Study Material

Program Code: All Program

Semester: First

Course Name: Basic Science (Physics)

Course Code: 220102

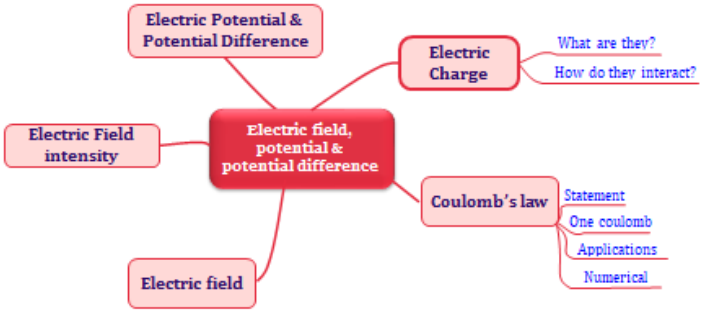
Topic Name: Electricity, Magnetism & Semiconductors

UO2a: Calculate electric field, potential and potential difference of given static charge.

LO1: Student will be able to define electric charge and state Coulomb's inverse square law.

Course Expert: S. K. Rawat	**Date: 24/07/2020**

Concept Map:



Key words: Electric charge, electrostatic force , permittivity, coulomb's law,

Key Questions:

1. What are electric charges and how do they interact?
2. What is coulomb's law of electrostatics?
3. What are the applications of coulomb's law of electrostatics?

Key Definition:

1. Electric charge is a quantitative polarity of electrons & protons in an atom.
2. Coulomb's law states that the magnitude of the force is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.
3. 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 10^9 N on each other, then each charge is said to be of one coulomb or unit charge.

Formula:

1. The numerical value of electron e = 1.6 x 10^{-19} C
2. Permittivity of free space ϵ_0 = 8.85 x 10^{-12} C^2/Nm^2
3. Force between two charges $F = 9 \times 10^9 \times \frac{Q_1 \times Q_2}{kd^2}$
4. One unit charge = Q = ± 1 Coulomb
5. One coulomb charge = 1 C = 6.24×10^{16} electrons

Notes

Introduction

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

When an ebonite rod is rubbed to a fur cloth, the ebonite rod becomes negatively charged. Now if a glass rod is brought close to this negatively charged ebonite rod then a positive charge is induced in glass rod. Thus the glass rod becomes positively charged.

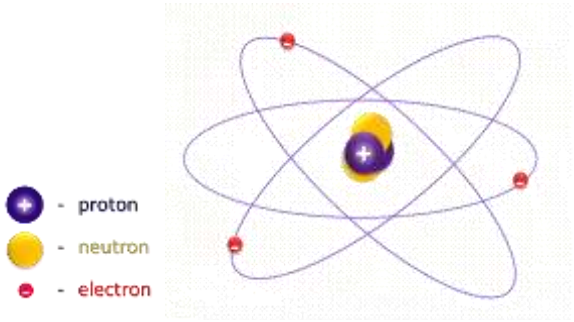
Electric charges

- Electric charge is a quantitative polarity of electrons & protons in an atom.
- There are two types of charges called positive and negative.
- A quantity of charge should always be identified with a positive or a negative sign
- We know unlike charges attract each other and like charges repel each other.
- The unit of electric charge is the coulomb (C).

Charges within atoms

An Atom consists of protons, neutrons & electrons.

An atom has a heavily charged positive nucleus at its centre 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.



Atom becomes positively charged when electron is taken away from it.

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 = 1.6×10^{-19} C

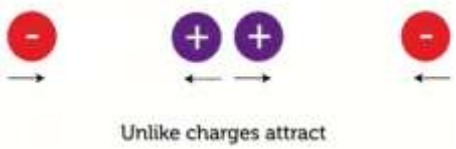
Force between Two Charges

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

In 1785, the French physicist Charles-Augustin de Coulomb published three papers on electricity and magnetism in which he described the electrostatic force.

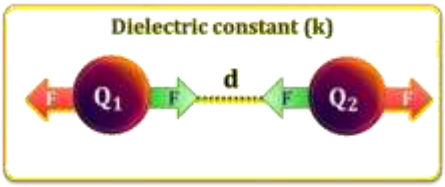
The law has become known as Coulomb's Law, and it states:

1) Like charges repel each other, and unlike charges attract one another.
2) The attraction or repulsion acts along a line between the two charges.
3) The magnitude of the force is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.


Charles-Augustin deCoulomb

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) ,$\mathbf{F \propto Q_1 \times Q_2}$

(ii) $\mathbf{F \propto \frac{1}{d^2}}$

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

$\therefore \mathbf{F = C \times \frac{Q_1 \times Q_2}{d^2}}$

(where **C** is is called constant of proportionality and is also called as Coulomb's constant of electrostatics)

$$\therefore F = \frac{1}{4\pi\epsilon} \times \frac{Q_1 \times Q_2}{d^2} \qquad \therefore F = \frac{1}{4\pi\epsilon_0 k} \times \frac{Q_1 \times Q_2}{d^2}$$

(where $\epsilon = \epsilon_0 k$ is called the permittivity of medium)

$\epsilon_0 = 8.85 \times 10^{-12}\ C^2/Nm^2$, is called the permittivity of free space
k = relative permittivity or dielectric constant of medium)

NOTE: If we substitute valve of π and ϵ_0 in $\frac{1}{4\pi\epsilon_0 k}$,

we get $F = 9 \times 10^9 \times \frac{Q_1 \times Q_2}{kd^2}$

Now if we consider $Q_1 = Q_2 = Q$ (suppose), $k = 1$, $d = 1$ and $F = 9 \times 10^9$

Then, $F = 9 \times 10^9 \times \frac{Q_1 \times Q_2}{kd^2} \Rightarrow$

$9 \times 10^9 = 9 \times 10^9 \times \frac{Q \times Q}{1 \times (1)^2} \Rightarrow Q^2 = 1 \Rightarrow$

$Q = \pm 1C$

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

Application of Concept/ Examples in real life:

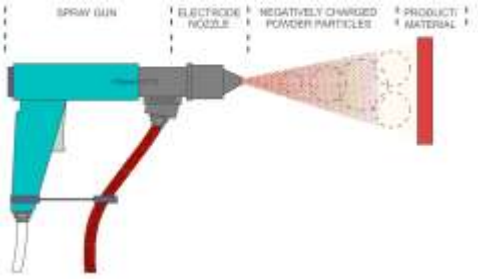
Coulomb's Law has a great many applications to modern life, from powder coating to xerox machines to printers, to life sciences.

Dry Powder Coating

Electrostatic spray deposition process is electrostatic painting or coating, also known as "dry powder coating."

The process uses a high voltage electrostatic charge which is applied to both the object to be coated and the sprayer mechanism.

The particles are then electrostatically charged, in order that they are attracted to the product being sprayed, which is grounded. The entire process is called Electrostatic, Spray Deposition (ESD). This process takes place in a dust free environment.

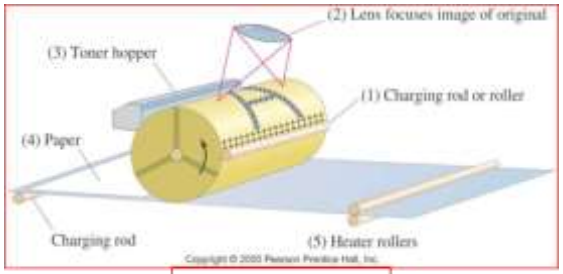


- Spray gun funnels mixture of resin, pigment and additives into the electrode nozzle.
- Particles are electrically charged in electrode nozzle.
- The negatively charged powder particles exit nozzle at a defined speed towards the product/ materials.
- Material is painted with minimal waste.
- Powder coating is a specialist process and is carried out by trained operators. It is applied in a well-ventilated area, by skilled technicians wearing appropriate protective clothing, with goggles and breathing masks.

XEROR Machine to LASER Printers

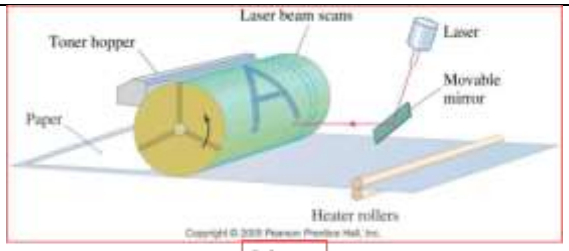
The electrostatic process called as xerography process is what makes the photocopies or print outs.

- The electrostatic process is what makes copies. In the first stage of the xerography process, a negative charge is induced under a thin layer of positively charged selenium.
- The surface of the drum is then exposed to the image to be copied and where the image is light, the positive charge is neutralized, and where the image is dark, the positive charge remains. The image has now been transferred to the drum.



Photocopy Machines

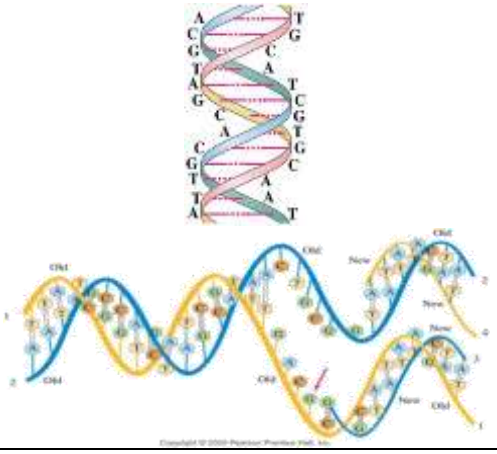
- Then, a dry black powder, called toner, is sprayed with a negative charge, which will be attracted to the positive areas of the drum.
- A blank piece of paper is given a greater positive charge than the drum, so that it will pull the toner from the drum, and finally, the paper and toner are passed through heated rollers that melt and permanently adhere the toner to the paper.
- In laser printers, a laser beam is scanned across a photo conducting drum, which leaves a positively charged image, then the next steps are the same as in xerography. Because laser light can be very precisely controlled, laser printers can produce very high-quality images.
- The electrostatic process is also used in ink jet printers where a nozzle finely sprays tiny ink droplets, which are then given an electrostatic charge. The droplets are directed using pairs of charged plates, and they form letters and images on paper. Color inkjet printers use black, cyan, magenta, and yellow jets.



Printers

Electric Forces in Molecular Biology: DNA Structure and Replication

- **Molecular biology** is the study of the structure and functioning of the living cell at the molecular level.
- The **DNA molecule** is a double helix: The A-T and G-C nucleotide bases attract each other through electrostatic forces.
- **Replication:** DNA is in a "soup" of A, C, G, and T in the cell. During random collisions, A and T will be attracted to each other, as will G and C; other combinations will not.



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

1. https://openpress.usask.ca/physics155/
2. http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html
3. http://hyperphysics.phy-astr.gsu.edu/hbase/electric/elefor.html#c1
4. http://hyperphysics.phy-astr.gsu.edu/hbase/electric/elecur.html#c2
5. https://www.cliffsnotes.com/study-guides/physics/electricity-and-magnetism/electrostatics

Key Take away:

1. Concept of electrostatics
2. Statement of Coulomb's inverse square law
3. Application of Electrostatic force.

Formative Assessments

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

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

Set 1		
Question No 1	Question No 2	Question No 3
In an atom, electric charge is a quantitative polarity of	In electricity, positive electric charge refers to	The force between the two electrically charged body is called
Remembering	Understanding	Understanding
a) electrons	a) protons	a) electromotive force
b) protons	b) neutrons	b) electrostatic force
c) electrons and protons	c) electrons	c) electromagnetic force
d) neutrons	d) atoms	d) magnetic force
Ans: <electrons and protons>	Ans: <protons>	Ans: <electrostatic force>

Set 2		
Question No 1	Question No 2	Question No 3
According to Coulomb's law, the force between two charges separated by a distance is	The relation between ϵ_0, k and ϵ is given by	Determine the force in Newton between 4μC charges separated by 0.1 meter in air.
Remembering	Understanding	Application
a) $F \propto Q_1 \times Q_2$	a) $\epsilon\epsilon_0 = k$	a) 1.44 N
b) $F \propto 1/d^2$	b) $\epsilon_0/\epsilon = k$	b) 14.4 N
c) Both (a) and (b)	c) $\epsilon = \epsilon_0 k$	c) 144 N
d) None of the above	d) $\epsilon_0 = \epsilon k$	d) 1440 N
Ans: <Both (a) and (b)>	Ans: <$\epsilon = \epsilon_0 k$>	Ans: <14.4 N>

Practice Worksheet

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

<S. K. Rawat>

Assessment Type: Practice Worksheets: End of CO: in LMS/ downloadable PDF

A. The study of the effect associated with charges at rest is known as - a) electrostatics b) electro-magnetism c) magnetism d) magnetostatics	B. _____ is CGS unit of charge a) Statcoulomb b) electron volt c) electron unit d) static unit
Ans A:	Ans B:
C. The basic law for interaction of charged bodies at rest is called _____. a) Newton's law b) Gauss law c) Faraday's law d) Coulomb's law	D. The force between two charges placed at a given distance, _____ as ϵ_r of the medium is increased. a) Increases b) decreases c) remains unchanged d) becomes infinite
Ans C:	Ans D:
E. The value of the absolute permittivity of air is _____ a) 8.85×10^{-10} C^2/Nm^2 b) 8.85×10^{-9} C^2/Nm^2 c) 8.85×10^{-12} C^2/Nm^2 d) 8.85×10^{-11} C^2/Nm^2	F. The value of dielectric constant of air is approximately __ a) 0 b) 1 c) 2 d) 3
Ans E:	Ans F:
G. If the relative permittivity of a material is 10, then its permittivity is a) $4\pi \times 10^{-7}$ C^2/Nm^2 b) $4\pi \times 10^{-6}$ C^2/Nm^2 c) 8.85×10^{-11} C^2/Nm^2 d) 8.85×10^{-12} C^2/Nm^2	H. If two equal charges are placed in air at a distance of 1m from each other & if they exert a force of 9×10^9 N on each other, then each charge is said to be of _____. a) 1 C b) 9 C c) 8.85 C d) 1 A
Ans G:	Ans H:
I. Relative permittivity is also known as _____. a) potential gradient b) electric charge c) dielectric constant d) dielectric strength	J. In Coulomb's law equation for force, the value of $1/4\pi\epsilon_0$ is - a) 9×10^9 Nm^2/C^2 b) 9×10^9 C^2/Nm^2 c) 9×10^{-9} Nm^2/C^2 d) 9×10^{-9} C^2/Nm^2
Ans I:	Ans J: