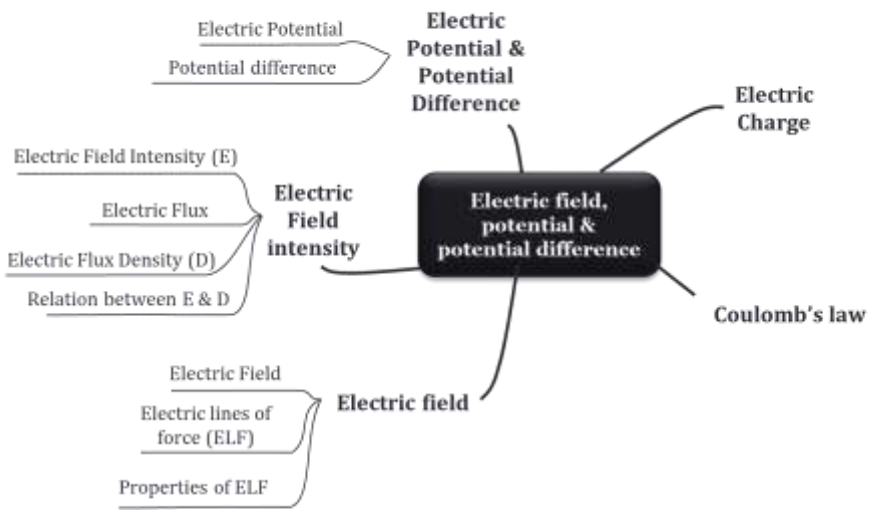
Study Material

Program Code: All Program **Semester: First** **Course Name: Basic Science (Physics)** **Course Code: 22102** **Topic Name: Electricity, Magnetism & Semiconductors** **Unit Outcomes (UO2a): Calculate electric field, potential and potential difference of given static charge** **LO2: Student will be able to define and calculate alculate electric field, potential and potential difference of given static charge.**	
Course Expert: S. K. Rawat	**Date: 02/08/2020**

Concept Map:



Key words: Electric field, electric lines of force, electric field intensity, electric flux, electric flux density, electric potential

Key Questions:

1. What are electric field and electric lines of force?
2. What are properties of electric lines of force?
3. What are electric field intensity, electric flux and electric flux density?
4. State the relation between electric field intensity and electric flux density.
5. State the difference between electric potential and potential difference.
6. State the applications of electrostatics in real life examples.

Key Definition:

1. Electric Field is defined as the space around a charge where force of attraction or repulsion can be observed or felt.
2. Electric lines of Force are defined as the path along which an unit positive charge moves when placed in an Electric field.
3. Electric Flux is defined as total number of electric lines of force starting from a unit positive charge.
4. Electric Flux Density is defined as total number of electric line of force passing through a surface area.
5. The relation between electric field intensity € and electric flux density (D) is D = є0 k E.
6. Electric Potential: It is defined as amount of work done in bringing a unit positive charge from infinity to any point inside electric field.
7. Potential Difference: It is defined as amount of work done in bringing a unit positive charge from one point to another point inside electric field.
8. One volt (1V): If one joule of work is done in bringing a charge of one coulomb then the potential is said to be one volt.

Formula:

1. Electric field intensity $\mathrm{E} = \frac{\mathrm{F}}{\mathrm{Q}} = 9 \times 10^9 \times \frac{Q}{kd^2}$
2. Electric flux $\emptyset = \mathrm{Q}$

3. Electric flux density $D = \frac{\emptyset}{A} = \frac{Q}{A} = \epsilon_0 kE$
4. Electric potential $V = \frac{W}{Q} = 9 \times 10^9 \times \frac{Q}{kd}$
5. Potential due to point charge $V = 9 \times 10^9 \times \frac{Q}{kr}$
6. P.D between two points $V = 9 \times 10^9 \times \frac{Q}{k}\left[\frac{1}{d} - \frac{1}{D}\right]$
7. Potential due to charged sphere $V = 9 \times 10^9 \times \frac{Q}{kr}$

Notes

Introduction

Electrostatics relates to electric charges at rest or to fields or phenomena produced by stationary charges.

Electric charges

There are two types of charges called positive and negative. Like charges repel each other and unlike charges attract each other.

Charges within atoms

An atom has a heavily charged positive nucleus at its center surrounded by tiny negatively charged electrons which cause the atoms to be electrically neutral and therefore the number of positive charges is equal to the number of negative charges. Each electron carries a charge equal to –e, the neutron has no net charge and each proton has a charge +e.

Therefore, Number of protons = Number of electrons

NOTE: The numerical value of e = 1.6 x10-19 C

Force between Two Charges

It is observed that there are forces of attraction are repulsion between two charges. Like charges repel while unlike charges attract each other.

Attractive force between dissimilar charges

We have seen that a glass rod rubbed with silk get positively charged while an ebonite rod rubbed with fur get negatively charged.
When one end of positively charged glass rod is brought near a freely suspended negatively charged ebonite rod they attract each other. This shows that two unlike or opposite charges attract each other.

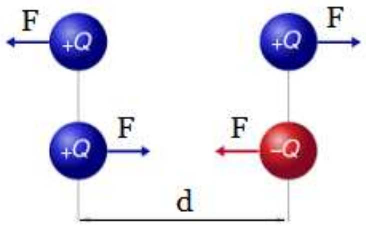
Repulsive force between like charges
When one end of positively charged glass rod is brought near another freely suspended positively charged glass rod they repel each other. Similarly two negatively charged ebonite rods, when brought near each other, repel each other. This shows that two like or similar charges repel each other.

Coulomb's law
Charles Coulomb in 1785, studied about the forces of attraction and repulsion between electrical charges. His observations are given as Coulomb's law of electrostatics.

Statement
Coulombs law states that the force (F) of attraction or repulsion between two point charges (Q1 and Q2) is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (d) between them.
i.e., (i) $F \propto Q_1 \times Q_2$
(ii) $F \propto \frac{1}{d^2}$

Thus from (i) and (ii) we get, $F \propto \frac{Q_1 Q_2}{d^2}$ $\therefore F = C\frac{Q_1 Q_2}{d^2}$

where C = $\frac{1}{4\pi\epsilon}$ = $\frac{1}{4\pi\epsilon_0 k}$ is called constant of proportionality and is also called as Coulomb's constant of electrostatics
where ε= ε0k is called the permittivity of medium.



As we know $$F = \frac{1}{4\pi\varepsilon_0 k} \times \frac{Q_1 Q_2}{d^2}$$

where ε0 = 8.85 x 10-12 C2/Nm2, is called the permittivity of free space.
k = relative permittivity or dielectric constant of medium.

NOTE: If we substitute valve of π and ε0 in 1/(4πε0k) , we get $$F = 9 \times 10^9 \times \frac{Q_1 Q_2}{kd^2}$$
Now if we consider Q1 = Q2 =Q (suppose), k = 1, d = 1 m and F = 9 x 109 N.

Then, Q2 = 1 Thus Q = ± 1 Coulomb

Unit Charge: If two equal charges are placed in air at a distance of 1 meter from each other & if they exert a force of 9 x 109 N on each other, then each charge is said to be of One Coulomb

Electric Field
Even if two charges are kept at a certain distance, there will be a force or interaction between them. To explain such interactions we use the concept of fields.

Faraday introduced the concept of electric field to explain how the electric charges exert forces of attraction or repulsion on another charge. We can see that if the distances from the charges increases, then the strength of the field's decreases i.e. the force is exerted only in the region around the charge. This region is called the electric field due to the charge.

Electric Field is defined as the space around a charge where force of attraction or repulsion can be observed or felt due to charge.

Electric field Intensity
Electric Field Intensity is defined as the force experienced by a unit positive charge placed at the point.

By definition, $E = \frac{F}{Q}$
Unit of E is N/C

We know according to Coulomb's law $$F = 9 \times 10^9 \times \frac{Q_1 Q_2}{kd^2}$$

Now if Q1 = Q2 = Q, then $$F = 9 \times 10^9 \times \frac{Q^2}{kd^2}$$
But by definition, we know $E = \frac{F}{Q}$

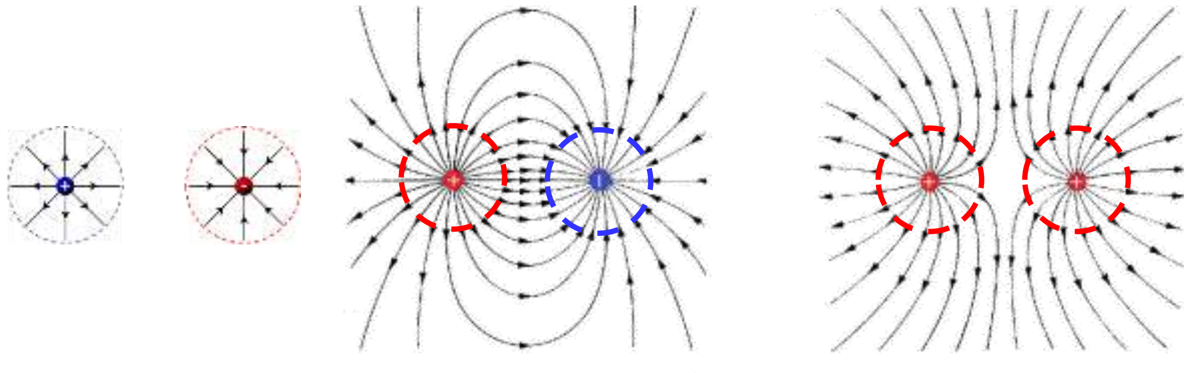
Thus $$E = 9 \times 10^9 \times \frac{Q}{kd^2}$$ or $$E = \frac{1}{4\pi\varepsilon_0} \times \frac{Q}{kd^2}$$

Electric Lines Of Force:
The line along which a unit positive charge moves when placed in an electric field is known as the electric line of force.

When a test charge +q is placed in an electric field of another charge +Q, the electric field due to that charge exert a force on the text charge. If the test charge is free to move, then it will move in the direction of electric field at that point. The path of the test charge is called electric line of force.

It should be noted that these lines are imaginary lines and is used to explain the concept of electric field.

The lines of force due to (i) a single positive charge, (ii) single negative charge, (iii) unlike charges and (iv) like charges are as shown below.



unlike charges　　　　like charges

Properties of electric force:
Electric lines of force originate from a positive charge and terminate on a negative charge.
No lines of force exist inside a force conductor.
The number of lines of forces due to charge is proportional to the magnitude of the charge.
Lines of force do not intersect each other.
The lines of force are always normal to the surface.
The tangent to the line of force at any point gives the direction of electric field at that point.
The lines of force exert lateral pressure on each other.
Lines of force are parallel in a uniform field and curved in a non-uniform field.
Lines of force are imaginary and do not exist in reality.

Electric flux and Electric flux density:

The strength of the electric field can also be measured in terms of another term called electric flux and flux density.

Electric flux due to a charge can be defined as the total number of electric lines of force starting from the charge.

Faraday assumed that the number of lines of force starting from a charge is equal to the charge itself. Hence the electric flux (φ) due to a charge is equal to the charge i.e. $\varphi = Q$.

Hence the unit of electric flux is coulomb.

Electric flux through a surface is equal to the total number of lines of force passing through that surface.

Electric flux density (D) is defined as the number of electric lines of force crossing normally through unit area of the surface.

