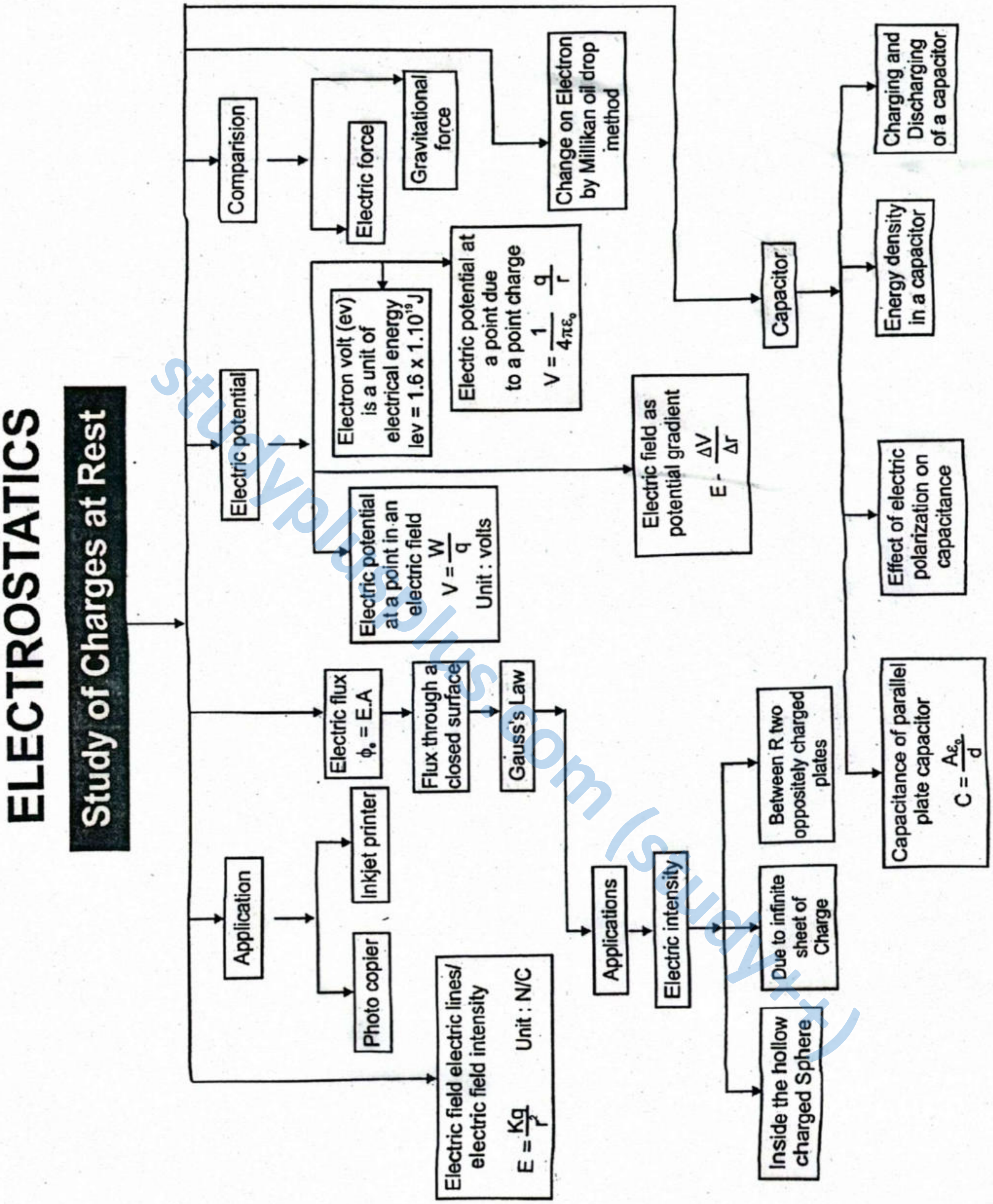
Chapter # 12
Electrostatistics

Learning Objectives

- Understand and describe Coulomb's law.
- Describe that a charge has a field of force around it.
- Understand fields of like and unlike charges.
- Appreciate the principle of inkjet printers and Photostat copier as an application of electrostatic phenomena.
- Explain the electric intensity in a free space and in other media.
- State and prove Gauss's law.
- Appreciate the applications of Gauss's law.
- Explain electric potential at a point in terms of work done in bringing a unit positive charge from infinity to that point.
- Relate electric field strength and potential gradient.
- Find expression for potential at a point due to a point charge.
- Describe and derive the value of electric charge by Millikan's method.
- Calculate the capacitance of parallel plate capacitor.
- Recognize the effect of dielectric on the capacitance of parallel plate capacitor.
- Understand and describe electric polarization of dielectric.
- Know the process of charging and discharging of a capacitor through a resistance and calculate the time constant.
- Find energy expression of a charged capacitor.

CONCEPT MAP



ELECTROSTATICS
Study of Charges at Rest
Comparision
Electric force
Gravitational force
Change on Electron by Millikan oil drop method
Electric potential
Electron volt (ev) is a unit of electrical energy 1ev = 1.6 x 1.10^19 J
Electric potential at a point due to a point charge $V = \frac{1}{4\pi\varepsilon_0} \frac{q}{r}$
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 $C = \frac{A\varepsilon_0}{d}$
Electric flux $\phi_e = E.A$
Flux through a closed surface
Gauss's Law
Applications
Electric intensity
Between R two oppositely charged plates
Due to infinite sheet of Charge
Inside the hollow charged Sphere
Application
Inkjet printer
Photo copier
Electric field electric lines/ electric field intensity $E = \frac{Kq}{r^2}$ Unit : N/C

Electrostatics

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

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.

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

Like charges **repel** and unlike charges **attract** each other.

Q.1 State and Explain the Coulomb's Law. ***RWP – 2017, FSD- 2018, MIRPUR 2017***

Ans.

COULOMB'S LAW

Each charge exerts a force of attraction or repulsion on another charge. Charles Coulomb observed the quantitative nature of these forces. He stated his experimental observations in mathematical form called Coulomb's law in 1784 A.D.

Statement

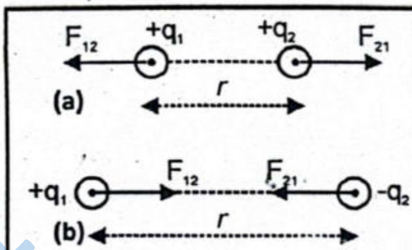
The force between two point charges is directly proportional to the product of magnitudes of charges and inversely proportional to the square of distance between them.

Mathematical Form

If two point charges q_1 and q_2 are separated by a distance r. Then the electric force between the charges,

$$F \propto q_1 q_2 \quad \text{———— (i)}$$

$$F \propto \frac{1}{r^2} \quad \text{———— (ii)}$$



(a) Repulsive forces between like charges and (b) attractive forces between unlike charges

Combining (i) and (ii), we get

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

OR $$F = k\left[\frac{q_1 q_2}{r^2}\right]$$

Where k is the constant of proportionality called **electrostatic constant.**

Dependence of k

Its value depends upon the nature of **medium** between the charges and the **system of units.** For free space.

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

Where ε_o is known as permittivity of free space and its value is

$8.85 \times 10^{-12}\ C^2N^{-1}m^{-2}$.

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

> **Point Charge**
>
> A point particle with non-zero charge is called point charge.
>
> **Note:** A particle with no dimensions is called point particle.

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

So, the electric force between the charges,

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

For Your Information
Charles Coulomb
(1736-1806)

Vector form of Coulomb's Law

Coulomb's force is **mutual force**, it means that if q_1 exerts a force on q_2, then q_2 also exerts an equal and opposite force on q_1.

Let

$\vec{F}_{21}$ = force exerted on charge q_2 by q_1

$\vec{F}_{12}$ = force exerted on charge q_1 by q_2

Then,

$$\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0} [\frac{q_1 q_2}{r^2}] (\hat{r}_{21}) \quad \text{———— (1)}$$

And $$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0} [\frac{q_1 q_2}{r^2}] (\hat{r}_{12}) \quad \text{———— (2)}$$

Where

$\hat{r}_{21}$ = unit vector directed from q_1 to q_2

$\hat{r}_{12}$ = unit vector directed from q_2 to q_1

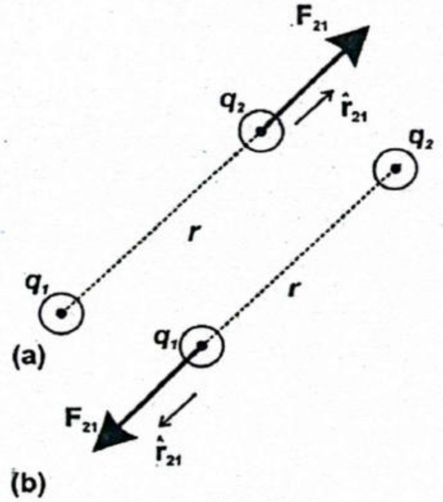


Fig. 12.2

From figure, we get

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

Hence, equation (1) becomes

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

OR $$\vec{F}_{21} = -\frac{1}{4\pi\varepsilon_0} [\frac{q_1 q_2}{r^2}] (\hat{r}_{12})$$

OR $$\vec{F}_{21} = -\vec{F}_{12}$$

Thus, ***Coulomb's law is in accordance with Newton's third law of motion.***

For Your Information
$\varepsilon_{med} = \varepsilon_0 \ \varepsilon_r$ Where $\varepsilon_r \geq 1$
For all metals
$\varepsilon_r \rightarrow \infty$

Effect of medium on electric force between two charges

If an insulating medium is placed between the charges. Then, it will **reduce** *the* electrostatic force as compared to free space by a factor ε_r called **relative permittivity** whose value varies with nature of dielectric.

Thus, in the presence of dielectric, the Coulomb force becomes

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

OR $$F' = \frac{1}{\varepsilon_r}\left[\frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\right]$$

$$F' = \frac{1}{\varepsilon_r}[F]$$

Table 2.1

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

So $\varepsilon_r = \frac{F}{F'}$

$F = \varepsilon_r F'$

$F > F'$

For Your Information

As ε_r is the ratio of identical quantities, So, it has no units.

For vacuum the value of ε_r is **1** while **for air** the value of ε_r is **1.0006.**

Relative Permittivity (ε_r)

As $$\varepsilon_r = \frac{F}{F'}$$

Thus

Relative permittivity or dielectric constant ε_r can be defined as *the ratio of electrostatic force between the charges in vacuum to the force when the medium between the charges is dielectric.*

MCQ's From Past Board Papers

1. **Relative permittivity for air is:** **(Azad Kashmir 2017, Multan 2018 G II, Lhr 2011, Bwp 2013, Mtn 2015 G – I)**
(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 ϵ_r = 2.1 between, the charges, then the force become equal to:** **(Rwp 2011, Grw 2014, Bwp 2015)**
(A) 42 N (B) 83.2 N (C) 20 N (D) 2N

3. **Presence of dielectric always:** **(D.G.Khan 11,2017, Lhr 11,12,2014 Bwp 2018, Lhr 2014 Grw 2013 G I)**
(A) Increases the electrostatic force (B) Reduces the electrostatic force
(C) Does not affect the electrostatic force (D) Doubles the electrostatic force.

4. **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:** **(Mirpur 2016, Lhr 2011, 2012 Grw 2010)**
(A) $\frac{1}{2}$ N (B) 2 N (C) 4 N (D) 8 N

5. **The value of relative permittivity for all the dielectrics other than air or vacuum is always** **(Lhr 2010, 12)**
(A) Less then unity (B) Greater than unity (C) Equal to unity (D) zero

6. **If F_1 and F_2 are forces acting on α particle and electron respectively in an electric field, then** **(Rwp 2016)**
(A) $F_1 = F_2$ (B) $F_1 > F_2$ (C) $F_1 < F_2$ (D) $F_1 = 4F_2$

7. **The constant of proportionality "K" depend upon:** **(D.G.Khan 2018 G I, Bwp 2016)**
(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

8. **The value of Coulomb's constant (K) in SI units is** **(Grw 2013, Fsd 2012-13, Mtn 2011, Lhr 2015 G – I)**
(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) $9 \times 10^9 Nm^2C^2$

9. **The force between two similar unit charges placed one meter apart in air is:** **(Sgd 2018 G I, Fsd 2016, Bwp 2017)**
(A) Zero (B) One Newton (C) 9×10^9 N (D) 9×10^{-9} N

10. **The value of ε_0 permittivity for free space is:** **(Fsd 2015, D.G.Khan 2017 G II, Sgd 2017 G I, Grw 2016)**
(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) $8.85 \times 10^{-12}m^2N^{-1}C^2$

11. **The electrostatic force of repulsion between two electrons at a distance 1m is:** **(Rwp 2015)**
(A) 2.3×10^{-24} N (B) 2.3×10^{-26} N (C) 2.3×10^{-28} N (D) 2.3×10^{-30} N

12. **Two charges 1 μC and 5 μC separated by 20 cm, the ratio of electrical forces acting on them will be:** **(Lhr 2016 G II)**
(A) 1 : 2 (B) 1 : 5 (C) 1 : 1 (D) 5 : 1

13. **SI unit of relative permivity is** **(Lhr 2018 G II, Grw 2017)**
(A) $\frac{C^2}{Nm^2}$ (B) $\frac{C^{-2}}{Nm^2}$ (C) $Nm^{-2}C^{-1}$ (D) None

14. **If the distance between the two charged bodies is halved, the force between them becomes:** **(Lhr 2017 G II)**
(A) Double (B) Half (C) Four time (D) One fourth

15. **If both the magnitude of charge and distance between them is doubled, then doubled, then coulomb's force will be:-** **(Mtn 2017 G I)**
(A) Doubled (B) Half (C) Remains same (D) One fourth

16. **The direction of field lines around an isolated charge "-q" is** **(Sgd 2017 G I)**
(A) Radically inward (B) Radically outward (C) Elliptical (D) Circular

17. Two oppositely charged balls A and B attract the third ball C, when placed near them turn by turn. The third ball C must be: (Lhr GI 2018)

(A) Positively charged (B) Negatively charged
(C) Electrically neutral (D) Positively and negatively charged

18. If the distance between two charges is halved and charges are also doubled, then force between them will be: (Bwp GI 2018)

(A) Two Times (B) Four Times (C) Eight Times (D) Sixteen Times

19. The force between two charges is 28 N. If Paraffin Wax of relative permittivity 2.8 is introduced between the charges as medium, then the force reduces to: (Bwp GII 2018)

(A) 25 N (B) 20 N (C) 15 N (D) 10 N

ANSWER KEY'S

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

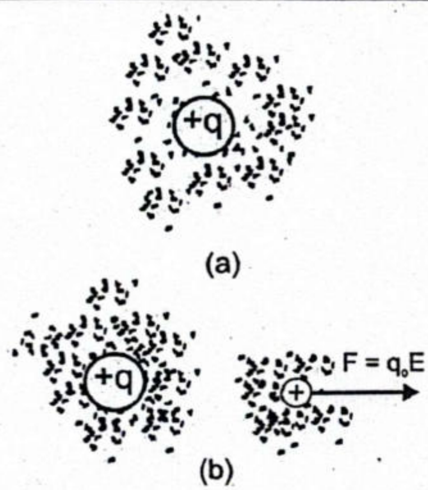
Q.2 What is meant by electric field of force?

Ans.

FIELDS OF FORCE

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.



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

Michael Faraday theory of transmission of electric force

According to his theory, It is **intrinsic** property of nature that an electric field exists in space around an electric charge. This electric field exerts a force on a test charge placed in that region. Thus,

Electric Field

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

How a charge interacts with another charge

The interaction between a charge q and a test q_o is completed in two steps:

(i) the charge q produces a field
(ii) the field interacts with charge q_o to produce a force on q_o

Note: They test charge has to be very small so that it may not distort the field which has to be measured.

Q.3 Define and explain electric intensity field?

Ans.

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

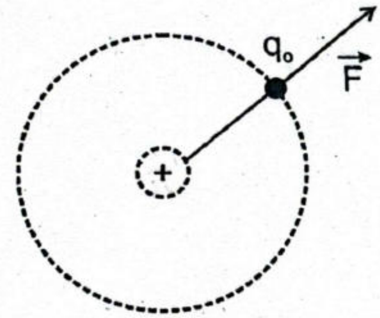
$$\vec{E} = \frac{\vec{F}}{q_o}$$

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}.



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

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

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

Putting value of F, we get

So $$E = \frac{\frac{1}{4\pi\varepsilon_o}\left[\frac{qq_o}{r^2}\right]}{q_o}$$

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

In vector form,

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

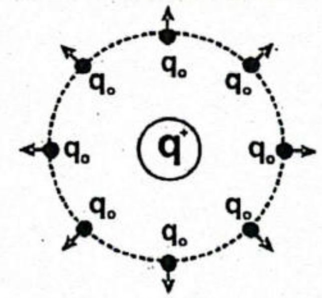
Where $\hat{r}$ is the unit vector directed from q to q_o.

For Your Information

Electrical field lines are always normal to the surface of the charge.

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

Ans.

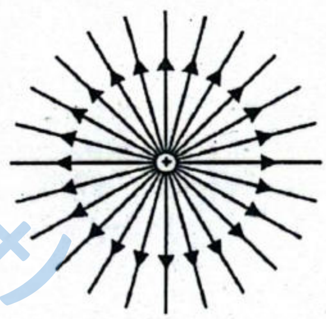


A positive test charge $+q_o$ place anywhere in the vicinity of a positive point charge +q, experiences a repulsive force directed radially outward.

ELECTRIC FIELD LINES

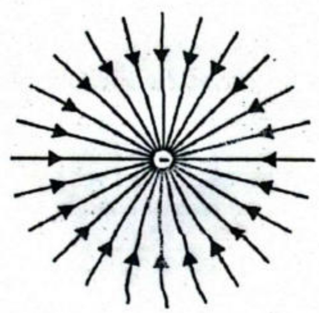
Electric field line is an imaginary line on which a free small test charge moves in an electric field.

Michael Faraday proposed the idea of representation of electric field by electric field lines. Electric lines of forces can be thought a map that represents the direction as well as strength of electric field. As they give information about electric force exerted on a charge. So the lines are commonly called as **lines of force**.



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

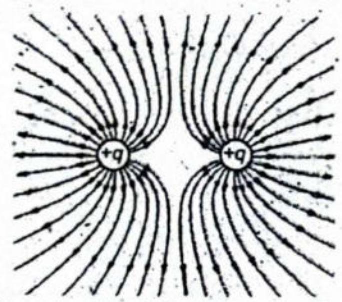
The electric field created by positive point charge +q repels the positive test charge q_o. The electric lines of forces are directed **radially outward**.

(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.**

(3) Electric field lines for like charges

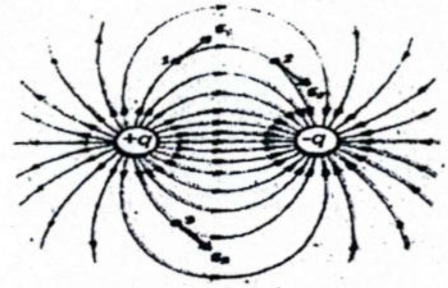
For two similar positive charges of equal magnitudes, the field lines are curved as shown in figure. The lines in region between the two charges seem to repel each other. The middle region shows the presence of a zero field spot or neutral zone.



The electric field lines for two identical positive point charges

(4) Electric field lines for unlike charges

For two opposite charges, the field lines starts from positive charge and end on negative end as shown in figure.



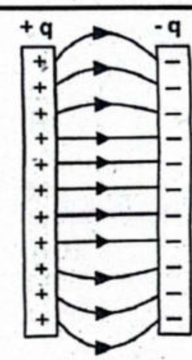
Attractive forces between unlike charges

Note

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

(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.



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

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.

MCQ's From Past Board Papers

1. **Concept of electric field was given by** **(Rwp 11, Sgd 13, Lhr 15 G – II , Grw 14, Mir 13 Supp, D.G.Khan 2017 G II)**
   (A) Michelson (B) Henry (C) Michel Faraday (D) Orested
2. **The fact that Electric Field exists in space around an electrical charge is _______.** **(AJK 2018, Fsd 2014, Federal 2012)**
   (A) Electrical property (B) Gravitational Field (C) Intrinsic property of nature (D) All of these
3. **The force experience per unit positive charge placed at a point in an electric field is called:** **(Lhr 2011, 2012 G I) (Mtn 2013, Bwp 2010 Swl 2014)**
   (A) Coulomb's force (B) Faraday's force (C) Electric field intensity (D) None of these
4. **The force on Neutron due to a field of 10^2 N/C is:** **(Lhr 2014 Sgd 2011, 2014)**
   (A) 1.6×10^{-17} N (B) 1.6×10^{-19} N (C) Zero (D) 1.6×10^{-21} N
5. **Special organ called Ampullae of lorenzini that are very sensitive to electric field are found in:** **(Sgd 16, Mirpur 13)**
   (A) Bats (B) Cats (C) Doges (D) Sharks

6. An ECG records the -------- between points on human skin generated by electric process in the heart: (Bwp 2016)
(A) Heart Beat (B) Pulse Rate (C) Pressure (D) Voltage

7. The electric field lines are closer where the field is: (Grw 2017, Fsd 2016)
(A) Strong (B) Weak (C) Uniform (D) Variable

8. The electric field created by positive charge is:- (Lhr 2018, Federal 2017, Sgd 13 Lhr 14 Grw 13 G I, Mtn 16 G II)
(A) Radially inward (B) Zero (C) Circular (D) Radially outward

9. S.I unit of strength of electric field is: (Lhr 2017 G I)
(A) J/C (B) C/V (C) N/C (D) J/N

10. A charge of 4 coulomb is in the field of intensity 4 N/C . The force on the charge is: (Sgd GI 2018)
(A) 8 N (B) 16 N (C) 4 N (D) 1 N

11. If electric lines of force are equally spaced the electric field is: (Rwp 2018)
(A) uniform (B) non-uniform (C) weak (D) strong

ANSWER KEY'S

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

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

Ans.

XEROGRAPHY (Photocopier)

The coping process is called Xerography. It is derived from Greek word Xeros and Graphos meaning **dry writing**. It is one of the applications of electrostatics.

Principle

Unlike charges attract each other.

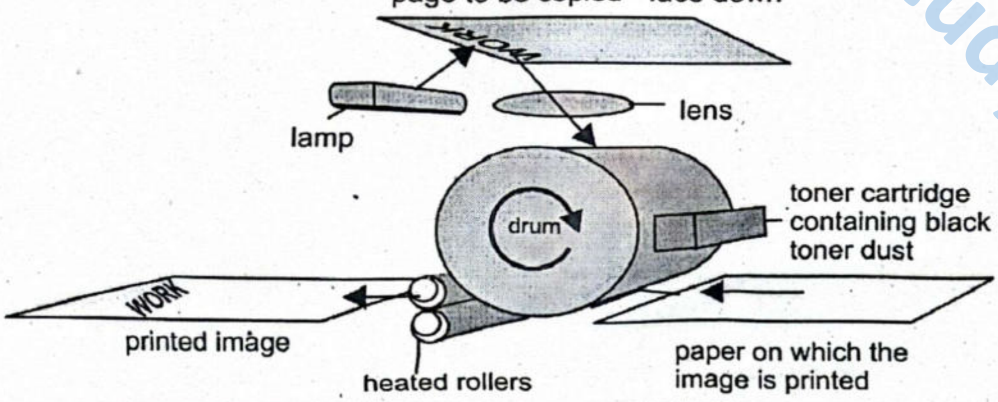
Construction

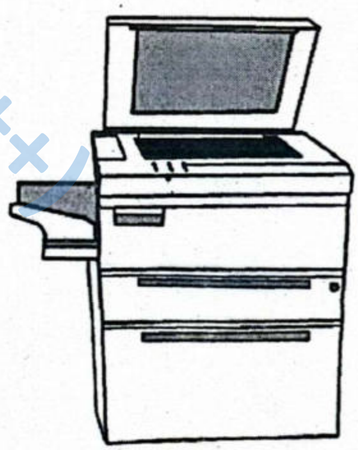
- The main part of photocopier is the **drum** (heat of photocopier) made up of aluminium coated with a layer of selenium.
- A **lamp** which provides enough light energy to eject electrons from photoconductive atoms.
- A **lens** to focus the image on drum. It can also reduce or magnify the size of image.
- A special kind of dry ink called **toner**.
- Heated pressure **roller** with some heating arrangement.

Corona Wires

For a photocopier to work a field of +ve charges must be generated on the surface of the drum and the copy paper.
This is done by wire subjected to high voltage called corona wires. One of the wires is stretched parallel to the drum surface that charges the photo conductive surface with +ive ions, while the other wire charges the copy paper positively.

Schematic Diagram





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

Working

Aluminium is an excellent conductor but selenium is an insulator in the dark and becomes conductor when light falls on it. In other words, it is a **photo conductor**.

The selenium is made positively charged by corona wires. It will remain positively charged as long as it remains in dark. When light is incident on a document, it is reflected, passes through the lens and falls on the selenium, the corresponding dark and bright areas are formed on the drum.

The dark areas retain their positive charge, but the light areas become conducting. So the electrons from aluminium pass through the selenium and neutralize the positive charges. Thus, a positive charge image of the document remains on selenium surface. Then, a special dry **negatively charged** black powder called toner is sprayed over the drum, where it sticks to the positively charged areas. The toner from drum is transferred on the highly positively charged sheet of paper. Heated pressure roller then melt the toner into the paper to produce the permanent impression of the document.

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

Ans.

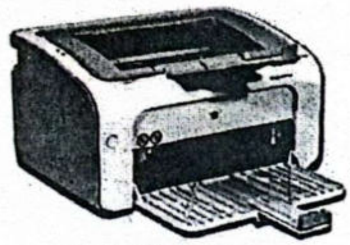
INKJET PRINTER

An inkjet printer is a printer which that places very small droplets of ink on to paper to make an image. It uses **electric charge** in its operation. It is also an application of electrostatics.

Principle

A charged particle is deflected when passes through uniform electric field between two oppositely charged parallel plates.

Construction



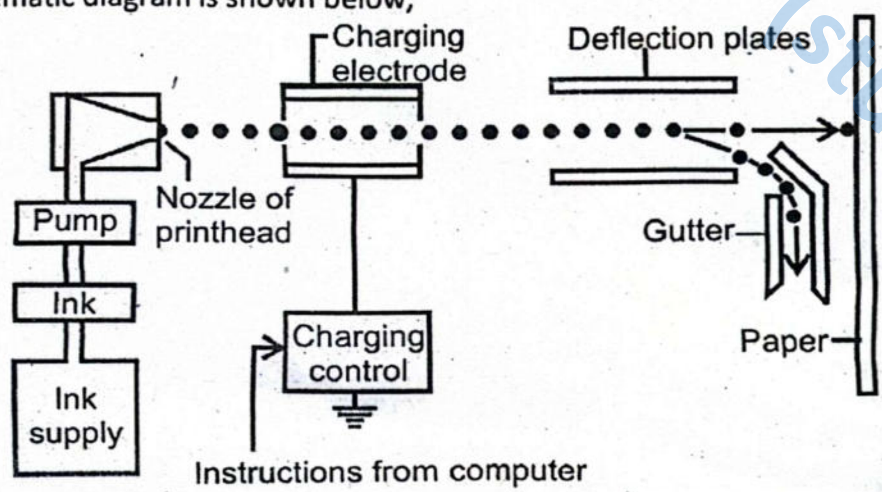
An Inkjet printer

Mainly, it consists of:

- **Print head** which consists of a nozzle with an ink pump.
- Two electrical components called charging **electrodes.**
- **Deflection plates.**
- A **gutter** (for residual part of ink)

Schematic diagram

The schematic diagram is shown below,



(b) An inkjet printhead ejectrs a steady flow of ink droplets. The charging electrodes are used to charge the droplets that are not needed on the paper. Charged droplets are deflectred into a gutter by the deflection plates. while uncharged droplets fly straight onto the paper.

For Your Information

This computer image shows the electric field lines generated by the fish at the top of the picture. Through the electric field, the presence of other fish can be detected , such as the one silhouetted at the bottom.

Working

Print head

Inkjet print head ejects a thin stream of ink when it shuttles back and forth across the paper. The ink comes out of a small jet (nozzle) and breaks up into very small droplets.

Charging electrodes

These small droplets become charged when pass through the charging electrodes. Charging electrodes are used to charge the droplets that are not needed on paper.

Deflection plates

When these charged ink droplets pass through the deflection plates, they are directed towards the gutter hence no image is formed on the paper.

How to place ink on paper

To place ink on the paper, the charging controls turn off the charging electrodes. The uncharged droplets pass straight through the deflection plates and strike the paper.

Inkjet printer is also used for color printing.

> **Types of printers**
>
> **Impact printer**
>
> These printers have a mechanism that touches the paper to produce an image .e.g. dot matrix
>
> **Non-impact printer**
>
> These printers do not touch the paper to produce an image .e.g. inkjet printers and laser printer

MCQ's From Past Board Papers

1. **Selenium is a:** **(Grw 2014, Rwp 2016, Mtn 2015 Group I, Lhr 10,16,17,2018, Bwp 2012 Mtn 2015 G I)**
   (A) Insulator (B) Photoconductor (C) Conductor (D) First insulator then conductor
2. **The toner of the printer is given** **(D. G. Khan 2015 G – I)**
   (A) Positive charge (B) Negative charge (C) Neutral (D) First positive then negative
3. **The word "Xerography" means:** **(Grw 2011, 12 Lhr –12 G I)**
   (A) Writing by left hand (B) Writing by children (C) Dry writing (D) Writing by water colours
4. **Photo copier and inkjet printer are the application of:** **(D.G.Khan 18, Mirpur 2016, Lhr 2016, Mtn 2014 Fsd 2014)**
   (A) Magnetism (B) Electricity (C) Electro magnetism (D) Electro statics
5. **The drum in a photocopier is coated with a layer of:-** **(Mtn 2017 G II, 2018)**
   (A) Aluminium (B) Silver (C) Gold (D) Selenium
6. **The photo copying process is called** **(Sgd 2017 G II)**
   (A) Photography (B) Scanning (C) Xerography (D) Holography
7. **Drum of photocopier is made of:** **(Rwp 2018)**
   (A) Copper (B) Toner (C) Selenium (D) Aluminium

ANSWER KEY'S

1.	B	2.	B	3.	C	4.	D	5.	D	6.	C	7.	D

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,

Definition (physical)

The number of field lines passing through certain area element is called electric flux through that area. OR

Definition (quantitative)

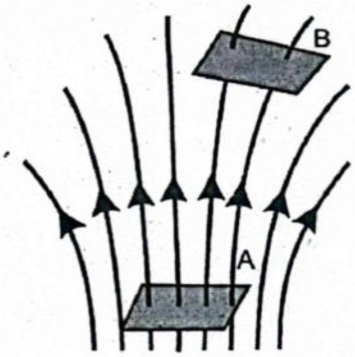
Electric flux through an area is defined as *the scalar product of electric field intensity $\vec{E}$ and vector area $\vec{A}$*

Mathematically

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

OR $\Phi = E\,A\cos\theta$

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



(a) Electric flux through a surface normal to E

Dependence of Electric flux

Electric flux depends upon

i) **Number** of electric lines of forces per unit area.

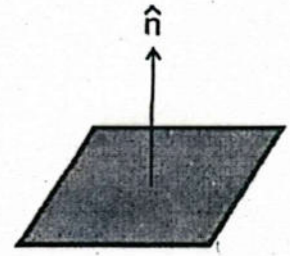
ii) **Area** of surface.

iii) **Orientation** of the surface.

Special cases

Case 1 (maximum flux)

When area is held perpendicular to electric intensity, then electric flux will be **maximum.** In this case, the angle between $\vec{E}$ and $\vec{A}$ will be zero i.e. $\theta = 0^\circ$



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

or $\Phi_e = E\,A\cos\theta$

$\Phi_e = E\,A\cos 0^\circ$

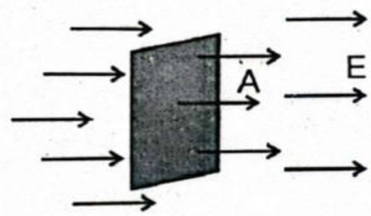
$\Phi_e = EA\,(1)$

$\Phi_e = EA$

Which is the maximum value of electric flux.

Case 2 (zero flux)

When area is held parallel to electric intensity, then electric flux is ***minimum.*** In this case $\theta = 90^\circ$



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

or $\Phi_e = E\,A\cos\theta$

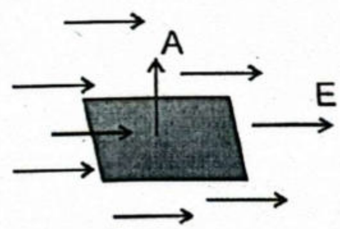
$\Phi_e = E\,A\cos 90^\circ$

$\Phi_e = EA\,(0)$

$\Phi_e = 0$

Case 3(When area is inclined at an angle θ with the lines)

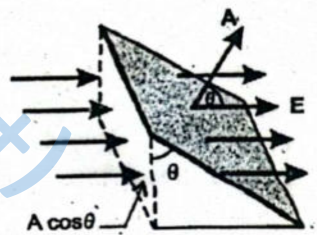
When the area is inclined at a certain angle θ with electric field strength, then



$\Phi_e = E$ (projection of $\vec{A}$ on $\vec{E}$)

$\Phi_e = E\,(A\cos\theta)$

$\Phi_e = E\,A\cos\theta$



As electric flux is a scalar product so, it is a **scalar quantity.**

Unit

SI unit of electric flux is $\mathbf{N\,m^2\,C^{-1}}$.

Note (Vector Area)

The physical quantity whose magnitude is equal to the area of surface and whose direction is along the direction of outward normal is called vector area $\vec{A}$.

Thus $\vec{A} = A\hat{n}$

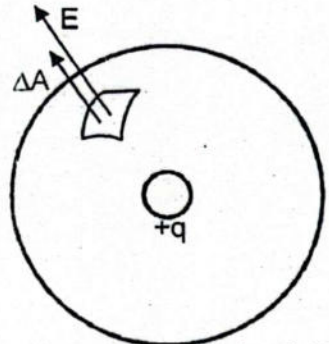
Where

$A\hat{n}$ is called vector area and whose magnitude is A and its direction is along the direction of outward normal $\hat{n}$ to the surface.

Q.8 Derive an expression for electric flux through a surface enclosing a charge. *GRW – 2017*

Ans.

ELECTRIC FLUX THROUGH A SURFACE ENCLOSING A CHARGE



The total electric flux through the surface of the spheredue to a charge q at its centre is q /ε₀

Consider a closed surface in form of sphere of radius r having a point charge +q at its centre.

In order to apply the formula, $\Phi_e = \vec{E} \cdot \vec{A}$, the surface should be flat.

Thus, surface area is divided into n number of small patches $\Delta\vec{A}_1, \Delta\vec{A}_2, \Delta\vec{A}_3, \ldots, \Delta\vec{A}_n$, so that for each patch is a flat element area.

Let the electric intensities at the centre of vector areas $\Delta\vec{A}_1, \Delta\vec{A}_2, \Delta\vec{A}_3, \ldots, \Delta\vec{A}_n$ are $\vec{E}_1, \vec{E}_2, \vec{E}_3, \ldots, \vec{E}_n$ respectively. Thus, the total flux through the closed surface is,

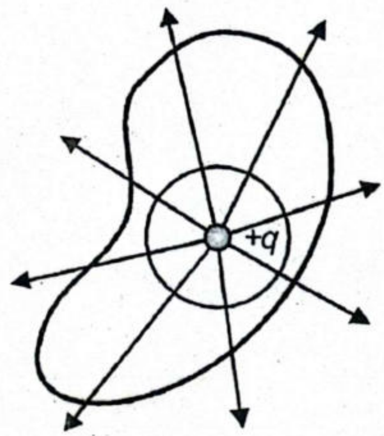
For 1st patch, $\Phi_{e_1} = \vec{E}_1 \cdot \Delta\vec{A}_1$

For 2nd patch, $\Phi_{e_2} = \vec{E}_2 \cdot \Delta\vec{A}_2$

For 3rd patch, $\Phi_{e_2} = \vec{E}_3 \cdot \Delta\vec{A}_3$

And so on for the nth patch

$$\Phi_{e_n} = \vec{E}_n \cdot \Delta\vec{A}_n$$



The total electric flux through the closed surface will be

$$\Phi_e = \Phi_{e_1} + \Phi_{e_2} + \Phi_{e_3} + \ldots + \Phi_{e_n}$$

$$\Phi_e = \vec{E}_1 \cdot \Delta\vec{A}_1 + \vec{E}_2 \cdot \Delta\vec{A}_2 + \vec{E}_3 \cdot \Delta\vec{A}_3 + \ldots + \vec{E}_n \cdot \Delta\vec{A}_n$$

As the direction of electric intensity and vector area is same at each patch, so $\theta = 0^o$

$$\Phi_e = E_1 \Delta A_1 \cos 0^o + E_2 \Delta A_2 \cos 0^o + E_3 \Delta A_3 \cos 0^o + \ldots + E_n \Delta A_n \cos 0^o$$

$$\Phi_e = E_1 \Delta A_1 + E_2 \Delta A_2 + E_3 \Delta A_3 + \ldots + E_n \Delta A_n \qquad [\because \cos 0^o = 1]$$

As all the surface elements are at equal distances from q,

So $E_1 = E_2 = E_3 = \ldots = E_n = E$ (say)

Hence $\Phi_e = E\Delta A_1 + E\Delta A_2 + E\Delta A_3 + \ldots\ldots + E\Delta A_n$

$$\Phi_e = E(\Delta A_1 + \Delta A_2 + \Delta A_3 + \ldots\ldots + \Delta A_n)$$

$$\Phi_e = E \text{ (surface area of sphere)}$$

As $E = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}$ and surface area of the sphere $= 4\pi r^2$

Thus $$\Phi_e = \frac{1}{4\pi\varepsilon_o}\left[\frac{q}{r^2}\right](4\pi r^2)$$

or $$\Phi_e = \frac{q}{\varepsilon_o}$$

Now consider a closed surface around the sphere as shown in figure. The flux through the closed surface is the same as the flux through the sphere. So we can conclude,

Conclusion

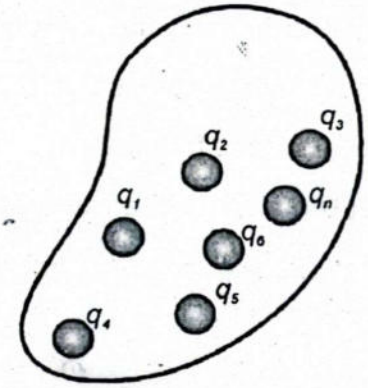
- The electric flux through a closed surface does not depend upon the **shape or geometry** of closed surface.
- The flux through the surface depends upon the **medium** and **charge** enclosed.

Q.9 State and explain Gauss's Law.

Ans.

GAUSS'S LAW

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



Explanation

Consider an irregular closed surface having n point charges $q_1, q_2, q_3, \ldots, q_n$ as shown in figure. Thus the total electric flux passing through the closed surface is,

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

OR

$$\Phi_e = \frac{q_1}{\varepsilon_o} + \frac{q_2}{\varepsilon_o} + \frac{q_3}{\varepsilon_o} + \ldots + \frac{q_n}{\varepsilon_o}$$

$$\Phi_e = \frac{1}{\varepsilon_o}(q_1 + q_2 + q_3 + \ldots + q_n)$$

$$\Phi_e = \frac{1}{\varepsilon_o}(\text{total charge enclosed})$$

$$\Phi_e = \frac{1}{\varepsilon_o}(Q) \qquad (\because Q = q_1 + q_2 + \ldots + q_n)$$

This represents the mathematical form of Gauss's Law.

Q.10 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.

In order to calculate the electric intensity at a point, we take the following steps.

1. *Consider* an imaginary closed surface (called **Gaussian surface**) which passes through that point.
2. Find the **charge enclosed** by the Gaussian surface.
3. Calculate the **flux** passing through the surface.
4. Apply Gauss's law to calculate the value of **electric field**.

> **For Your Information**
> If a surface encloses a positive as well as a negative charge of same magnitude then net flux through that surface is zero.

Q.12 Calculate the Electric Intensity for Hollow Charged Sphere?

Ans.

INTENSITY OF FIELD INSIDE A HOLLOW CHARGED SPHERE

Consider a positively charged hollow conducting sphere of radius R.

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

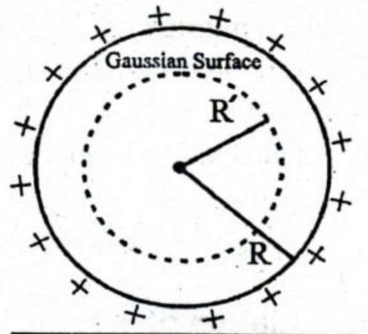
It can be seen in figure that the charge enclosed by Gaussian sphere is zero. i.e.

$$q = 0 \quad \text{\_\_\_\_\_\_\_\_} \quad (1)$$

Flux through the surface

The electric flux through the closed surface is

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



Calculation of Electric Intensity

By Gauss's law

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

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.

Consequence

Any apparatus placed within the metal enclosure is **shielded from electric fields.**

Do you know?

To eliminate stray electric field interference, circuits of sensitive electronics devices such as T.V. and Computers are often enclosed within metal boxes.

Q.13 Calculate the Electric Intensity Due to an Infinite Sheet of Charge.

FSD – 2017, GRW – 2015, 16, LHR 2017

Ans.

ELECTRIC INTENSITY DUE TO AN INFINITE SHEET OF CHARGE

Consider an infinite plane sheet on which the positive charges are uniformly distributed.

Gaussian surface

In order to calculate electric intensity at any point P close to the sheet. Imagine a closed Gaussian cylinder passing through the sheet.

Charge enclosed

Let

A = surface area of flat cylindrical surface.

σ = uniform surface charge density.

Then, the charge enclosed by the Gaussian surface is

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

Flux through the surface

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

From symmetry we can conclude that $\vec{E}$ is directed at right angle to end faces and is away from the plane.

i) Flux through right end flat surface

$$\Phi_{e_1} = \vec{E} \cdot \vec{A}$$

$$\Phi_{e_1} = EA\cos 0^\circ \qquad (\because \theta = 0^\circ)$$

$$\Phi_{e_1} = EA(1)$$

$$\Phi_{e_1} = EA$$

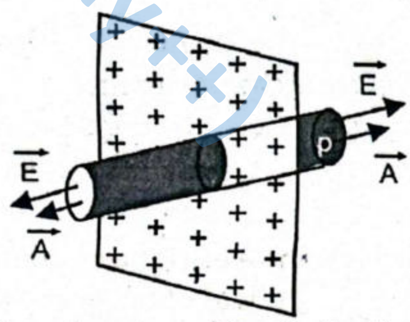
ii) Flux through left end flat surface

$$\Phi_{e_2} = \vec{E} \cdot \vec{A}$$

$$\Phi_{e_2} = EA\cos 0^\circ \qquad (\because \theta = 0^\circ)$$

$$\Phi_{e_2} = EA(1)$$

$$\Phi_{e_2} = EA$$



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

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,

$\Phi_e = \Phi_{e_1} + \Phi_{e_2} + \Phi_{e_3}$

$\Phi_e = EA + EA + 0$

$\Phi_e = 2EA$ ______________ (2)

Calculation of electric intensity

According to Gauss's Law

$\Phi_e = \frac{1}{\varepsilon_o}(q)$ ______________ (3)

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

$$2EA = \frac{1}{\varepsilon_o}(\sigma A)$$

or

$$\boxed{E = \frac{\sigma}{2\varepsilon_o}}$$

In vector form, $\vec{E} = [\frac{\sigma}{2\varepsilon_o}]\hat{r}$

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

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

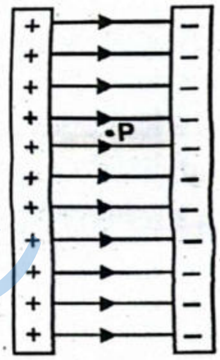
Ans.

ELECTRIC 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.

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.



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

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

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

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

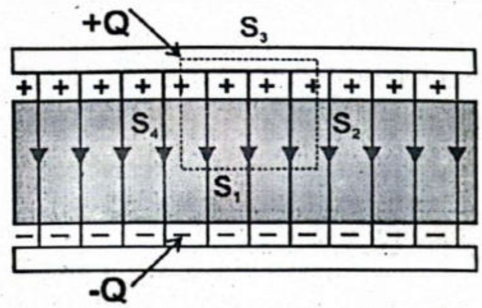
The flux through the lower surface of the box is given by,

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

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

$$\Phi_e = EA\,(1)$$

$$\Phi_e = EA$$



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.

Total flux through the box

Hence net flux through the box is,

$$\Phi_e = EA \qquad \_\_\_\_\_\_\_\_ (2)$$

Calculation of electric intensity

According to Gauss's Law:

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

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,

$$\vec{E} = \left[\frac{\sigma}{\varepsilon_o}\right]\hat{r}$$

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:** **(Grw 2016, AJK 2017, Bwp 2017 G I, Fed 2011 Lhr 2013 Mtn 2015 G – II)**
   (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:** **(Bwp 2016, Mirpur 2015, Grw 2014, Bwp 2015)**
   (A) Shape of Surface (B) Charge enclosed only (C) Medium Only (D) Both b & c
3. **The Electric intensity near an infinite plate of positive charge will be ________.** **(Rwp 14, Fed 13)**
   (A) $\frac{q}{\varepsilon_o}$ (B) $\frac{\sigma}{2\varepsilon_o}$ (C) $\frac{q}{A}$ (D) None of these
4. **Electric intensity inside the hollow sphere is:** **(Federal 2012, Grw 2018, Grw 2015)**
   (A) $\frac{\sigma}{\varepsilon_0}$ (B) $\frac{\sigma}{2\varepsilon_0}$ (C) $\frac{1}{\varepsilon_0}$ (D) Zero
5. **Which one of the following can be taken as measure of electric field intensity:** **(Lhr 2015 Group I)**
   (A) $\frac{F}{A}$ (B) $\frac{\phi e}{A}$ (C) $\frac{qA}{\varepsilon_o}$ (D) $\frac{\phi\varepsilon_o}{A}$
6. **A charged conductor has charge on its:** **(Rwp 2015)**
   (A) Inner-surface (B) Outer-surface (C) Middle point (D) Surrounding space
7. **For computation of electric flux, the surface area should be** **(Lhr 2014, Mtn 12, Lhr 13 G I,14 G II, D.G.Khan 15 Group II, Swl 2016)**
   (A) Parallel (B) Flat (C) Curved (D) Spherical
8. **Electro Encephalo Graphy (EEG) is the diagnostic test for the working of** **(Sahiwal 2017)**
   (A) eyes (B) heart (C) brain (D) lungs
9. **Electric Flux is expressed as:** **(Bwp GII 2018)**
   (A) $\phi_e = \vec{E} \times \vec{A}$ (B) $\phi_e = \vec{E} \cdot \vec{Q}$ (C) $\vec{E} \cdot \vec{A}$ (D) $\phi_e = EA^2$
10. **Gauss's law can only be applied to** **(D.G.Khan GI 2018)**
    (A) A curved surface (B) A flat surface (C) A surface of any shape (D) A closed surface

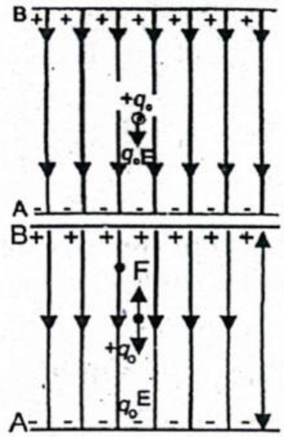
ANSWER KEY'S

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

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

Ans.

ELECTRIC POTENTIAL



Concept of electric potential difference

The idea of electric potential difference is introduced to describe electric field.

Consider a unit positive charge q_o allowed to move in an electric field due to two oppositely charged parallel plates.

The charge q_o gain K.E, while moving along the direction of electric field. In order to move it against the direction of electric field, we should apply some external force F equal and opposite to $F = q_oE$ to keep electrostatic equilibrium. In this case, it gains P.E.

Let

W_{AB} = work done by the force in carrying the positive charge q_o from A to B, then the change in its P.E,

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

OR

$$U_B - U_A = W_{AB}$$

Where U_A = potential energy of charged particle at point A

U_B = potential energy of charged particle at point B

For Your Information

Electric potential energy is the characteristic of charge while electric potential is the characteristic of field.

Electric potential difference

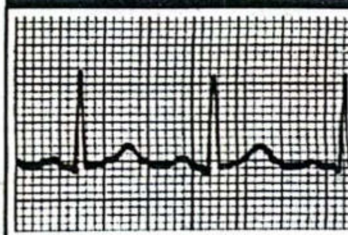
The potential difference between two points is defined as *the work done in carrying a unit positive charge from one point to the other while keeping the charge in electrostatic equilibrium.*

Mathematically, if A and B be two points in electric field then,

$$\Delta V = V_B - V_A = \frac{W_{AB}}{q_o}$$

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

Do You Know?



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

Another Definition

Potential difference between two points can also be defined as *the difference of electric potential energy per unit charge.*

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

Relation between electric potential difference and potential energy

$$\Delta U = q_o \Delta V = W_{AB}$$

Unit

SI unit of potential difference is **volt**.

Volt

If one joule work is done in carrying a unit positive charge from one point to another keeping electrostatic equilibrium then the potential difference is said to be one volt.

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

Absolute Potential or Electric Potential

Electrical potential at a point or absolute electric potential can be defined as *the work done in bringing a unit positive charge from infinity to that point keeping electrostatic equilibrium.*

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

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

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

So $$V_B - 0 = \frac{W_{\infty B}}{q_o}$$

In general,

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

Where V is the absolute potential

Note

- Electric potential at a point is still ***a potential difference*** between the potential at that point and potential at infinity.
- Both potential and potential differences are ***scalar quantities***, because both W and q_o are scalars.

Q.16 Derive the relation between electric field and electric potential gradient. OR Show that, $\vec{E} = -\frac{\Delta V}{\Delta r}$

Ans. **ELECTRIC FIELD AS POTENTIAL GRADIENT**

Let E be the uniform electric field between two oppositely charged parallel plates A and B. then potential difference between the two points is

$$V_B - V_A = \frac{W_{AB}}{q_o} \quad \text{———— (1)}$$

As $$W_{AB} = \vec{F} \cdot \vec{d}$$

Since $\vec{F}$ and $\vec{d}$ are in opposite direction, so $\theta = 180^o$

$$W_{AB} = Fd \cos 180^o$$

OR $$W_{AB} = -Fd$$

OR $$W_{AB} = -q_oEd \qquad [\because \; F = q_oE]$$

Where –ve sign shows that F must be equal and opposite to q_oE to keep it in equilibrium. So equation (1) becomes

$$V_B - V_A = -\frac{q_oEd}{q_o}$$

$$\Delta V = -Ed$$

OR $$E = -\frac{\Delta V}{d}$$

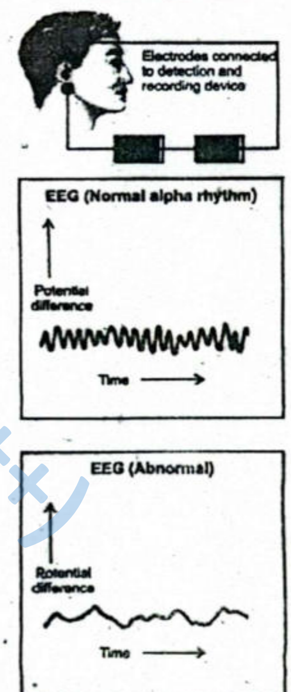
If plates A and B are separated by very small distance Δr (i.e. d = Δr), then above equation becomes

So $$E = -\frac{\Delta V}{\Delta r} \quad \text{———— (2)}$$

Potential gradient

The quantity $\frac{\Delta V}{\Delta r}$ gives the maximum value of rate of change of electric potential in magnitude and direction with respect to distance. It is known as potential gradient.

Do You Know?



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

Electric field in terms of potential gradient

From equation (2),

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

The negative sign shows that direction of $\vec{E}$ is along the decreasing potential. (i.e. from high potential towards low potential)

Q.17 Show that $\frac{\text{volt}}{\text{meter}} = \frac{\text{newton}}{\text{coulomb}}$

Ans. Proof

Do You Know?

The maximum rate of increase in scalar function in magnitude and direction with respect position is called gradient of the scalar field.

$$\text{L.H.S.} = \frac{\text{volt}}{\text{meter}}$$

$$= \frac{\text{joule}/\text{coulomb}}{\text{meter}}$$

$$= \frac{\text{joule}}{\text{coulomb meter}}$$

$$= \frac{\text{newton meter}}{\text{coulomb meter}}$$

$$= \frac{\text{newton}}{\text{coulomb}}$$

$$= \text{R.H.S.}$$

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

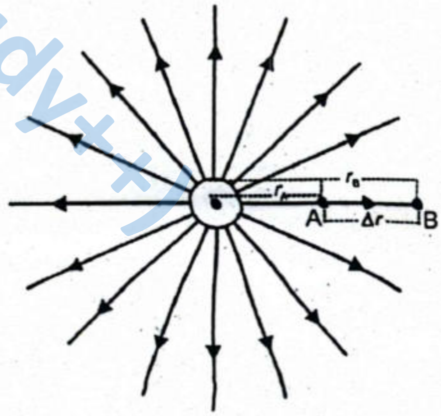
Q.18 Derive a relation for the electric potential (or absolute potential) at a certain point due to a point charge. ***DG KHAN 2011***

Ans.

ELECTRIC POTENTIAL AT A POINT DUE TO A POINT CHARGE

Electric potential at a point due a charge q is *the work done in taking a unit positive charge from infinity to that point keeping electrostatic equilibrium.*

Expression for electric potential



Let a unit positive charge is moved from point B to A against the electric field due to point charge q. As $E \propto \frac{1}{r^2}$ which shows that E varies inversely with square of distance. So we take two points A and B very close to each other in the radial field, such that E is nearly constant between these two points.

Let

r_A = distance of point A from charge q

r_B = distance of point B from charge q

Then, change in position = $\Delta r = r_A - r_B$ ________ (1)

distance of midpoint of A and B from charge q = $r = \frac{r_A + r_B}{2}$

magnitude of electric intensity at midpoint is,

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

Since the points A and B are very close to each other, therefore we can make approximation that

$$r_A \approx r_B \approx r$$

Therefore $r^2 = r \times r = r_A r_B$ __________ (3)

Putting value of r^2 in equation (2), we get

$$E = \frac{1}{4\pi\varepsilon_o}\frac{q}{r_A r_B} \quad \text{\_\_\_\_\_\_\_\_\_\_ (4)}$$

The potential difference between points A and B is the work done in moving the unit positive charge from B to A against electric field, i.e.,

$$\Delta V = -E\Delta r$$

OR $V_A - V_B = -E\Delta r$ ______________ (5)

Putting value of Δr and E from equation (1) and (4) in equation (5), we get

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

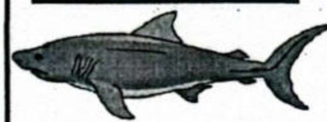
OR $$V_A - V_B = \frac{1}{4\pi\varepsilon_o}\frac{q}{r_A r_B}(r_B - r_A)$$

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

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

OR $$V_A - V_B = \frac{q}{4\pi\varepsilon_o}\left(\frac{1}{r_A} - \frac{1}{r_B}\right) \quad \text{\_\_\_\_\_\_\_\_\_\_ (6)}$$

Do You Know?



Fish and other sea creatures produce electric field in a variety of ways. Sharks have special organs, called the ampullae of Lorenzini, that are very sensitive to electric field and can detect potential difference of the order of nanovolt and can locate their prey very precisely.

Absolute potential or potential at A

In order to calculate the absolute potential or potential at A, point B is assumed to lie at infinity, so that

$V_B = 0$ at $r_B = \infty$

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

Putting it in equation (6), we get

$$V_A - 0 = \frac{q}{4\pi\varepsilon_o}\left(\frac{1}{r_A} - 0\right)$$

OR $$V_A = \frac{1}{4\pi\varepsilon_o}\frac{q}{r_A}$$

In general, electric potential V_r at a distance r from q is given by

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

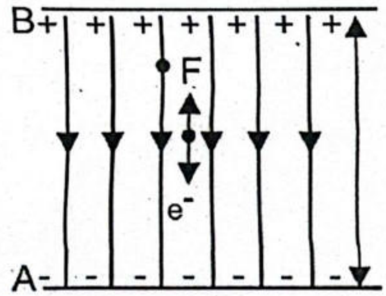
Q.19 Define the term electron volt? Is electron volt (eV) the unit of potential difference or energy? Explain.

Ans.

ELECTRON VOLT

Electron volt is the **unit of energy** and it can be defined as, ***the amount of energy acquired or lost by an electron as it traverses through a potential difference of one volt.***

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



Explanation

When a particle of charge q moves from point A with potential V_A to a point B with potential V_B, change in potential energy ΔU of the charged particle is,

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

If charged particle is allowed to move then this change in P.E appears as change in K.E, i.e.

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

Now, if $q = e = 1.6 \times 10^{-19}$ C and $\Delta V = 1V$

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

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

This amount of energy equal to $\mathbf{1.6 \times 10^{-19}}$ **J** *is called one electron volt.*

For Your Information

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

Or

$1\ J = 6.25 \times 10^{18}\ eV$

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** **(Sgd 2018, Grw 2012, Lhr 2012,2014, Grw 2013, Sgd 2015 G – II)**
(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:** **(AJK 2018, Bwp 2013, Lhr 2015 G – II)**
(A) 1V (B) 2V (C) Zero (D) $\frac{V}{2}$

3. **The work done in moving a positive charge on an equipotential surface is:** **(Lhr 2018)**
(A) Finite and Positive (B) Infinite (C) Finite and Negative (D) Zero

4. **One Electron Volt is equal to ________.** **(Rwp 2017, Lhr 2014, Mtn 2011, 13 Fed 2013, Sgd 2016 Group I)**
(A) 6.25×10^{18} Joule (B) 6.25×10^{-18} Joule (C) 1.6×10^{-19} Joule (D) 1.6×10^{19} Joule

5. **If an electron of charge is accelerated through a potential difference V, it will acquire energy.** **(Lhr 2017,Grw 2013 II)**
(A) Ve (B) V/2 (C) E/2 (D) Ve^2

6. **A particle carrying a charge of 2e falls through potential difference of 3V. Energy acquired by it is:** **(Lhr 2014 G I)**
(A) 9.6×10^{-16}J (B) 9.6×10^{-20}J (C) 9.6×10^{-15}J (D) 9.6×10^{-19}J

7. **If a positive charged body is moved against the electric field, it will gain:** **(Lhr 2016 Group I, Mtn 2017 G II)**
(A) P.E (B) K.E
(C) Mechanical energy (D) Electrical potential energy

8. **One Joule is equal to:-** **(Mtn 16 Group I, D.G.Khan 16 Group I)**
(A) 1.6×10^{-19} eV (B) 1.6×10^{19} eV (C) 6.25×10^{-18} eV (D) 6.25×10^{18} eV

9. **The electron volt is the unit of** **(Fed 2015, Swl 2016)**
(A) electric current (B) electric energy (C) potential (D) potential difference

10. **The quantity $\frac{\Delta V}{\Delta r}$ is called:** **(D.G.Khan 2017, Federal 2011, Mtn 2015 Group II)**
(A) Electric potential (B) Electric energy (C) Potential barrier (D) Potential gradient

11. **The work done in bringing a unit positive charge from infinity to that point in an electric field is called.** **(Mirpur 2015)**
(A) Potential (B) Potential difference (C) Absolute potential (D) All of these

12. **The absolute Electric potential at a point distance 20cm from a charge of 2 μc is** **(Bwp 2017 G I)**
(A) 9×10^2 V (B) 9×10^3 V (C) 9×10^4 V (D) 9×10^5 V

13. **The electric potential at a mid-point in an electric dipole is:** **(Lhr GI 2018)**
(A) 0 V (B) 0.5 V (C) 1 V (D) 1.5 V

14. **The unit of Electric intensity other than NC^{-1} is:-** **(Bwp 2017, Mtn 2016 Group II)**
(A) $\frac{V}{A}$ (B) $\frac{V}{m}$ (C) $\frac{V}{C}$ (D) $\frac{N}{V}$

ANSWER KEY'S

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

Q.20 Make a Comparison between Electric and Gravitational Forces?

Ans.

ELECTRIC AND GRAVITATIONAL FORCES

Dissimilarities

No.	Electric Forces	Gravitational Forces
(i)	According to Coulomb's Law $F_e = K[\frac{q_1 q_2}{r^2}]$	According to gravitational law $F_g = G[\frac{m_1 m_2}{r^2}]$
(ii)	The value of electrostatic constant (k) is much larger. i.e. $k = 9 \times 10^9\ Nm^2/C^2$	The value of gravitational constant (G) is much smaller as compared to electrical constant. $G = 6.673 \times 10^{-11}\ Nm^2/Kg^2$
(iii)	It is much stronger force	It is a weaker force.
(iv)	It may be attractive or repulsive.	It is attractive force only.
(v)	It is a medium dependent force.	It does not depend upon the nature of medium.
(vi)	It is a short range force.	It is a long range force.
(vii)	It can be shielded.	It can not be shielded.
(viii)	It is charge dependent.	It is mass dependent.

Similarities:

(i) Both of them are **conservative** forces.

(ii) **Inverse square law** (i.e. $F \propto 1/r^2$) holds good for both the forces.

(iii) Both obey **superposition principle.**

Q.21 Describe the Experiment for Determination of Charge on an Electron by Millikan's oil drop method. ***LHR 2018***

Ans.

MILLIKAN'S METHOD

In 1909, R.A. Millikan devised a technique with which he measured the charge on an electron.

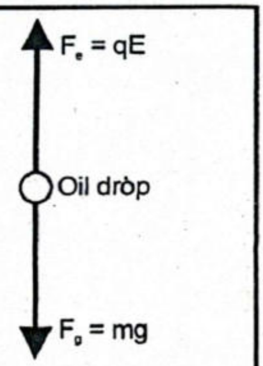
Principle

Suspension of oil drop between two plates by adjustment of electric field in such a way that electric force becomes equal to the gravitational force.

Construction

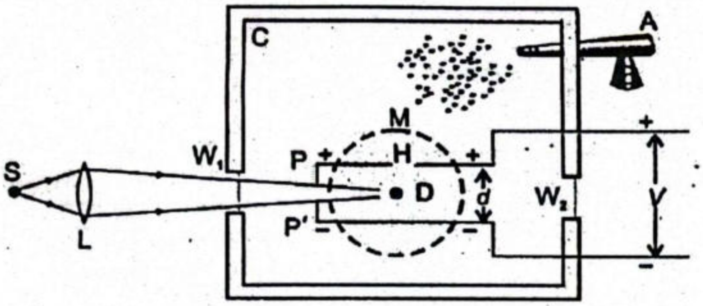
It consists of;

- An observation **chamber** C.
- Window W_1 for light.
- Window W_2 for x-rays.
- Two **parallel plates** P and P′ placed inside the chamber.
- The upper plate P has a small hole H.
- An **atomizer** used for spraying oil drops into the chamber.
- A **light source** S to make the droplet visible.
- A **D.C. source** applied across the plates.
- A **microscope** to observe the path of motion of droplets



Oil drop balanced by the gravitational force and the Coulomb force.

Schematic Diagram



Working

The tiny oil droplets are sprayed into the chamber through small nozzle of the atomizer. The oil droplets get negatively charged due to friction between the walls of atomizer and oil drops. Some of these drops pass through the hole H in the upper plate. A potential difference is applied between the plates to produce the electric field. Now, the electric field between plates PP' is adjusted in such a way that electric force becomes equal to the gravitational force (mg) on the droplet. In this case the oil droplet becomes suspended in air.

Charge on droplet

Let

Mass of droplet = m

Charge on droplet = q

Distance between plates = d

Potential difference applied = V

Electric field between plates = E

Then

$$F_e = F_g$$

$\Rightarrow$ $$qE = mg$$

OR $$q\frac{V}{d} = mg \qquad [\because \; E = \frac{V}{d}]$$

OR $$q = \frac{mgd}{V} \quad \text{\_\_\_\_\_\_\_\_\_\_ (1)}$$

FOR YOUR INFORMATION

Number of electrons in one coulomb

As $q = ne$

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

$$n = \frac{1\,C}{1.6 \times 10^{-19}}$$

$$n = 6.25 \times 10^{18} \text{ electrons}$$

Mass of droplet

To find the mass of the droplet m, the electric field is switched off. So the droplet starts to fall under the action of gravity through the air and gains the terminal velocity v_t. At this stage the weight of the droplet must be equal to the drag force. So

$$W = F_D$$

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

OR $$m = \frac{6\pi r\eta v_t}{g} \quad \text{\_\_\_\_\_\_\_\_\_\_ (2)}$$

In this equation v_t and r are unknown.

Determination of v_t

Terminal velocity v_t can be calculated by noting the time t which the droplet takes to fall through a known distance S i.e.,

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

Determination of radius of droplet

If ρ is the density of droplets then its volume can be expressed as $V = \frac{4}{3}\pi r^3$

As $\rho = \frac{m}{V}$

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

OR $m = \frac{4}{3}\pi r^3 \rho$ ________ (3)

Comparing equations (2) and (3), we get

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

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

OR $r = \sqrt{\frac{9\eta v_t}{2\rho g}}$ ________ (4)

By putting the value of r, in eq. (3) we can calculate the mass m of the droplet. Hence we can calculate the value of charge q of the oil droplet by substituting the value of mass m in equation (1).

Conclusion

Millikan measured that charge on each droplet is the integral multiple of 1.6×10^{-19} C. So the *minimum value of charge is the charge on electron.* (i.e. 1.6×10^{-19}C)

MCQ's From Past Board Papers

1. The number of electrons in one coulomb charge is equal to:
(Fed 2018, Fsd 2013, Mtn 2015, Swl 2015, D.G.Khan 2016 Group II, Swl 2015) (Sahiwal 2017)
(A) 1.6×10^{-19} (B) 6.25×10^{-19} (C) 6.25×10^{18} (D) 6.25×10^{19}
2. The minimum charge on any object cannot be less than: (Fsd 15, Mir 2011, 13 Supp, 2015)
(A) 1.6×10^{19} C (B) 9.1×10^{-31} C (C) 1.6×10^{-27} C (D) 1.6×10^{-19} C
3. If electric and gravitational force on an electron in a uniform electric field balance each other, then the intensity of electric field will be:
(Mirpur 2009, 2014, 13 Supp, Sgd 2018, Bwp, Fed 2014)
(A) $\frac{q}{mg}$ (B) $\frac{qg}{m}$ (C) $\frac{mg}{q}$ (D) $\frac{m}{qg}$
4. A billion electrons are added to pith ball. Its charge is: (Fsd 2018)
(A) -1.6×10^{-10}C (B) -1.6×10^{-12}C (C) -1.6×10^{-14}C (D) -1.6×10^{-7}C
5. In Millikan's oil drop experiment a charged particle of mass 'm' is in equilibrium in an applied electric field ___. If the direction of electric field is reversed then acceleration of the particle will be: (Swl 2018)
(A) zero (B) g/2 (C) g (D) 2g

ANSWER KEY'S

1.	C	2.	D	3.	C	4.	A	5.	A

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

Ans.

CAPACITOR

The device which is used to store electric charge is called capacitor.

For Your Information

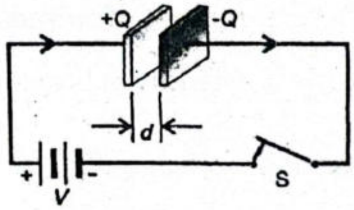
One farad is an enormous amount of capacitance.

For practical purposes its sub-multiple units are used which are given below,

1 micro-farad = 1μF = 10^{-6} farad

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

Parallel plate capacitor



A simple capacitor consists of two parallel conducting plates separated by air, or some insulating medium called dielectric. This type of capacitor is called parallel plate capacitor.

Charging of capacitor

If the plates are connected to a battery of voltage V, then one of the plates has +Q charge and the other plate have –Q charge. These charges remain on the inner surface of the plates due to attraction between the opposite charges.

Let Q is the magnitude of the charge on either of plates and V is potential difference between the plates. Then it is observed that,

$$Q \propto V$$

$$Q = CV$$

OR $$C = \frac{Q}{V}$$

FOR YOUR INFORMATION

For series combination.

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots\ldots$$

For parallel combination.

$$C_{eq} = C_1 + C_2 + C_3 + \ldots\ldots\ldots$$

Where C is the 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.

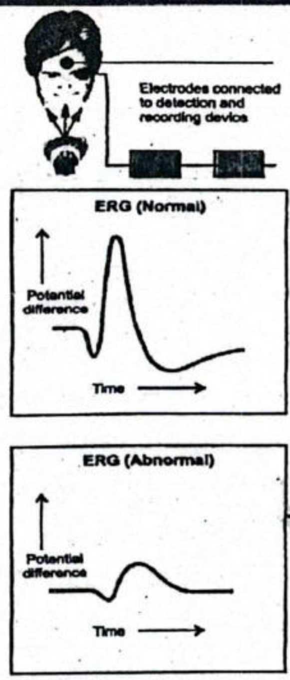
$$1\text{ farad} = \frac{1\text{ coulomb}}{1\text{ volt}}$$

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.

Do You Know?



The electrical activity of the retina of the eye generates the potential difference used in electroretinography.

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 between 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

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

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

If an insulating material, called dielectric, of relative permittivity ε_r is placed between the two plates, then capacitance of capacitor is **increased** by the factor ε_r called as dielectric constant. So, equation (6) can be written as

$$C_{med} = \frac{A\varepsilon_o\varepsilon_r}{d} \quad \text{\_\_\_\_\_\_\_\_ (7)}$$

How capacitances increases with dielectric

Note:

Consider a parallel plate capacitor when plates are connected to a voltmeter as shown in figure. The voltmeter measures the potential difference between the plates. When an insulating material is placed between the plates, reading drops indicating a decrease in the potential difference between the plates.

As $$C = \frac{Q}{V}$$

Since V decreases while Q remains constant, so value of C increases,

Dielectric constant

Dielectric constant can be defined as ***the ratio of capacitances of a parallel plate capacitor with a dielectric to its capacitance with vacuum or air as the medium between the plates.***

Mathematically

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

ELECRORETINOGRAPHY

A test in electrical potentials generated by generated by retina of eye are measured when retina is stimulated by light.

It measures electrical responses of various cell types in retina including rod and cone (the visual cells in retina at the back of eye).The instrument used to conduct ERG is called electroretinograph and the resultant recording is called electroretinogram.

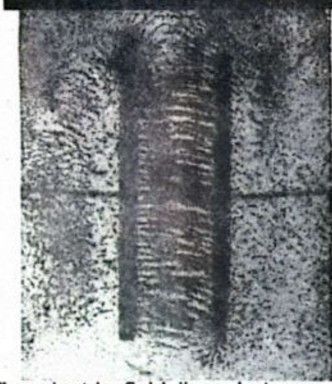
For Your Information

One farad is an enormous amount of capacitance. For practical purposes its sub-multiple units are used which are given below,

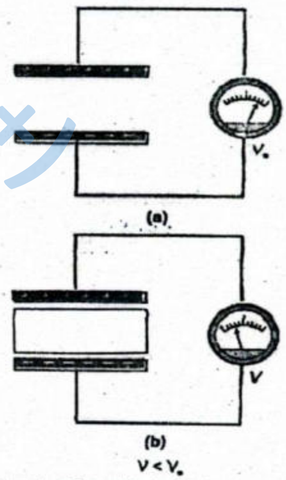
1 micr-farad = $1\mu F = 10^{-6}$ farad

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

For Your Information



The electric field lines between the plates of a parallel-plate capacitor. Small bits of thread are suspended in oil and become aligned with the electric field. Note that the lines are equally spaced, indicating that the electric field there is uniform.

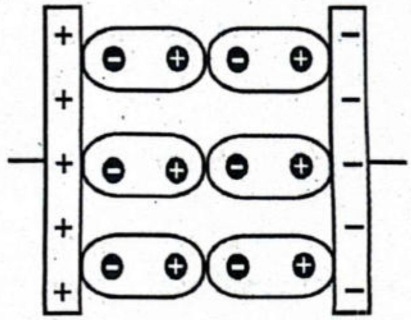


Effect of a dielectric on the capacitance os a capacitor.

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 OF DIELECTRICS



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

The dielectric consists of atoms and molecules which are electrically neutral on average (i.e. they have equal number of positive and negative charges). The distribution of these charges in the atoms and molecules is such that the centre of positive charge coincides with the center of negative charge.

If a dielectric material is placed in electric field between the plates of a capacitor, negative charges (electrons) are attracted towards the positively charged plates and the positive charges (nuclei) are attracted towards the negatively charged plates. Thus, the electrons and nuclei are slightly displaced. As a result the centre of positive and negative charges no longer coincides with each other. So, one end of the molecule shows negative charge and the other end shows an equal amount of positive charge, hence a dipole is formed, the molecule is said to be polarized and the phenomenon is called polarization.

Dipole

Two equal and opposite charges separated by a small distance make a dipole.

EFFECTS OF POLARIZATION ON CAPACITANCE

When a dielectric is placed between the plates of a capacitor, then capacitance of a capacitor **increases** due to polarization of dielectric.

Reason

Dielectric material effectively decreases surface charge density (σ) on plates. This decreases the electric intensity ($E = \frac{\sigma}{\varepsilon_o}$) between the plates. With the decrease of electric intensity E between the plates, the potential difference ($V = Ed$) between the plates decreases. With the decrease of voltage V the capacitance ($C = \frac{Q}{V}$) of a capacitor increases.

Q.26 Derive an Expression for Energy stored by the Capacitor. ***RWP – 2016, BWP 2017***

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.It increases the potential difference between plates and a large amount of work is needed to bring up next increment of charge.

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

Average potential difference = $\frac{0+V}{2} = \frac{1}{2}V$

Thus, the average work done in bringing the unit positive charge q from one plate to another is

$$\text{Work} = \text{Average potential difference} \times \text{charge}$$

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

or

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

$$P.E. = \frac{1}{2}(CV)V \qquad [\because q = CV]$$

$$\text{Energy} = \frac{1}{2}CV^2 \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_} (1)$$

Interesting Application

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

Energy stored in terms of electric field

When we consider that energy is being stored between the two plates rather than the potential energy of the charges on the plates then we put

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

(It is the capacitance of parallel plate capacitor with a dielectric medium)

and $V = Ed$

Putting these values in equation (1), we get

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

$$\text{Energy} = \frac{1}{2}\varepsilon_o\varepsilon_r E^2(Ad)$$

It is an expression for energy stored in the electric field between the plates.

FOR YOUR INFORMATION

In the absence of dielectric the energy stored in a capacitor will increase.

Energy density

Energy density is defined as *the energy stored per unit volume.*

$$\text{Energy density} = \frac{\text{energy}}{\text{volume}}$$

Here,

Volume between plates = Ad

$$\text{Energy density} = \frac{1/2[\varepsilon_o\varepsilon_r E^2](Ad)}{Ad}$$

$$\text{Energy density} = \frac{1}{2}\varepsilon_o\varepsilon_r E^2$$

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

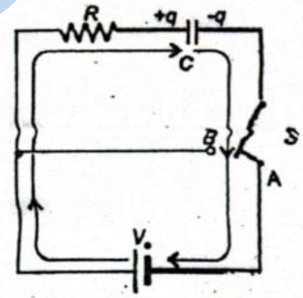
Ans.

CHARGING AND DISCHARGING OF A CAPACITOR

The circuit consisting of a capacitor and a resistor is called R-C circuit

CHARGING OF A CAPACITOR

According to figure 1(a) when the switch S is set at terminal A. the, R-C combination is connected to the battery of voltage V_o which starts charging the capacitor.



Charging a capacitor

The capacitor is not charged immediately, rather charges build up gradually to the equilibrium value of $q_o = CV_o$. The growth of charge with time for different resistances is shown in figure 1(b). According to graph q = 0 at t = 0 and increases gradually with time till it reaches its equilibrium value $q_o = CV_o$.

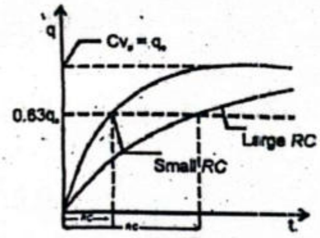


Fig. 12.28

The time for charging or discharging of a capacitor depends upon the product of the resistance R and the capacitance C used in the circuit.

As the unit of product RC is that of time, so this product is known as time constant and this can be defined as,

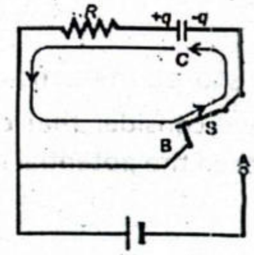
Time constant

The time required by the capacitor to deposit 0.63 times the equilibrium charge q_o is called time constant.

OR

The time during which the capacitor charges to 63% of its maximum value is called time constant.

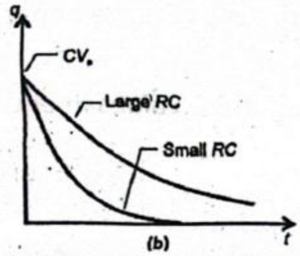
So for small value of time constant, the capacitor reaches to its equilibrium value very quickly.



(a)

DISCHARGING OF A CAPACITOR

In fig 2(a) when switch S is set at point B, then the battery connection is cut-off and circuit is completed with a resistor and a capacitor. The charge +q on the left plate of the capacitor start to discharge through 'R' and neutralize the charge on the right plate.



(b)

Discharging a capacitor

The graph between time and charge shown in fig 2(b) represents that discharging starts at t = 0 when $q = CV_o$ and decreases gradually to zero.

Smaller value of time constant RC lead to a more rapid discharging.

Note

The charging and discharging of a capacitor is exponential

EQUATION OF CHARGING

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

EQUATION OF DISCHARGING

$$q = q_o \, e^{\frac{-t}{RC}}$$

Interesting Application

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

MCQ's From Past Board Papers

1. **Energy stored in Capacitor is given by the relation.** **(Mtn 2015, Sgd 2015 G – II)**

(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:**
(D.G.Khan 2018, Fsd 2017, Mirpur 2014, D.G.Khan 2015 Group II, Sgd 2015 Group I, Grw 2015)

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

3. **Due to polarization, electric field E** **(D.G.Khan 2015 G – I, 2016)**

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

4. **If Potential difference across two plates of a parallel plates capacitor is doubled then energy stored in if will be:**
(Bwp 2014, Fsd 2014, Sgd 2016 Group II, Mirpur 2014)

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

5. **The energy stored per unit volume in the electric field between the plates of charged capacitor with dielectric is ____.** **(Fed 2014)**

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

6. The increase in capacitance of a capacitor due to presence of dielectric is due to _____ of dielectric. (Grw 2012,2013,2018, Swl 2014, Mirpur 2014, Grw 2011, Lhr 12 II)
(A) electric polarization (B) electrification (C) ionization (D) electrolysis

7. Energy density in case of a capacitor is always proportional to: (Grw 2013 G II)
(A) E^2 (B) ε_0 (C) V^2 (D) C

8. In a capacitor, energy is stored in the: (Rwp 2014, Lhr 2015, Grw 2014)
(A) magnetic field (B) electric field (C) gravitational field (D) nuclear field

9. A capacitor of 50 μF capacitance has P.D of 8 volt across its plates then charge on each plate of capacitor is: (Sgd 2014)
(A) 4×10^{-10} C (B) 4×10^{-6} C (C) 400 C (D) 4×10^{-4} C

10. A capacitor is perfect insulator for: (Lhr 2011G I, 2012 G – I)
(A) Alternating current (B) Direct current (C) Both a & b (D) None of these

11. In the time constant of RC circuit, how much charge is stored out of maximum charge q_o? (Grw 2011)
(A) 0.37 q_o (B) 0.51 q_o (C) 0.63 q_o (D) 0.90 q_o

12. Capacitance of a capacitor does not depend upon: (Rwp 2016)
(A) Distance between plates (B) Area of plates
(C) Electric field between plates (D) Medium between plates

13. If the separation between the plates of a capacitor is doubled then its capacitance become (Sgd 2016 Group I)
(A) Double (B) Half (C) One fourth (D) Three times

14. Capacitance of a Capacitor in Vacuum is given by (Mirpur 2009, Mtn 10, 14 Rwp 14, Sgd 15 G I, Mtn 16 G I)
(A) $\frac{A\varepsilon_0}{d}$ (B) $\frac{A\varepsilon_r}{d}$ (C) $\frac{Ad}{\varepsilon_0}$ (D) $\frac{A}{\varepsilon_0 d}$

15. Coulomb/volt is called:- (Bwp 2018, Lhr 2010, 2014, Mtn 2017 G I)
(A) farad (B) ampere (C) joule (D) henry

16. 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: (Federal 2017)
(A) $\frac{W}{4}$ (B) $\frac{W}{2}$ (C) 2W (D) 4W

17. If time constant in RC Circuit is small, than the capacitor is charged or discharged. (Mtn 2018, D.G.Khan GI 2018)
(A) Slowly (B) Rapidly (C) At constant rate (D) intermittently

18. The capacitance of capacitor depends upon: (Fsd 2018)
(A) Thickness of plates (B) Charges on the plates
(C) Voltage applied (D) Geometry of the capacitor

19. RC factor has same dimensions as that of: (Sgd GII 2018)
(A) Potential difference (B) Resistance (C) Time (D) Capacitance

20. Which material should be inserted between the plates of a capacitor in-order to increase its capacitance? (Swl 2018)
(A) copper (B) mica (C) iron (D) tin

21. The net charge on a capacitor (each plate having magnitude of charge q) is: (Swl 2018)
(A) infinity (B) 2q (C) q/2 (D) zero

ANSWER KEY'S

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

IMPORTANT SHORT QUESTIONS FOR BOARD EXAMS

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 $$R = \frac{Vt}{q} \quad ......(1)$$

According to equation

$$q = CV$$

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

Multiplying equation (1) and (2), we get

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

Or $$RC = t$$

Hence, 1 ohm × 1 farad = 1 second

where ohm is the unit of resistance R.

2. Write down two differences between gravitational force and Coulomb's electrostatic force.

(Lhr 2016 Group II)

No.	Electric Forces	Gravitational Forces
(i)	According to Coulomb's Law $F_e = K[q_1q_2/r^2]$	According to gravitational law $F_g = G[m_1m_2/r^2]$
(ii)	The value of electrostatic constant (k) is much larger. i.e. $k = 9 \times 10^9\ Nm^2/C^2$	The value of gravitational constant (G) is much smaller as compared to electrical constant. $G = 6.673 \times 10^{-11}\ Nm^2/Kg^2$
(iii)	It is much stronger force	It is a weaker force.
(iv)	It may be attractive or repulsive.	It is attractive force only.
(v)	It is a medium dependent force.	It does not depend upon the nature of medium.
(vi)	It is a short range force.	It is a long range force.
(vii)	It can be shielded.	It can not be shielded.

3. Write down the four properties of electric field lines. **(D.G.Khan 2016 Group II) (Rwp 2016)**

Ans. *(i)* *Electric field* lines start from positive charges and end on negative charges.

(ii) The tangent to a field line at any point gives the direction of electric field at that point.

(iii) Number of electric field lines represent the strength of electric field at certain area.

(iv) *No two* electric lines cross each other.

(v) The lines of force do not exist inside the conductor.

(vi) Field line is always normal to the surface of change distribution.

(vii) If the field lines are parallels and equally spaced then the field is surd to be uniform.

4. What is difference between electrical potential energy and electrical potential difference?

(Fsd 2016)

Ans. (i) Electric potential energy is defined as the energy stored in the charge 'q' because of its position in an electric field. Mathematically,

$$\text{Electric P.E.} = U = q_o\Delta V$$

(ii) Electric potential difference between two points is defined as the work done in moving a unit positive charge from one point to the other keeping the charge in electrostatic equilibrium.

Mathematically,

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

5. Show that $\frac{1\ volt}{1\ meter} = \frac{1\ newton}{1\ coulomb}$. (Mtn 2016 Group I)

Ans.

$$LHS = \frac{volt}{meter}$$
$$= \frac{joule}{coulomb - meter}$$
$$= \frac{newton - meter}{colomb - meter}$$
$$= \frac{newton}{colomb}$$
$$= RHS$$

6. How capacitance is increased by placing a dielectric between the plates of a capacitor?
(Mirpur Kashmir 2016)

Ans. When a dielectric is placed between the plates of a capacitor, then capacitance of a capacitor increases due to polarization of dielectric.

Reason

Dielectric material effectively decreases surface charge density (σ) on plates. This decreases the electric intensity ($E = \frac{\sigma}{\varepsilon_o}$) between the plates decreases. With the decrease of electric intensity E between the plates, the potential difference ($V = Ed$) between the plates decreases. With the decrease of voltage V the capacitance ($C = \frac{Q}{V}$) of a capacitor increases.

7. Define electron volt, give its mathematical value.
(Lhr 2015 Group I) (D.G.Khan 2015 Group I) (Fsd 2015)(Mtn 2015 Group I)(Mtn 2015 Group II)

Ans. The amount of energy acquired as lost by an electron if it is traversed by a potential difference of one volt.

$$1eV = (1.6\times10^{-19}\ C)\ (1V)$$
$$= 1.6\times10^{-19}\ CV$$
$$= 1.6\times10^{-19}\ J$$

8. Define electron volt. Show that 1 e.V = 1.6 × 10^{-19} J. **(D.G.Khan 2015 Group II)(Mirpur Kashmir 2015)**

Ans. As during the motion of a charge, it acquired K.E., which is equal to $q\Delta V$.

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

As q = charge on electron = $1.6\times10^{-19}C$

And Δv = 1 volt

Then K.E. = $1.6\times10^{-19}C\times1V$

Or K.E. = $1.6\times10^{-19}J$ ($C\times V = J$)

The amount of energy equal to $1.6\times10^{-19}J$ is called an electron volt. Hence

$$1eV = 1.6\times10^{-19}J$$

3. What are similarities between electrostatic force and gravitational force?

Ans. The two forces are similar in the following aspects

(i) Both obey the inverse square law $\left[F \propto \frac{1}{r^2}\right]$.

(ii) Both the forces are conservative forces.

(iii) Both the forces are central forces.

(iv) The two forces act along the line joining the two charges or two masses.

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	$\phi = \frac{q}{\varepsilon_o}$		
7	Gauss's Law for electrostatics	$\phi = \frac{1}{\varepsilon_o}\times(Q)$		
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	$E = \frac{\sigma}{2\varepsilon_o}$	$\vec{E} = \frac{\sigma}{2\varepsilon_o}\hat{r}$	
11	Electric field intensity between two oppositely charged parallel plates	$E = \frac{\sigma}{\varepsilon_o}$	$\vec{E} = \frac{\sigma}{\varepsilon_o}\hat{r}$	
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	$C_{vac} = \frac{A\varepsilon_o}{d}$	$C_{med} = \frac{A\varepsilon_o\varepsilon_r}{d}$	
18	Dielectric constant,	$\varepsilon_r = \frac{C_{med}}{C_{vac}}$	$\varepsilon_r = \frac{\varepsilon_{med}}{\varepsilon_o}$	$\varepsilon_r = \frac{F_{vac}}{F_{med}}$
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	$= \frac{1}{2}\varepsilon_o\varepsilon_r E^2$		
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	$1.6\times10^{-19}C$

SOLVED EXAMPLES

Example 12.1:

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

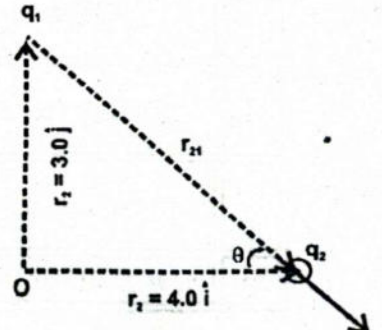


Fig: 12.3

Given data:

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

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

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

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

To find:

Coulomb's force on $q_2 = \vec{F}_{21} = ?$

Calculations:

From figure $\vec{r}_{21} = \vec{r_2} - \vec{r_1}$

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

Magnitude of $\vec{r}_{21} = |\vec{r}_{21}| = \quad r = \sqrt{(4)^2 + (-3)^2} = \sqrt{16+9} = \sqrt{25} = 5\text{m}$

Unit vector can be written as,

$$\hat{r}_{21} = \frac{\vec{r}_{21}}{r} = \frac{4\hat{i} - 3\hat{j}}{5}$$

Now force on charge q_2 due to charge q_1 is

$$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2}\hat{r}_{21}$$

Putting the values, we get

$$\vec{F}_{12} = 9\times10^9 \times \frac{100\times10^{-6}\times50\times10^{-6}}{(5)^2} \times \frac{4\hat{i}-3\hat{j}}{5}$$

$$\vec{F}_{12} = \frac{9\times100\times50\times10^{9-6-6}}{25} \times \frac{4\hat{i}-3\hat{j}}{5}$$

$$\vec{F}_{12} = 360\times10^{-3}(4\hat{i} - 3\hat{j})$$

$$\vec{F}_{12} = 0.360 \times (4\hat{i} - 3\hat{j})$$

$$\vec{F}_{12} = 1.44\hat{i} - 1.08\hat{j}$$

Magnitude of $\vec{F}_{12} = \quad F = \sqrt{(1.44)^2 + (1.08)^2}$

$F = 1.8$N

Direction of $\vec{F}_{12} = \tan^{-1}\left(\frac{y}{x}\right) = \tan^{-1}\left(-\frac{1.08}{1.44}\right)$

$$\theta = \tan^{-1}(-0.75)$$

$$\boxed{\theta = -37^\circ} \text{ with x-axis}$$

Example 12.2:

Two positive point charges $q_1 = 16.0\ \mu C$ and $q_2 = 4.0\ \mu C$ are separated by a distance of 3.0 m, as shown in Fig. 12.5. Find the spot on the line joining the two charges where electric field is zero.

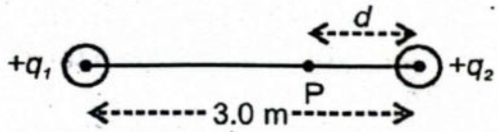


Fig: 12.5

Given data:

First charge = $q_1 = 16.0\ \mu c = 16 \times 10^{-6}$ C

Second charge = $q_2 = 4.0\ \mu c = 4 \times 10^{-6}$ C

Distance between the charges = r = d = 3.0 m

To find:

Spot on the line where electric field (i.e. E) is zero = ?

Calculations:

As the charges are similar, so electric field will be zero at a point, where magnitude of $\vec{E}_1$ is equal to magnitude of $\vec{E}_2$ i.e., $E_1 = E_2$

where E_1 is the electric intensity at point 'P' due to q_1 and E_2 is the electric intensity at point 'P' due to q_2.

Electric field at point P due to charge q_1 is

$$E_1 = \frac{1}{4\pi\varepsilon_o}\frac{q_1}{(3-d)^2}$$

Electric field at point P due to charge q_2 is

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

Since $E_1 = E_2$

Thus $\frac{1}{4\pi\varepsilon_o}\frac{q_1}{(3-d)^2} = \frac{1}{4\pi\varepsilon_o}\frac{q_2}{d^2}$

or $\frac{q_1}{(3-d)^2} = \frac{q_2}{d^2}$

or $\frac{16\times10^{-6}}{(3-d)^2} = \frac{4\times10^{-6}}{d^2}$

or $\frac{4}{(3-d)^2} = \frac{1}{d^2}$

or $4d^2 = (3-d)^2$

Taking square root of both sides

$$2d = 3 - d$$

$$2d + d = 3$$

$$3d = 3$$

$$d = 1\ \text{m}$$

Example 12.3:

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

Give data:

Two opposite point charges, such that

$q_1 = +q$

$q_2 = -q$

Distance between the charges = 2d

To find:

Electrical potential at mid point between charges = V = ?

Calculations:

Potential at P due to charge +q = $V_+ = \frac{1}{4\pi\varepsilon_o}\frac{q}{r}$

As the point P is midway between the charges, So r = d

Potential at P due to charge +q = $V_+ = \frac{1}{4\pi\varepsilon_o}\frac{q}{d}$

Potential at P due to charge −q = $V_- = \frac{1}{4\pi\varepsilon_o}\frac{(-q)}{d} = \frac{-1}{4\pi\varepsilon_o}\frac{q}{d}$

Electric potential at point 'P' due to both changes is

$$V = V_+ + V_-$$

Putting the values, we get

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

$$\boxed{V = 0}$$

Hence, *electric* potential at point P due to two equal and opposite *charges is zero*.

Example 12.4:

A particle carrying a charge of 2e falls through a potential difference of 3.0V. Calculate the energy acquired by it.

Given data:

Charge = q = 2e

Potential difference = ΔV = 3.0 V

To find:

Energy acquired = Δ(K.E.) = ?

Calculations:

Energy *acquired* by the particle is given by

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

Putting values, we get

$$\Delta(K.E.) = 2e \times 3.0$$

$$\Delta(K.E.) = 6\ eV$$

So, $\Delta(K.E.) = 6 \times 1.6 \times 10^{-19}$ J [As 1 eV = 1.6×10^{-19} J]

$$\boxed{\Delta(K.E.) = 9.6 \times 10^{-19}\ J}$$

Example 12.5:

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

Given data:

Mass of the drop = 4.9×10^{-15} kg

Potential difference = V = 750 V

Spacing between plates = d = 5.0 mm = 5.0×10^{-3} m

To find:

Charge on the droplet = q = ?

Calculations:

When charge is stationary, then

$$F_e = F_g$$

$$qE = mg$$

$$q \times \frac{V}{d} = mg \qquad [\text{As } E = \frac{V}{d}]$$

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

Putting the values, we get

$$q = \frac{4.9 \times 10^{-15} \times 9.8 \times 5 \times 10^{-3}}{750}$$

$$q = \frac{240.1}{750} \times 10^{-15-3}$$

$$q = 0.32 \times 10^{-18}$$

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

Example 12.6:

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

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 $$R = \frac{Vt}{q} \qquad \text{......(1)}$$

According to equation

$$q = CV$$

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

Multiplying equation (1) and (2), we get

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

Or $$RC = t$$

Hence, 1 ohm × 1 farad = 1 second

where ohm is the unit of resistance R.

SHORT QUESTIONS OF THE EXERCISE

12.1 The potential is constant through a given region of space. Is the electrical field zero or non zero in this region? Explain. (Grw 2017, Bwp 2018, DG khan 2015, Mirpur 2011)

Ans. The electrical field will be ***zero*** in this region.

Reason:

We know that

$$E = -\left(\frac{\Delta V}{\Delta r}\right)$$

Where '–' sign shows that direction of $\vec{E}$ is along decreasing potential.

In the present case.

$$V = \text{constant}$$

therefore $$\Delta V = 0$$

Hence

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

$$E = 0$$

12.2 Suppose that you follow an electric field line due to a positive point charge. Do electric field and the potential increase or decrease? (Grw 2010,11, Lhr 2018 G II, Fsd 2017)

Ans. Both electric field and potential will ***decrease***.

Reason:

As $$E = k\frac{q}{r^2} \quad ..... (1)$$

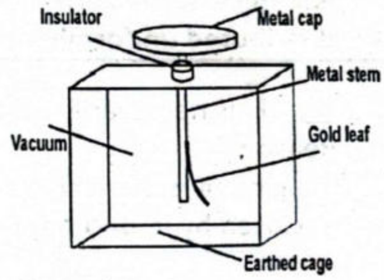
and $$V = k\frac{q}{r} \quad ..... (2)$$

From these two equations it is clear that

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

Hence when we move away from the charge q. (i.e. when r increases), both $\vec{E}$ and V decrease.

12.3 How can you identify that which plate of a capacitor is positively charged? **(Grw 2011, Lhr 2009, Bwp 2009, Mirpur 2011)**

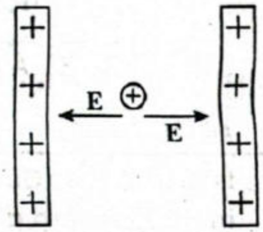


Ans. To identify that which plate of a capacitor is positively charged, ***a gold leaf electroscope*** is used.

Explanation:

To check the polarity of a capacitor plate, it is brought near the cap (or disc) of positively charged electroscope. If the divergence of gold leaves increases, the plate is positively charged and vice versa.

12.4 Describe the force or forces on a positive point charges when placed between parallel plates.
(a) with similar and equal charges
(b) with opposite and equal charges
(Grw 2008,10, Lhr 2009, DG khan 2009)



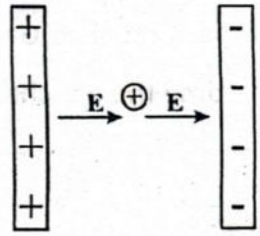
Ans. (a) Net force acting on the positive point charge is ***zero***

Reason:

The electric field intensity due to one plate is equal and opposite to that of other, hence resultant electric intensity is zero (i.e. E=0)

So $F = qE$

$\Rightarrow$ $F = 0$



(b) Net force acting on the positive point charge will be ***maximum.***
Its direction is from positive plate to negative plate.

Reason:

The electric field intensities due to the two plates are equal and in the same direction, hence the resultant electric intensity is maximum. (i.e 2E)

So, maximum force acts on point charge. i.e.

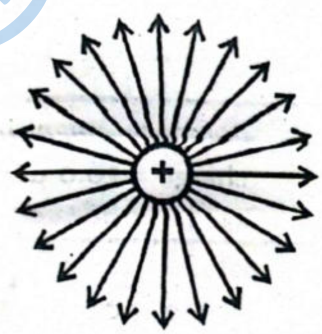
$F = qE$

12.5 Electric lines of force never cross. Why? **(Grw 2014, Lhr 2009,10,11, Bwp 2015)**

Ans. Reason:

This is because electric field $\vec{E}$ has only ***one direction*** at any given point. If the lines cross then at the point of intersection $\vec{E}$ will have more than one direction which is physically not possible.

12.6 If a point charge q of mass m is released in a non-uniform electric field with field lines pointing in the same direction, will it make a rectilinear motion? **(Lhr 2017 G II, Sgd 2017 G I)**



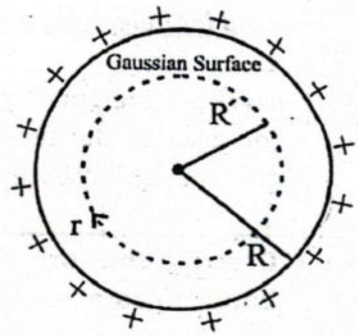
Ans. ***Yes***, it will make a rectilinear motion.

Reason:

If a point charge is placed in a non-uniform electric field, it moves along the field lines. As in the present case, the field lines are ***pointing in the same direction*** (i.e radially outward). Therefore it makes rectilinear motion.

12.7 Is E necessarily zero inside a charged rubber balloon, if balloon is spherical? Assume that charge is distributed uniformly over the surface. (Grw 2016, Lhr 2017 G I)

Ans. ***Yes,*** $\vec{E}$ is necessarily zero inside a charged rubber balloon.



Reason:

Imagine a spherical Gaussian surface inside the balloon. The charge enclosed by it, q=0 Applying Gauss's law, we have

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

$$\Phi_e = 0$$

$$\vec{E} \cdot \vec{A} = 0$$

As $\vec{A} \neq 0$, so $\vec{E} = 0$

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

Ans. ***Yes,*** it is a true statement.

Reason:

According to Gauss's law the flux (i.e. number of electric field lines through any closed surface) is $\frac{1}{\varepsilon_o}$ time the net charge (positive or negative) enclosed in it i.e.

$$\Phi_e = \frac{1}{\varepsilon_o} \times Q$$

OR $\Phi_e \propto Q$ [since ε_o= constant]

Here, Φ_e= number of electric field lines passing a certain area.

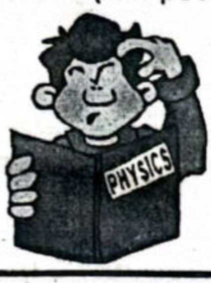
Q = net charge enclosed by the Gaussian surface.

12.9 Do electrons tend to go to region of high potential or of low potential? (Grw 2008,09,12, Bwp 2017 G I, DG khan 2015 G I, Fsd 2016)

Ans. Electrons tend to go the region of ***high*** potential.

Reason:

As the electrons are ***negatively*** charged particles so when they are released in an electric field. They will move from negative end (low potential) to positive end (high potential)



Exercise Problems

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

Given data:

As the two objects are identical, therefore their masses and charges are equal to each other, thus

$$m_1 = m_2 = 10\text{ g} = \frac{10}{1000}\text{kg} = 0.01\text{ kg}$$

$q_1 = q_2 = 20\ \mu C = 20 \times 10^{-6}$ C

Distance between charges = r = 10 cm = 0.1 m

Gravitational constant = G = 6.67×11^{-11} $Nm^2 kg^{-2}$

and $K = \frac{1}{4\pi\varepsilon_o} = 9 \times 10^9 Nm^2C^{-1}$

To find:

$$\frac{\text{Electrical force}}{\text{Gravitational force}} = \frac{F_e}{F_g} = ?$$

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

Calculations:

Using Columbus's law

$$F_e = \frac{1}{4\pi\varepsilon_o}\frac{q_1q_2}{r^2}$$

Putting the values, we get

$$F_e = 9 \times 10^9 \times \frac{20\times10^{-6}\times20\times10^{-6}}{(0.1)^2}$$

$$F_e = \frac{9\times400\times10^{-3}}{0.01}$$

$$F_e = 360\text{ N} \quad \text{\_\_\_\_\_\_\_\_(1)}$$

Using Newton's law of gravitation

$$F_g = G\frac{m_1m_2}{r^2}$$

Putting values, we get

$$F_g = 6.67\times10^{-11}\times\frac{0.01\times0.01}{(0.1)^2}$$

$$F_g = 6.67\times10^{-11}\times\frac{10^{-4}}{0.01}$$

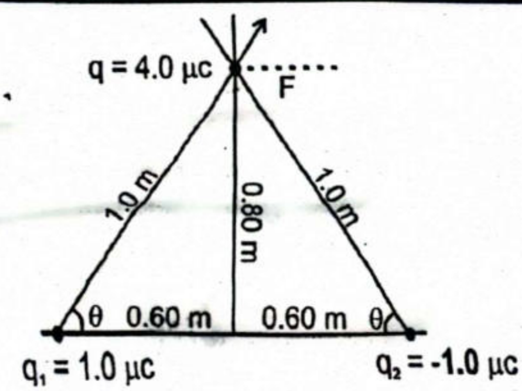
$$F_g = 6.67\times10^{-13}\text{ N} \quad \text{\_\_\_\_\_\_\_\_(2)}$$

Dividing equ. (1) by equ. (2), we get

$$\frac{F_e}{F_g} = \frac{360}{6.67\times10^{-13}} = 53.9\times10^{13}$$

or $$\boxed{\frac{F_e}{F_g} = 5.4\times10^{14}}$$

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



Given data:

Charge $q = 4.0\ \mu c = 4.0 \times 10^{-6}$ C

Charge $q_1 = 1.0\ \mu c = 1.0 \times 10^{-6}$ C

Charge $q_2 = -1.0\ \mu C = -1.0 \times 10^{-6}$ C

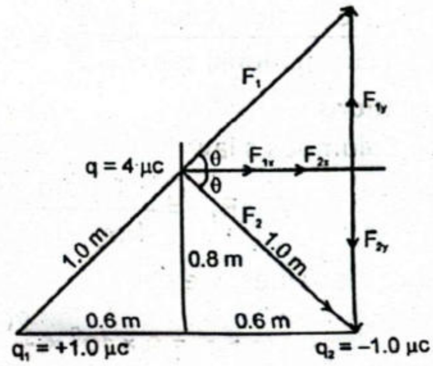
Distance between the charges q and $q_1 = r_1 = 0.1$ m

Distance between the charges q and $q_2 = r_2 = 0.1$ m

To find:

Net electrostatic force on q = F = ?

Calculations:



Let force exerted by charge q_1 on q is F_1 and force exerted by charge q_2 on q is F_2, thus

Force exerted by q_1 on q:

$$F_1 = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q}{r_1^2}$$

Putting the values, we get

$$F_1 = 9\times10^9 \times \frac{1.0\times10^{-6}\times4.0\times10^{-6}}{(1.0)^2} = 36\times10^{-3}\text{N}$$

$$\boxed{F_1 = 0.036\text{ N}}$$

Force exerted by q_2 on q:

$$F_2 = \frac{1}{4\pi\varepsilon_o}\frac{q_2 q}{r_2^2}$$

$$F_2 = 9\times10^9 \times \frac{(1.0\times10^{-6})\times(4.0\times10^{-6})}{(1.0)^2}$$

$$F_2 = 36\times10^{-3}\text{ N}$$

$$\boxed{F_2 = 0.036\text{ N}}$$

Thus $F_1 = F_2 = F = 0.036$ N

From above diagram,

$$\tan\theta = \frac{0.8}{0.6}$$

or $$\theta = \text{Tan}^{-1}(1.33)$$

$$\boxed{\theta = 53^o}$$

Now resolving $\vec{F_1}$ and $\vec{F_2}$ into rectangular components, such that $\vec{F_1}$ has rectangular components F_{1x} and F_{1y}.

Similarly $\vec{F_2}$ has rectangular components F_{2x} and F_{2y}.

Thus, resultant force acting along x-axis is

$$F_x = F_{1x} + F_{2x}$$

$$F_x = F_1\cos\theta + F_2\cos\theta \qquad \text{[As } F_1 = F_2 = F\text{]}$$

$$F_x = F\cos\theta + F\cos\theta$$

$$F_x = 2F\cos\theta$$

$$F_x = 2 \times 0.036 \times \cos 53^o$$

$$F_x = 2 \times 0.036 \times 0.60$$

$F_x = 0.0432$ N

and Resultant force acting along y-axis is

$$F_y = F_{1y} + (-F_{2y})$$

$$F_y = F_1 \sin\theta - F_2 \sin\theta$$

$$F_y = F \sin\theta - F \sin\theta \qquad (\text{As } F_1 = F_2 = F)$$

$$F_y = 0$$

Being F_{1y} and F_{2y} equal in magnitude and opposite in direction will cancel each other.

Now the magnitude of force $\vec{F}$ is

$$F = \sqrt{(F_x)^2 + (F_y)^2}$$

$$F = \sqrt{(0.0432)^2 + (0)^2}$$

$$F = 0.0432 \text{ N}$$

As $F_y = 0$, so F is directed towards positive x-axis.

Thus $\boxed{\vec{F} = 0.0432\hat{i}\text{N}}$

Direction of $\vec{F}$:

$$\alpha = \tan^{-1}\left(\frac{F_y}{F_x}\right)$$

or

$$\alpha = \tan^{-1}\left(\frac{0}{0.0432}\right)$$

$$\boxed{\alpha = 0^\circ}$$

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

Given data:

Point charge = $q = -8.0 \times 10^{-8}$ C

Distance of charge from origin = $r = 2.0$ m

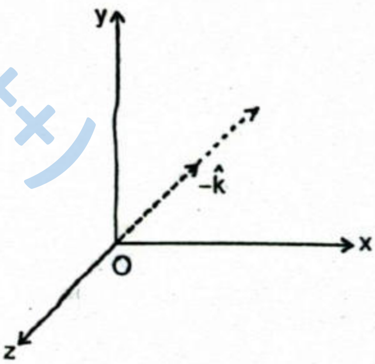
To find:

Electric field intensity = $\vec{E}$ = ? (on z-axis)

Calculations:

As electric intensity along z – axis is

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



Putting the values, we get

$$\vec{E} = 9\times10^9 \frac{(-8.0\times10^{-8})}{(2.0)^2}\hat{k}$$

$$\boxed{\vec{E} = (-1.8 \times 10^2 \hat{k}) \text{ NC}^{-1}}$$

Negative sign shows that $\vec{E}$ is along negative z-axis.

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

Given data:

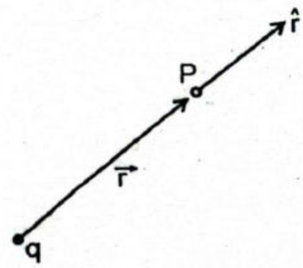
Position vector = $\vec{r} = (4\hat{i}+3\hat{j})$m

Point charge = $q = 5.0 \times 10^{-6}$ C

Constant of proportionality = $k = \frac{1}{4\pi\varepsilon_o} = 9\times10^9 Nm^2C^{-2}$

To find:

Electric intensity = $\vec{E}$ = ?



Calculations:

As $\quad \vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}\hat{r}$ ......(1)

First, we have to calculate values of r & $\hat{r}$.

As $\quad \vec{r} = (4\hat{i}+3\hat{j})$m

Thus $\quad r = |\vec{r}| = \sqrt{(4)^2+(3)^2} = \sqrt{16+9} = \sqrt{25} = 5$m

and $\quad \hat{r} = \frac{\vec{r}}{r} = \frac{4\hat{i}+3\hat{j}}{5}$

Putting the values in eq. (1), we get

$$\vec{E} = 9\times10^9 \times \frac{5\times10^{-6}}{(5)^2} \times \left(\frac{4\hat{i}+3\hat{j}}{5}\right)$$

$$\vec{E} = 9\times10^9 \times \frac{5\times10^{-6}}{25} \times \left(\frac{4\hat{i}+3\hat{j}}{5}\right)$$

$$\vec{E} = \frac{9\times10^3}{25} \times (4\hat{i}+3\hat{j})$$

$$\vec{E} = \frac{9000}{25} \times (4\hat{i}+3\hat{j})$$

$$\vec{E} = 360 \times (4\hat{i}+3\hat{j})$$

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

12.5 **Two point charges, $q_1 = -1.0\times10^{-6}$ C and $q_2 = +4.0\times10^{-6}$ C, are separated by a distance of 3.0 m. Find and justify the zero-field location.**

Given data:

First charge = $q_1 = -1.0 \times 10^{-6}$ C

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

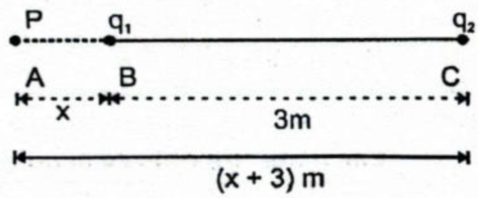
Distance between charges = r = 3.0 m

To find:

Location at which electric field (i.e., resultant electric intensity) is zero = ?

Calculations:

Let P be a point at a distance x from charge q_1 at which electric intensities cancel each other (i.e., electric field is zero).



Now electric field intensity at P due to $-q_1$ is

$$E_1 = \frac{1}{4\pi\varepsilon_o}\frac{q_1}{x^2} \quad \text{(Taking magnitude only)}$$

$$E_1 = \frac{1}{4\pi\varepsilon_o}\frac{1\times10^{-6}}{x^2} \quad ......(1)$$

Electric intensity at P due to q_2 is

$$E_2 = \frac{1}{4\pi\varepsilon_o}\frac{q_2}{(x+3)^2}$$

$$E_2 = \frac{1}{4\pi\varepsilon_o}\frac{4\times10^{-6}}{(x+3)^2} \quad ......(2)$$

As E_1 balances E_2, at P therefore

$$E_1 = E_2$$

$$\frac{1}{4\pi\varepsilon_o}\frac{1\times10^{-6}}{x^2} = \frac{1}{4\pi\varepsilon_o}\frac{4\times10^{-6}}{(x+3)^2}$$

or $$\frac{1\times10^{-6}}{x^2} = \frac{4\times10^{-6}}{(x+3)^2}$$

or $$\frac{1}{x^2} = \frac{4}{(x+3)^2}$$

Cross-multiplying

$4x^2 = (x+3)^2$

Taking square root of both sides

$2x = x+3$

$2x-x = 3$

$X= 3m$

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

Given data:

Mass of the particle = $m = 1.0 \times 10^{-6}$ kg

Charge on the particle = $q = 1.0\ \mu c = 1.0 \times 10^{-6}$ C

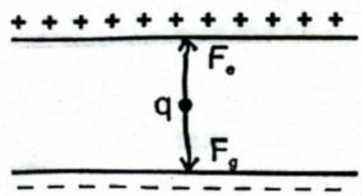
Distance between the plates = d = 10 cm = 0.1 m

To find:

Electric field strength = E = ?

Calculations:

The particle will be suspended between the plates, when



Electric force = weight

$$F_e = F_g$$

$$qE = mg$$

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

Putting the values, we get

$$E = \frac{1\times10^{-6}\times9.8}{1\times10^{-6}}$$

$$\boxed{E = 9.8\ NC^{-1} \text{ or } Vm^{-1}}$$

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

Given data:

Number of electron = n = 20

Charge on each electron = e = 1.6×10^{-19} C

Total charge on 20 electrons = q = ne = $20\times1.6\times10^{-19}C = 3.2\times10^{-18}$ C

Potential difference = ΔV = 100 V

To find:

Change in Kinetic energy = Δ (K.E.) = ?

Calculations:

As $\Delta(K.E.) = q\Delta V$

Putting values, we get

$$\Delta(K.E.) = 3.2\times10^{-18}\times100$$

$$\Delta(K.E.) = 3.2\times10^{-16}\ J$$

Since $1\ eV = 1.6\times10^{-19}\ J$

Thus $$\Delta(K.E.) = \frac{3.2\times10^{-16}}{1.6\times10^{-19}}\,eV$$

$$\boxed{\Delta(K.E.) = 2.0\times10^{3}\ eV}$$

12.8 In Millikan's experiment, oil droplets are introduced into the space between two flat horizontal plates, 5.00 mm apart. The plate voltage is adjusted to exactly 780 V so that the droplet is held stationary. The plate voltage is switched off and the selected droplet is observed to fall a measured distance of 1.50 mm in 11.2 s. Given that the density of the oil used is 900 kg m^{-3}, and the viscosity of air at laboratory temperature is 1.80×10^{-5} Nm^{-2} s, calculate

(a) The mass, and

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

Given data:

Distance between the plates = d = 5.00 mm = 5.00×10^{-3} m

Potential difference = V = 780 volt

Distance moved by droplet = S = 1.50 mm = 1.50×10^{-3} m

Time taken = t = 11.2 sec

Density of oil = ρ = 900 kg m^{-3}

Coefficient of viscosity of air = $\eta = 1.80\times10^{-5}\ Nm^{-2}$ s

To find:

(a) Mass of the droplet = m = ?

(b) Charge on the droplet = q = ?

Calculations:

(a) Mass of the droplet

Mass = (density)(volume)

$$m = \rho \times \frac{4}{3}\pi r^3 \quad ......(1)$$

For calculating radius 'r' using the formula

$$r = \sqrt{\frac{9\eta V_t}{2\rho g}} \quad ......(2)$$

Where 'v_t' is terminal velocity and is given as

$$v_t = \frac{S}{t} = \frac{1.50\times10^{-3}}{11.2} = 0.134\times10^{-3}\,ms^{-1}$$

Putting the values in eq. (2), we get

$$r = \sqrt{\frac{9\times1.80\times10^{-3}\times0.134\times10^{-3}}{2\times900\times9.8}}$$

$$r = 1.11\times10^{-6}\,m$$

Now, putting the value of r in eq. (1), we get

$$\text{Mass} = m = 900\times\frac{4}{3}\times3.14\times(1.11\times10^{-6})^3$$

$$m = 900\times\frac{4}{3}\times3.14\times1.367\times10^{-18}$$

$$m = 900\times5.72\times10^{-18}$$

$$\boxed{m = 5.14\times10^{-15}\,kg}$$

(b) Charge on droplet

As charged droplet is held stationary in gravitational field, so

Weight of the droplet = Electrical force

$$mg = qE$$

$$mg = \frac{V}{d}q \qquad [\text{As } E = \frac{V}{d}]$$

or

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

Putting values, we get

$$q = \frac{5.14\times10^{-15}\times9.8\times5\times10^{-3}}{780}$$

$$q = 0.322\times10^{-18}\,C$$

$$\boxed{q = 3.22\times10^{-19}\,C}$$

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

(a) Potential difference between the two points

(b) Work done by the field

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

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

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

Given data:

Electric field intensity = E = 5000 NC^{-1}

Distance moved = d = 10 cm = 0.1 m

Charge on proton = q = 1.6×10^{-19} C

Mass of proton = m = 1.67×10^{-27} kg

To find:

(a) Potential difference between two points = ΔV = ?

(b) Work done = W = ?

(c) Change in P.E. of proton = ΔU = ?

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

(e) Velocity = v = ?

Calculations:

(a) As $\Delta V = -Ed$

Putting the values, we get

$$\Delta V = -5000 \times 0.1$$

$$\boxed{\Delta V = -500\ V}$$

The –ive sign indicates that direction of E is along the decreasing potential.

(b) Work done = $W = q\Delta V$ (As $\Delta V = \frac{W}{q}$)

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

or $\boxed{W = 500\ eV}$ [As $1.6 \times 10^{-19}\ J = 1\ eV$]

(c) Since the proton moves from higher potential to lower potential, therefore it losses P.E., which is equal to the work done by a charge. Hence,

Change in P.E. = –Work done

$$\Delta U = -q\Delta V$$

$$\boxed{\Delta U = -500\ eV}$$

(d) The change in K.E. (i.e. gain of K.E.) is given by

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

$$\Delta(K.E.) = 1.6 \times 10^{-19} \times 500\ \text{Joules}$$

or $\boxed{\Delta(K.E.) = 500\ eV}$

(e) To find velocity, using the relation

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

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

Putting the values, we get

$$v = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 500}{1.67 \times 10^{-27}}}$$

$$v = \sqrt{\frac{1600 \times 10^{-19+27}}{1.67}}$$

$$v = \sqrt{\frac{1600}{1.67} \times 10^{8}}$$

$$v = \sqrt{958.08 \times 10^{8}}$$

$$v = = 30.9 \times 10^{4}$$

$$\boxed{v = 3.09 \times 10^{5}\ ms^{-1}}$$

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

(a) Charge is positive

(b) Charge is negative

Given data:

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

Distance = $r = 1.2$ m

Coulomb's constant = $k = \frac{1}{4\pi\varepsilon_o} = 9\times10^9 Nm^2C^{-2}$

To find:

(a) Electric potential when q is positive = $V_+ = ?$

(b) Electric potential when q is negative = $V_- = ?$

Calculations:

(a) When charge is positive

i.e., $q = +4.0 \times 10^{-8}$ C

Then $V_+ = \frac{1}{4\pi\varepsilon_o}\frac{q}{r}$

Putting the values, we get

$$V_+ = 9\times10^9 \times \frac{4.0\times10^{-8}}{1.2}$$

$$V_+ = \frac{36}{1.2}\times10 = 300 \text{Volt}$$

$$\boxed{V_+ = 3 \times 10^2 \text{ Volt}}$$

(b) When charge is negative

i.e., $q = -4.0 \times 10^{-8}$ C

then $V_- = \frac{1}{4\pi\varepsilon_o}\frac{q}{r}$

$$V_- = 9\times10^9 \frac{(-4.0\times10^{-8})}{1.2}$$

$$V_- = -\frac{36}{1.2}\times10 = -300 \text{ volt}$$

$$\boxed{V_- = -3 \times 10^2 \text{ V}}$$

12.11 **In Bohr's atomic model of hydrogen atom, the electron is in an orbit around the nuclear proton at a distance of 5.29×10^{-11} m with a speed of 2.18×10^6 ms^{-1}. (e = 1.60×10^{-19} C, mass of electron = 9.10×10^{-31} kg). Find**

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

(b) Total energy of the atom in eV

(c) The ionization energy for the atom in eV

Given data:

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

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

Charge on electron = e = 1.6×10^{-19} C
Mass of electron = m = 9.1×10^{-31} kg

To find:

(a) Electric potential = V = ?
(b) Total energy in eV = E = ?
(c) Ionization energy in eV = E_{ion} = ?

Calculations:

(a) Electric potential = V = ?

$$V = \frac{1}{4\pi\varepsilon_o}\frac{q}{r} \qquad (q = e)$$

Putting the values, we get

$$V = 9\times10^{9}\,\frac{1.6\times10^{-19}}{5.29\times10^{-11}}$$

$$V = \frac{1.44\times10^{-9}}{5.29\times10^{-11}} = 0.2722\times10^{2}\ \text{Volt}$$

or $\boxed{V = 27.22\ \text{Volt}}$

(b) Total energy of the atom

Total energy can be calculated by the following formula

Total energy = E_T = K.E. + P.E.

$$E_T = \frac{1}{2}mv^2 + (-qV)$$

$$E_T = \frac{1}{2}mv^2 - eV$$

Putting values, we get

$$E_T = \frac{1}{2}\times9.1\times10^{-31}\times(2.18\times10^{6})^2 - 1.6\times10^{-19}\times27.22$$

E_T = 2.17×10^{-18} Joules – $1.6 \times 10^{-19} \times 27.22$ Joules

or E_T = 13.6 eV – 27.22 eV

$\boxed{E_T = -13.62\ \text{eV}}$

(c) *Ionization energy in eV = E_{ion} = ?*

The amount of energy required to lift an electron in an atom from its ground state to the state at infinity (n = ∞) is called ionization energy.

Ionization energy of the atom = (Energy of the electron at infinity) – (Energy of the electron at ground state)

$E_i = E_\infty - E_{ground}$

E_i = 0 – (–13.61 eV)

$\boxed{E_i = 13.61\ \text{eV}}$

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

Given data:

Capacitance of a capacitor = C = 750 μF = 750×10^{-6} F
Potential difference between its plates = V = 330 V

To find:

Energy = E = ?

Calculations:

The energy stored in capacitor is given as

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

Putting the values, we get

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

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

$$\boxed{E = 40.8\text{ J}}$$

12.13 A capacitor has a capacitance of 2.5×10^{-8} F. In the charging process, electrons are removed from one plate and placed on the other one. When the potential difference between the plates is 450 V, how many electrons have been transferred? ($e = 1.6\times10^{-19}$ C)

Given data:

Capacitance of a capacitor = $C = 2.5\times10^{-8}$ F

Potential difference between plates = V = 450 volt

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

To find:

Number of electrons transferred = n = ?

Calculations:

If 'n' be the number of electrons in charge Q and e is the charge on each electron, then total charge on 'n' electrons is given by

$$Q = ne$$

Or $n = \frac{Q}{e}$ But $Q = CV$

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

Putting the values, we get

$$n = \frac{2.5\times10^{-8}\times 450}{1.6\times10^{-19}}$$

$$n = 703.12\times10^{11}$$

$$\boxed{n = 7.0\times10^{13}\text{ electrons}}$$

MCQ's From Past Board Papers

1. **Fact that electric field exist in space around a charge is:**
(a) Electrical property (b) Magnetic property (c) Intrinsic property (d) Gravitational property

2. **One columb of charge is carried by**
(a) 1 electron (b) 1.6×10^{-19} Electron (c) 6.25×10^{18} Electron (d) 6.25×10^{-18} Electron

3. **Electron volt is unit of**
(a) p.d (c) Capacitance (d) Energy (d) None

4. **After 5 time constants current through capacitor becomes**
(a) Zero (b) $\frac{kq}{d}$ (c) $2\frac{kq}{d^2}$ (d) Maximum

5. **Relative permittivity is defined as**
(a) $\frac{C_{med}}{C_{vac}}$ (b) $\frac{C_{vac}}{C_{med}}$ (c) $\frac{F_{vac}}{F_{med}}$ (d) Both a and c

6. **Flux through closed surface enclosing two opposite charges of equal magnitude**
(a) $q / \in_o$ (b) ev / 2m (c) Zero (d) $q / 2\in_o$

7. **Electron placed in potential difference "V" is accelerated from rest, then is final velocity is**
(a) $\sqrt{ve/m}$ (b) ev / 2m (c) $\sqrt{2ve/m}$ (d) ev / m

8. **In a region E = 0, then potential V, varies**
(a) $V \alpha r$ (b) $v \alpha 1/r$ (c) $v \alpha 1/r^2$ (d) not charge

9. **Two opposite charges of same magnitude are separated by distance "d" then at midway between then**
(a) $E = 0, v = 4kq / d$ (b) $E = 8kq / d^2, v = 0$ (c) $E = 2kq / d^2, v = 0$ (d) (a) $E = 0, v = 2kg / d$

10. **Energy stored in capacitor is given by**
(a) $\frac{1}{2}cv^2$ (b) $Q^2 / 2c$ (c) $\frac{1}{2}Qv$ (d) All of these

Answers Key

1.	c	2.	c	3.	c	4.	a	5.	d
6.	c	7.	c	8.	d	9.	b	10.	d

IMPORTANT PREVIOUS BOARDS SHORT QUESTIONS

1. Prove that Coulomb's law obeys third law of motion. (Lhr GI 2018)
2. Define potential gradient and give its SI units. (Grw 2018) (Lhr GI 2018) (Azad Kashmir 2018)
3. Suppose that you follow an electric field line due to a positive point charge. Do electric field and the potential increase or decrease? Explain. (Mtn GI 2018) (Lhr GI 2018)
4. Define electric polarization and electric dipole. (Lhr GI 2018)
5. What is meant by EEG and ERG? (Lhr GII 2018)
6. The potential is constant throughout a given region of space. Is the electric field zero or non-zero in this region? Explain.
7. Is it true that Gauss's law states that the total number of lines of force crossing any closed surface in the outward direction is proportional to the net positive charge enclosed within surface? Explain. (Lhr GII 2018)
8. Define Electrostatics and Electric Force. (Bwp GI 2018)
9. Define Xerography and Photoconductor. (Bwp GI 2018)
10. Electric Lines of Force never cross, why? (Bwp GI 2018) (Fsd 2018) (D.G.Khan GII 2018) (Azad Kashmir 2018) (Swl 2018) (Sgd GII 2018)
11. Write four characteristics of Electric Field Lines. (Lhr GII 2018) (Grw 2018) (Bwp GII 2018)

12. Differentiate between electric Potential Energy and Electric Potential Difference. Also define its unit. **(Mtn GI 2018) (Bwp GII 2018)**

13. Show that $1\ Vm^{-1} = 1NC^{-1}$. **(Bwp GII 2018)**

14. The potential is constant throughout a given region of space. Is the electrical field zero or non-zero in region? Explain.

15. Define electron field intensity. What is its unit and direction? **(D.G.Khan GI 2018)**

16. Define electric flux. Mention the factors upon which it depends. **(D.G.Khan GI 2018)**

17. Define electric flux, Gaussian surface. **(D.G.Khan GII 2018)**

18. Show $\frac{1V}{1m} = \frac{1N}{1C}$. **(D.G.Khan GII 2018)**

19. If a point charge q of mass m released in a non-uniform electric field with field lines pointing in same direction, will it make a rectilinear motion? **(D.G.Khan GII 2018)**

20. Define capacitance and electric polarization. **(Fsd 2018)**

21. Do electrons tend to go to region of high potential or of low potential? Give its reason. **(D.G.Khan GI 2018) (Fsd 2018) (Mtn GI 2018) (Mtn GII 2018) (Grw 2018)**

22. State Coulomb's Law and Gauss's Law. **(Mtn GI 2018)**

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

24. Define charging and discharging of a capacitor. **(Mtn GII 2018)**

25. How sharks locate their prey? Explain briefly. **(Mtn GII 2018)**

26. Distinguish between electric field and electric field intensity. **(Sgd GI 2018)**

27. Suppose that you follow an electric field line due to a positive point charge. Do electric field and the potential increase or decrease. **(Sgd GI 2018)**

28. Define dielectric constant and write its formula. **(Sgd GI 2018)**

29. Show that the unit of time constant RC is second. **(Sgd GI 2018) (Sgd GII 2018)**

30. What is the electric intensity at a distance 'r' 100 cm due to charge $10\mu C$? **(Sgd GII 2018)**

31. What is the effect of Polarization on the capacitance of capacitor? **(Sgd GII 2018)**

32. Suppose that a charge 'q' is moving in a uniform magnetic field with velocity 'v'. Why there is not work done by the magnetic force that acts on the charge q? **(Mtn GI 2018) (Sgd GII 2018)**

33. What is xerography? Name the heart of photo-copier. **(Swl 2018)**

34. A particle carrying a charge of 5 e falls through a potential difference of 10.0 V. What will be the energy acquired by it?

35. Write down any four difference among gravitational force and electric force. **(Swl 2018)**

36. What is capacitor? Define the capacitance. **(Rwp 2018)**

37. 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? **(Rwp 2018)**

38. Define electron volt. Show that $1eV = 1.6 \times 10^{-19}$ J. **(Fsd 2018) (Azad Kashmir 2018) (Rwp 2018)**

39. How can you identify that which plate of a capacitor fs positively charged? **(Bwp GI 2018) (Bwp GII 2018) (Grw 2018) (Rwp 2018) (Azad Kashmir 2018)**

IMPORTANT PREVIOUS BOARDS LONG QUESTIONS

Q1. Derive an expression for the potential at a certain point in the field of a positive point charge. **(Lhr GI 2018)**

Q2. A proton is placed in a uniform electric field of 5000 N/C directed to right is allowed to go to a distance of 10.0 cm from point A to the point B. Calculate: **(Lhr GII 2018) (Bwp GII 2018)**
(i) Work done by the field (ii) Its velocity

Q3. A point charge $q = -8.0\times10^{-8}C$ is placed at origin. Calculate electric field at measure the unknown resistance? **(Bwp GI 2018)**

Q4. Define capacitance of a capacitor, also derive a relation for capacitance of a parallel plate capacitor for air and dielectric as a medium. **(D.G.Khan GI 2018)**

Q5. Define capacitance. Derive an expression for capacitance of parallel plate capacitor when a dielectric material is inserted between the plates. **(Swl 2018) (D.G.Khan GII 2018) (Azad Kashmir 2018)**

Q6. Determine the electric field at the position $\vec{r}\,(4\hat{i} + 3\hat{i})$ m. Caused by a point charge $q = 5.0 \times 10^{-6}C$ placed at origin. **(Fsd 2018)**

Q7. Two point charges $q_1 = -1.0 \times 10^{-6}$ C and $q_2 = 4.0 \times 10^{-6}$ C are separated by a distance of 3.0m. Find and justify the zero-field location. **(Grw 2018)**

Q8. Define Electric Potential. Find the electric potential at a certain point due to a point charge. **(Mtn GI 2018)**

Q9. Find the electric field strength required to hold suspended a particle of mass 1.0×10^{-6} and charge 1.0μC between two plates 10.0 cm apart. **(Mtn GII 2018)**

Q10. State Gauss's Law. Derive relation foe electron intensity at a point near an infinite sheet of charge. **(Rwp 2018)**
