, $C_e = 18 \times 10^{-6} F = 18\mu F$

Also in parallel combination the voltage remain the same, $V_1 = V_2 = V$.

The voltage 'V' is $V = \frac{Q_T}{C_e}$

putting values

$$V = \frac{1600 \times 10^{-6} C}{18 \times 10^{-6} F}$$

Hence
$$V = 88.89V$$
$$\boxed{V_1 = V_2 = V = 88.89V}$$

Now the charge on each capacitor can be computed as:

$$q_1 = C_1V$$

putting values

$$q_1 = 8 \times 10^{-6}\,F \times 88.89V$$
$$q_1 = 711.21 \times 10^{-6}\,C$$
$$\boxed{q_1 = 711.12\,\mu C}$$

$$q_1 = C_1V$$

putting values

$$q_1 = 8 \times 10^{-6}\,F \times 88.89V$$
$$q_1 = 711.21 \times 10^{-6}\,C$$
$$\boxed{q_1 = 711.12\,\mu C}$$

Additional Conceptual Short Questions With Answers

1. The time constant of a series RC circuit is t = RC, verify that an Ohm times farad is equivalent to second.

(Grw 2016) (Lhr 2016 Group I)

Ans. Given data:

The time constant of a series circuit = t = RC

To prove:

1 ohm × 1 farad = 1 second

Proof:

According to Ohm's law
$$V = IR$$

Putting $I = \frac{q}{t}$, we have

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

or
$$R = \frac{Vt}{q} \qquad \ldots\ldots(1)$$

According to equation
$$q = CV$$

or
$$C = \frac{q}{V} \qquad \ldots\ldots(2)$$

Multiplying equation (1) and (2), we get

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

Or
$$RC = t$$

Hence, $\boxed{\text{1 ohm} \times \text{1 farad} = \text{1 second}}$

where ohm is the unit of resistance R.

2. Show that $\frac{\text{1 Volt}}{\text{1 meter}} = \frac{\text{1 Newton}}{\text{1 Coulomb}}$.

Ans.
$$\text{LHS} = \frac{\text{Volt}}{\text{meter}}$$
$$= \frac{\text{joule}}{\text{Coulomb} - \text{meter}}$$
$$= \frac{\text{newton} - \text{meter}}{\text{Colomb} - \text{meter}}$$

$$= \frac{\text{newton}}{\text{colomb}}$$

$$= \text{RHS}$$

3. Do electrons tend to go to region of high potential of low potential?

Ans. Electrons tend to go the region of ***high potential.***

Reason:

As the electrons are ***negatively charged particles*** when they are released in an electric field. They move from negative end (low potential) to positive end (high potential)

4. Vehicles carrying inflammable materials usually have metallic ropes touching the ground during motion. Why?

Ans. When vehicles move through air, they get charged due to air friction and charges develop on tyres also. If charges are sufficient, they will produce spark. The vapour which escape from the inflammable material carried by vehicle may catch fire. To prevent this metallic ropes touching the ground are suspended. Through this conducting metal the charges flow to the earth.

5. Force of attraction between two point charges placed at a distance d in a medium is F. At what distance apart should these changes be kept in the some medium so that force between them become $\frac{F}{3}$?

Ans.

$$F = K\frac{q_1q_2}{d^2} \longrightarrow (1)$$

$$F' = K\frac{q_1q_2}{x^2} \longrightarrow (2)$$

$$F' = \frac{F}{3}$$

$$K\frac{q_1q_2}{x^2} = \frac{1}{3}\left(K\frac{q_1q_2}{d^2}\right)$$

$$\frac{1}{x^2} = \frac{1}{3d^2}$$

$$x^2 = 3d^2$$

Taking square root of both sides

$$x = \sqrt{3d^2}$$

$$x = \sqrt{3}\,d$$

6. Why is it safe to stay inside an automobile during a light storm?

Ans. Although many people believe that this is safe because of the insulating rubber tyre, This is not true. Lighting is able to travel trough several kilometer of air, so it can certainly penetrate a few centimeter of rubber.

The interior of the car is safe because the charges on the car,s metal shell reside on its outer surface. Thus the occupant in the automobile touching the inner surface is not in danger.

7. The distance between the plates of a parallel plate capacitor is d. A metal plate of thickness $\frac{d}{2}$ is placed between the plates. What will be its effect on the capacitance?

Ans. When metal plate is introduced between two plates of a capacitor, it will act as two capacitors and the capacitance will increase.

8. A negatively charged balloon is set free, It first clings to the wall but eventually falls down. Why?

Ans. Due to phenomenon of electrostatic induction negatively charged balloon induces a positive charge on the wall, so it clings to the wall. It falls eventually because of leakage of charge through wall and surrounding.

Self-Assessment Paper 1

Q.No.1 Encircle the correct option.

1. ________ are the units of electric intensity
(a) NC^{-1} and NV^{-1} (b) NC^{-1} and Vm^{-1} (c) Nm^{-1} and Vm^{-1} (d) JC^{-1} and Vm^{-1}
2. Selenium is a ________
(a) photo conductor (b) super conductor (c) good conductor (d) insulator
3. Electric flux through a closed confining a charge +2e and -2e is
(a) $4e/\varepsilon_o$ (b) q/ε_o (c) zero (d) E.A
4. Nm^2C^{-1} ________ is the unit of
(a) Electric flux (b) magnetic flux (c) time constant (d) electric intensity
5. ECG records ________ between points on human skin generated by electric process in the heart.
(a) current (b) voltage (c) thermal power (d) magnetic flux
6. By making the area of plates of a parallel plate capacitor double and separation between the plates half, the capacitance of the capacitor
(a) becomes half (b) becomes double (c) becomes four times (d) becomes one fourth
7. A particle carrying a charge 2e falls through a potential difference of 3V acquires energy ________
(a) 6eV (b) 6watt (c) 9.6×10^{-19}eV (d) 6J
8. ohm × farad = ________
(a) Joule (b) watt (c) eV (d) second
9. The force experience per unit positive charge placed at a point in an electric field is called:
(a) Coulomb's force (b) Faraday's force (c) Lorentz's force (d) Electric field intensity
10. The force between two point charges separated by air is 4 N. When separated by a medium of relative permittivity 2, the force between them becomes
(a) ½ N (b) 2 N (c) 4 N (d) 8 N

Q.No.2 Write Short Answers any SIX of the following questions.

1. Define potential gradient. Shot that volt/meter = newton / coulomb.
2. Water has a large dielectric constant, but is rarely used in capacitors. Why?
3. Suppose that you follow an electric field line due to a negative point charge. Do electric field and electric potential increase or decrease?
4. What are uniform and uniform electric field lines, explain with example.
5. Is E necessarily zero inside a charged rubber balloon if balloon is spherical? Assume that charge is distributed uniformly over the surface.
6. What is the relationship between electric potential difference and change in potential energy?
7. Define electron volt and show that 1eV = 1.6×10^{-19}J.

Q.No.3Extensive Question.

Q. (a) State Gauss's law. Determine the electric intensity at a point due to an infinite sheet of charge.
(b) A 280 J of work is done in varying a charge of 2C from a place where the potential is -12 V to another placewhere potential is V, calculate the value of V?

Self-Assessment Paper 2

Q.No.1 Encircle the correct option.

1. **The SI units of permitivity ε_o are:**
(a) $C^2N^{-1}m^{-2}$ (b) Nm^2C^{-2} (c) NmC^{-2} (d) NmC^{-1}

2. **Electron volt is the unit of**
(a) electric potential (b) electric intensity (c) potential difference (d) potential energy

3. **The absolute Electric potential at a point distance 20cm from a charge of 2 μc is**
(a) 9×10^2 V (b) 9×10^3 V (c) 9×10^4 V (d) 9×10^5 V

4. **If the electric and gravitational forces on an electron balance each other, then the electric intensity will be**
(a) mg/q (b) mq/g (c) m/qg (d) q/mg

5. **The gradient of the scalar field is always be a**
(a) scalar quantity (b) vector quantity (c) tensor (d) none of these

6. **In the time constant of RC circuit, how much charge is stored, out of maximum charge q_o?**
(a) $0.37\ q_o$ (b) $0.51\ q_o$ (c) $0.63\ q_o$ (d) $0.90\ q_o$

7. **Energy density in case of a capacitor is always proportional to:**
(a) E^2 (b) ε_0 (c) V (d) C

8. **If Potential difference across two plates of a parallel plates capacitor is doubled then energy stored in if will be:**
(a) Two times (b) Eight times (c) Four times (d) Remain same

. **Two opposite point charge of same magnitude separated by distance 2d, electric potential mid-way between them is:**
(a) 1V (b) 2V (c) Zero (d) $\frac{V}{2}$

0. **The work done in moving a positive charge on an equi-potential surface is:**
(a) Finite and Positive (b) Infinite (c) Finite and Negative (d) Zero

.No.2 Write Short Answers of the following questions.

Describe the application of Electrostatic in the function of photocopier machine.

Why the equi-potential surface and hence the line is at one same potential in an electric field?

Write down four dissimilarities between electric and gravitational forces.

Sketch the graphs for charging and discharging of a capacitor.

Sketch the graphs for charging and discharging of a capacitor.

Do the electrons tends to go to a region of high potential or low potential?

Write down some important properties of electric field lines?

.No.3 Extensive Questions.

. (a) Explain Millikan's oil drop method to determine the charge on an electron.

(b) What is the potential difference between two points in a electric field if it takes 600J of energy to move a charge of 2C between two points?

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