If an electric flux (φ) crosses normally through the area A, then electric flux density is given as $D = \frac{\varphi}{A} = \frac{Q}{A}$

SI unit of electric flux density is coulomb/m2

Relation between E and D
Let us study relation between electric field intensity (E) & electric flux density (D).
(i) By Def'n Electric field intensity is E = $\frac{1}{4\pi\epsilon_0}\frac{Q}{kd^2}$

(ii) By Def'n Electric Flux Density is D = $\frac{Q}{A} = \frac{Q}{4\pi d^2}$

From (i) and (ii), we get E = $\frac{D}{\epsilon_0 k}$

Thus D = $\epsilon_0 k$ E

Electric Potential: It is defined as amount of work done in bringing a unit positive charge from infinity to any point inside electric field.

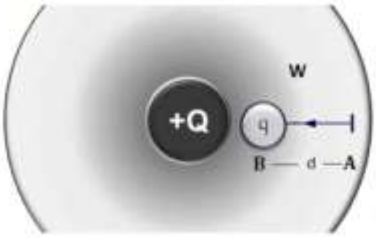
Potential Difference: It is defined as amount of work done in bringing a unit positive charge from one point to another point inside electric field.
Potential difference is defined as difference in potential of two charged bodies.

Electric potential (V) = (Work (W))/(Charge (Q))   i.e., V = W/Q

Symbol & SI Unit: Electric potential or potential difference is denoted by V & measured in volt (V).
Note: If W = 1J, Q = 1C, then 1 volt = (1 joule)/(1 coulomb)

One volt (1V): If one joule of work is done in bringing a charge of one coulomb then the potential is said to be one volt.

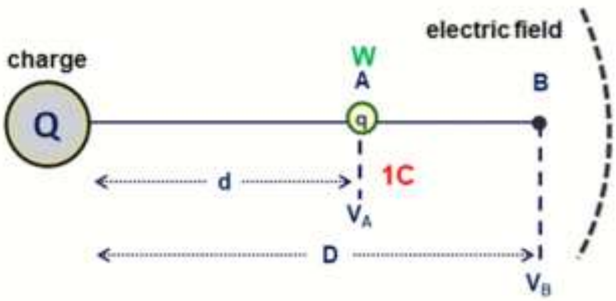
Potential due to point charge



- Let a point charge q moves from point A to B, i.e., AB = d.
- By definition, electric potential (V) = $\frac{\text{Work (W)}}{\text{Charge (q)}}$
- We know work done (W) = Force (F) $\times$ distance (d)
- Hence according to Coulomb's law, F = $\left(\frac{1}{4\pi\epsilon_0 k}\frac{Qq}{d^2}\right)$
- $\therefore$ W = F $\times$ d = $\left(\frac{1}{4\pi\epsilon_0 k}\frac{Qq}{d^2}\right) \times$ d
- $\therefore$ Electric Potential V = $\frac{\frac{1}{4\pi\epsilon_0 k}\frac{Qq}{d}}{q} = \frac{1}{4\pi\epsilon_0}\frac{Q}{kd}$
- $\therefore$ Electric Potential V = $\frac{1}{4\pi\epsilon_0}\frac{Q}{kd}$

P.D between two points

- Potential Difference between two points is defined as the work done in carrying unit positive charge from one point to another point against electric field.
- P.D between points 'A' & 'B' is defined as the work done in carrying a unit positive charge from B to A, and is given by V_{AB}. i.e., $V_{AB} = V_A - V_B$
- We know potential at A is $V_A = \frac{1}{4\pi\epsilon_0}\frac{Q}{kd}$ and potential at B is $V_B = \frac{1}{4\pi\epsilon_0}\frac{Q}{kD}$
- $V_{AB} = V_A - V_B = \left[\frac{1}{4\pi\epsilon_0}\frac{Q}{kd} - \frac{1}{4\pi\epsilon_0}\frac{Q}{kD}\right]$
  $= \frac{Q}{4\pi\epsilon_0 k}\left(\frac{1}{d} - \frac{1}{D}\right)$
- $V_{AB} = 9 \times 10^9 \times \frac{Q}{k}\left(\frac{1}{d} - \frac{1}{D}\right)$

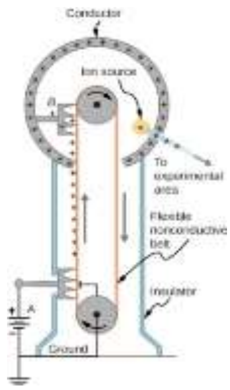


Application of Concept/ Examples in real life:

As we have already seen the applications of Coulomb's Law in the previous study materials. Other than these application some other applications are as follows -

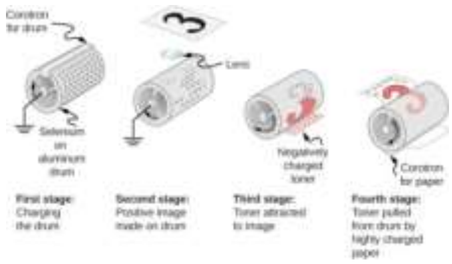
Van de Graaff generators

- A battery (A) supplies excess positive charge to a pointed conductor, the points of which spray the charge onto a moving insulating belt near the bottom.
- The pointed conductor (B) on top in the large sphere picks up the charge. (The induced electric field at the points is so large that it removes the charge from the belt.)
- This can be done because the charge does not remain inside the conducting sphere but moves to its outside surface.
- An ion source inside the sphere produces positive ions, which are accelerated away from the positive sphere to high velocities.



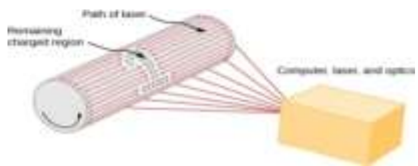
Xerography

- Xerography is a dry copying process based on electrostatics.
- The major steps in the process are the charging of the photo conducting drum, transfer of an image, creating a positive charge duplicate, attraction of toner to the charged parts of the drum, and transfer of toner to the paper.
- Not shown are heat treatment of the paper and cleansing of the drum for the next copy.



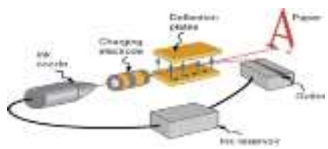
Laser Printers

- In a laser printer, a laser beam is scanned across a photo conducting drum, leaving a positively charged image.
- The other steps for charging the drum and transferring the image to paper are the same as in xerography.
- Laser light can be very precisely controlled, enabling laser printers to produce high-quality images.



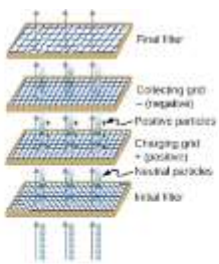
Ink Jet Printers and Electrostatic Painting

- The nozzle of an ink-jet printer produces small ink droplets, which are sprayed with electrostatic charge.
- Various computer-driven devices are then used to direct the droplets to the correct positions on a page.



Smoke Precipitators and Electrostatic Air Cleaning

- Schematic of an electrostatic precipitator. Air is passed through grids of opposite charge.
- The first grid charges airborne particles, while the second attracts and collects them.
- The dramatic effect of electrostatic precipitators is seen by the absence of smoke from this power plant.



Link to YouTube/ OER/ video/e-book:

1. http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html
2. http://hyperphysics.phy-astr.gsu.edu/hbase/electric/elefie.html#c1
3. https://www.cliffsnotes.com/study-guides/physics
4. https://openpress.usask.ca/physics155/chapter/3-6-applications-of-electrostatics/

Key Take away:

1. Concept of Magnetic field, Magnetic field intensity.
2. Theory of magnetic flux and magnetic flux density.
3. Application of Magnetism.

Formative Assessments

<22102> : <All Program> : < All Program >: <Electricity, Magnetism & Semiconductors>: <UO2a> : <LO2> : <Assessments> : <Formative>: <S. K. Rawat>

Assessment Type: Formative Assessments: Embedded questions in video/ PPT

Set 1		
Question No 1	Question No 2	Question No 3
The space around an electric charge where it has a force of attraction or repulsion is called ___________	The imaginary lines representing the electric field are known as __________	Calculate the electric field intensity 10cm from a charge Q = 5nC
Remembering	Understanding	Application
a) electric field	a) electric field	a) 450 N/C
b) magnetic field	b) electric lines of force	b) 900 N/C
c) electromagnetic field	c) electric flux	c) 4.5×10^3 N/C
d) nuclear field	d) electric field intensity	d) 9.0×10^3 N/C
Ans: <electric field>	Ans: <electric lines of force>	Ans: <4.5×10^3 N/C >
Set 2		
Question No 1	Question No 2	Question No 3
The symbol for electric flux is ______	The formula for permittivity of a material is given by ______	The relation between electric flux density and intensity of electric field is given as -
Remembering	Understanding	Understanding
a) $\boldsymbol{\phi}$	a) $D \times E$	a) $E = \epsilon_0 kD$
b) n	b) E/D	b) $D = \epsilon_0 kE$
c) X	c) 2D/E	c) $E/D = \epsilon_0 k$
d) P	d) D/E	d) $D/E = 1/\epsilon_0 k$
Ans: < $\boldsymbol{\phi}$ >	Ans: <D/E>	Ans: <$D = \epsilon_0 kE$>

Set 3		
Question No 1	Question No 2	Question No 3
The work done in bringing a unit charge from infinity to a given point in electric field is called ___________.	1 volt = _____.	A charged body in free space produces 10V at a distance 25 cm away. What will be the potential at 50 cm away?
Remembering	Understanding	Application
a) electric charge	a) 1 J/C	a) 5 V
b) electric current	b) 1 C/J	b) 7.5 V
c) electric potential	c) 1W	c) 10 V
d) electric power	d) 1 N/C	d) 15 V
Ans: <electric potential>	Ans: <1 J/C>	Ans: <5 V>

Practice Worksheets

<22102> : <All Program> : < All Program >: <Electricity, Magnetism & Semiconductors>: <UO2a> : <LO2> : <Assessments> : <Formative>

<S. K. Rawat>

A. The concept of electric field was introduced by a) André-Marie Ampère b) James Prescott Joule c) Michael Faraday d) James Watt	B. The imaginary lines representing the electric field are known as ________________. a) Electric field intensity b) Electric flux c) Electric flux density d) Electric lines of force
Ans A:	Ans B:
C. The path along which a unit positive charge moves when placed in an electric field is called ____________________. a) Electric flux b) Electric flux density c) Electric lines of force d) Electric field intensity	D. What do you call the total number of electric lines of force in an electric field? a) Electric field intensity b) Electric lines of force c) Electric flux density d) Electric flux
Ans C:	Ans D:
E. The tangent drawn to the Electric lines of force at any point indicates the direction of ________________. a) Electric field b) Magnetic field c) Electromagnetic field d) Electric flux	F. Electric lines of force are _________ crowded in the region of strong electric field and _________ crowded in the region of weak electric field. a) less, more b) more, less c) never, always
Ans E:	Ans F:
G. The force acting on a unit positive charge when placed in an Electric field is called as ________________. a) Electric flux density b) Electric lines of force c) Electric field intensity d) Electric flux	H. Electric field intensity at a point due to a given charge ___________ if the relative permittivity of the medium decreases. a) decreases b) remains unchanged c) increases d) becomes zero
Ans G:	Ans H:
I. Unit of Electric flux density is _______ a) Q/A b) C/m c) C/m^2 d) A/Q	J. The electric intensity at a point 50 cm from a charge of 3.2 μC in a medium of dielectric constant 2 is equal to - a) 57.6×10^3 N/C b) 576 N/C c) 5760 N/C d) 5.76×10^3 N/C
Ans I:	Ans J: