ELECTROSTATICS

Objectives

By the end of this lecture, the learner should be able to:-

a) Describe frictional electricity
b) Distinguish the two types of charges.
c) Describe the concepts of atomic model.
d) Explain the properties of a conductor, insulator and a semiconductor
e) Define and state the units of charge.
f) Describe the quantization of electric charge, charge conservation, electrostatic induction and Coulomb's law.

1.1: Frictional Electricity.

Mankind, as far back as 600 B.C., knew the science of electrification. It was known, for example, that when a material known as amber is rubbed with wool, it acquires the property of attracting light bodies such as paper, straws, etc. However, the observation was not given any importance for about 2000 years. In 1600, William Gilbert discovered that, like amber, several other materials like glass, ebonite, sulfur, etc. also attract some bodies when rubbed. Clearly, this property in the material is developed due to rubbing, i.e., friction. On acquiring this property, the material is said to have acquired an electric charge, or it is electrified, and the cause by which this property is developed is called "frictional electricity." Frictional electricity is also known as "static" electricity since the charge acquired by material cannot flow from one point to another.

SAQ 1: Explain why a rubbed glass or ebonite attracts light bodies?

SAQ 1: What is the other name of Frictional electricity

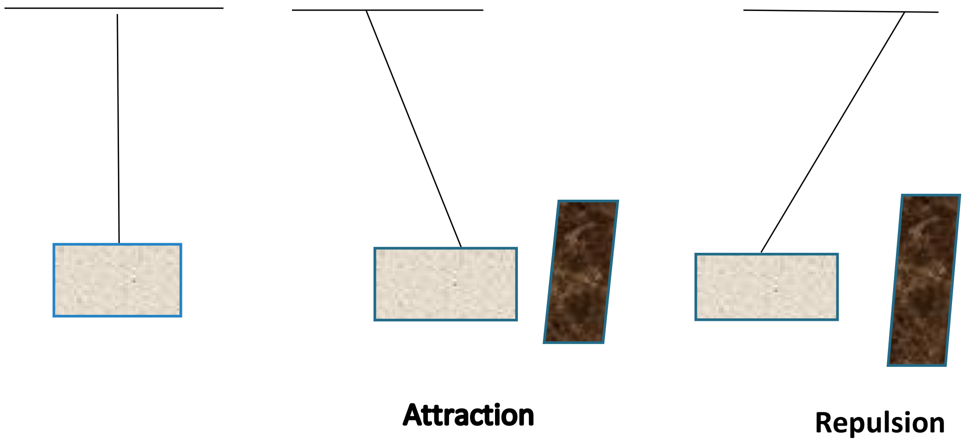
1.2: The two kind of electric charges: Positive and Negative Charges.

It was Benjamin Franklin (1706–1799), an American physicist, who was able to name the kind of electricity that appears on a glass when rubbed with silk as ***positive*** and that electricity that appears when an ebonite rod rubbed with fur *as* ***negative.*** It was also noted that if a glass rod rubbed with silk is suspended by a thread and a second rubbed glass rod is brought nearer to it, the suspended rod moves away from the suspended rod. However, when a rubbed ebonite rod is suspended with a thread and a rubbed glass rod is brought nearer to it, the ebonite rod is attracted towards the glass rod. From the above experiment, it shows that like charges repel each other while opposite charges attract each other

Activity:

Take a small piece of paper and suspend it by a thread. After combing your hair with a plastic comb, bring it closer to the paper and see what happens. First, you will see the paper being attracted to the comb; however, after a few seconds, the paper will move away from the comb. The explanation is that, when the paper is attracted, it acquires the charges from the charged comb. Since the acquired charges are the same as those of the comb, the comb and the paper now have the same charges, and as such, the paper is repelled off the comb. Furthermore, if we suspend two pieces of paper close to each other and a charged comb is brought closer to them, both pieces of paper will be attracted, and after a few seconds, both papers will be repelled by the comb. At the same time, both papers will also repel each other.

The force of attraction or repulsion between two like or unlike charges is called the Coulomb force.



1) Name the two types of charges.
2) What kind of charge does a rubbed glass require
3) What kind of charge does a rubbed ebonite require

1.3: Atomic model of electrification.

The modern explanation of the electrification of material is based on the atomic or electron model. According to this model, every material is made up of atoms. Every atom has an extremely small central portion called the nucleus, which consists of particles called protons and neutrons. The protons are positively charged, and the neutrons have no charge. Thus, the nucleus is positively charged. Around the nucleus revolves a third kind of particle called electrons in different orbits. The electrons have a negative charge equal to the charge of protons in the nucleus. Hence, an atom is electrically neutral since the number of positive charges is equal to the number of negative charges.

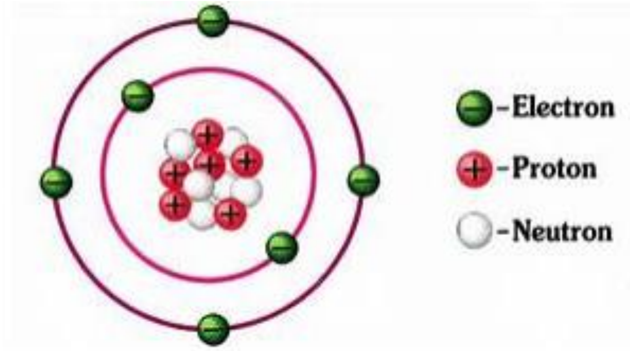


Fig1.2

- ❖ If we extract one or more electrons from an atom, the atom becomes positively charged. Thus, a positively charged body means a lack or deficiency of electrons in the body. The number of positive charges is now greater than the number of negative charges. Conversely, if we add one or more extra electrons, it becomes negatively charged. That is, the body has more or an excess number of electrons than the number of protons in the nucleus. Therefore, by rubbing a body to produce negative or positive charges on another body, we are either extracting electrons from the body or adding extra electrons to the body. The protons cannot be removed from the nucleus.

Charging by Friction

When a glass rod is rubbed by silk, a few electrons from the atom of the glass migrate to the silk. Thus, there is a deficiency of electrons in the glass and an excess of electrons in the silk. Hence, the glass rod becomes positively charged while the silk becomes negatively charged. Similarly, when an ebonite is rubbed with cat skin (fur), a few electrons from the fur migrate to the ebonite. Hence, the ebonite has excess electrons and becomes negatively charged, while the fur, due to a deficiency in the electrons, becomes positively charged.

SAQ

1) Explain why an atom is electrically neutral.
2) Using the atomic model, describe the process of electrification?
3) What do we mean when we say that, a body has excess electrons?
4) What do we mean when we say that, a body has deficiency of electrons and how does it come about?

1.4: Conductors, Insulators and Semiconductors

Electrically, most materials are categorized into conductors and insulators. We then define a conductor as a material in which charges can freely flow through it. Materials such as metals, the human body, water, earth, liquid mercury, and electrolytes are conductors.

As we have explained earlier, in metals, only the negative charge is free to move, but the positive charge is immobile. Therefore, the charge carriers in metals are electrons. In metals, of course, the outermost electrons of the atoms leave the atoms and become free to move throughout the volume of the metal. In electrotypes, however, both the positive and negative charges are free to move.

Substances in which electrons cannot move freely are called insulators. Some of these insulators are glass, plastic, dry wood, and rubber.

There are some substances whose electrical conductivities are intermediate between conductors and insulators. These kinds of materials are called semiconductors. Silicon and germanium are some of the materials that are semiconductors. Their conductivity can be greatly improved by adding some traces of impurities, a phenomenon known as doping.

SAQ

1) How can we differentiate a conductor from an insulator?
2) Define a semiconductor.
3) How can we increase the conductivity of an insulator?

1.5 Unit of electric charge.

The 'Meter', 'Kilogram', Second, and 'Ampere' (MKSA) units of measurement are the fundamental units of length, mass, time, and electric current, respectively. Hence, the MKSA unit of charge is the coulomb, and its symbol is C. As we shall learn later, the rate of flow of charge through a conductor is called electric current. That is

$$\boldsymbol{Electric\ current, I = \frac{Charge(Q)}{Time(t)}}$$

$$\boldsymbol{or\ Charge = Current \times Time}$$

If a conductor carries a current of 1 ampere for 1 second, then charge flow through the conductor will be 1 coulomb.

$$\boldsymbol{1\ coulomb\ =\ 1\ ampere/second}$$

$$\boldsymbol{Or\ 1c = 1As^{-1}}$$

An electron has $1.6 \times 10^{-19}C$ of negative charge. Hence if a body has an excess of 1 electron than its normal state, then it will have $1.6 \times 10^{-19}C$ of negative charge.

Similarly, when a body has a deficiency of 1 electron, it will have $1.6 \times 10^{-19}C$ of positive charge. Thus the number of charge on a body can expressed in terms of the number of electrons.

1.6: Quantization of charge.

The term quantization will be better explained when we come to modern physics at later stages of our degree program. However, here, we shall give a very simple definition of it. When Millikan performed his experiment on oil drops and many others have done the same, it has been established that, in nature, electric charges are found **as integral multiples of small amounts of charge**. The smallest amount is denoted by $\boldsymbol{e}$ and is the charge of the electron. All existing charges are found to be integral multiples of ***e*,** that is, ***ne***. Where *n* is a positive or negative number, such as ***e*, 2*e*, 3*e*,...** No charge is found *as a* fraction of ***e*** **(as 0.7*e* or 2.5*e*)**. It means that, electric charge cannot be divided indefinitely. The discrete nature of charges is the property called **quantization.** If the charges were continuous, then the principle of quantization would not come in.

SAQ
Explain why charges are quantized?

1.7 Conservation of Charge.

In electrostatics, the number of charges in an isolated system remains constant. Charges may, however, be transferred from one part of the system to another, but the net charge will always remain constant. It means that charges cannot be created or destroyed. This is the law of conservation of charge.

SAQ
Describe the principle of charge conservation

1.9: Coulomb's Law.

We have stated that opposite (unlike) charges attract each other, while like charges repel each other. Thus, it is evident that a force of some form acts between two charges. This force is called 'electric force'. The force between like charges is repulsive, and that between two unlike charges is attractive.

In 1785, on the basis of experiments, Michael Coulomb gave a law regarding force acting between two charges. According to Coulomb, ***two stationary charges repel or attract each other***

with a force F, which is directly proportional to the product of the charges and inversely proportional to the square of the distance r between them.

As shown in Fig. 1.4 below, if ***the*** two charges are separated by a distance r, then the force between them is

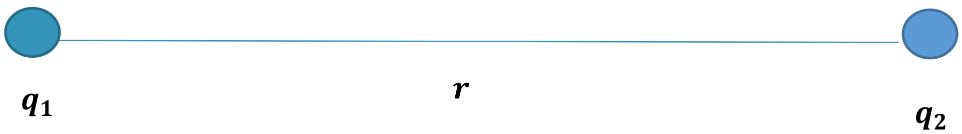


Fig.1.4. Two points charges $\boldsymbol{q_1}$ and $\boldsymbol{q_2}$ separated by distance r.

$$F \propto \frac{\boldsymbol{q_1 q_2}}{\boldsymbol{r^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{1.1}$$

When the charges are placed in vacuum (or air), then we write (1.1) as

$$F = \frac{1}{4\pi\epsilon_0}\frac{\boldsymbol{q_1 q_2}}{\boldsymbol{r^2}}$$

Where $1/4\pi\varepsilon_0$ is a dimensional quantity and is the constant of proportionality which depends on the units used for charges, distant between the charges and the force attained. Thus,

$$\boldsymbol{\frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9 \frac{Nm^2}{C^2}}$$

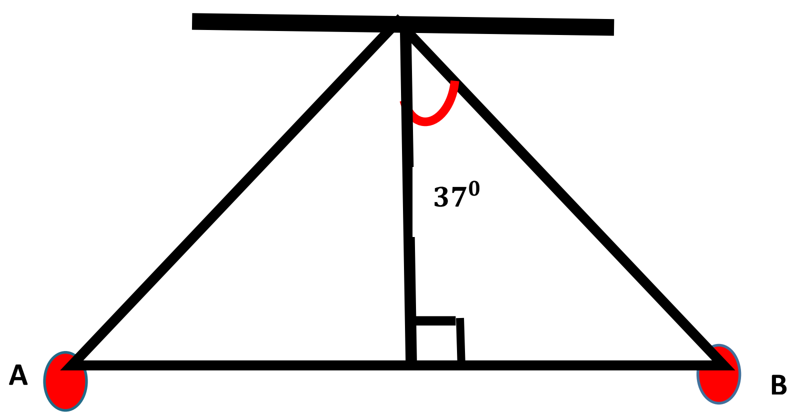
The constant $\boldsymbol{\varepsilon_0}$ (epsilon subzero) is called the 'permittivity of free space' and its value is $\boldsymbol{8.85\ x10^{-12}(C^2/(N-m^2)}$ or Farads/meter. The force F acts along the line joining the two charges $\boldsymbol{q_1}$ and $\boldsymbol{q_2}$.

The electric force, like any other vector quantity, obeys the principle of ***superposition***, that is, the resultant force is **equal to the vector sum of the individual force acting on the charged particles**.

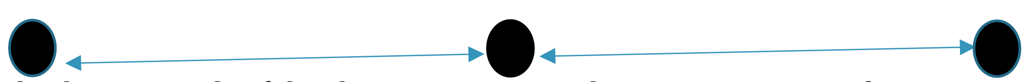
Revision Questions

1. What must be the distance between two point charges for the electrostatic force between them to have a magnitude of 5.70N? Assume each charge carries $4\mu C$.

2. In the return stroke of a typical lightning bolt, a current of 25000A exists for 20 S .How much charge is transferred in this event. How many electrons are involved in this process?
3. A positively charged ball is brought close to an electrically neutral, isolated conductor. The conductor is then grounded while the ball is kept close. Is the conductor charged positively, negatively, or neutrally if (a) the ball is first taken away and then the ground connection is removed and (b) the ground connection is first removed and then the ball is taken away?
4. Two tiny, identical metal balls of 10g each carrying equal positive charges are suspended from a 1 m-long string. These balls repel each other and then come to equilibrium, making an angle of 37 degrees with the vertical as shown in the figure below. Calculate the charge on each ball.



1. Calculate the net force on the charge q_3 due to charges q_1 **and** q_1 **as shown in the fig.**



Take the magnitude of the charge q_1, q_2, q_3 to be -4μC,$+4\mu$C,$and - 4\mu$C respectively

SUMMARY

- Frictional electricity is the property in which a body acquires electric charge when rubbed. Glass, ebonite, and sulfur acquire electric charge when rubbed.

- There are two types of electric charges, namely, positive and negative charges. It has been established that silk, when rubbed, acquires a positive charge, while ebonite, when rubbed, acquires a negative charge.
- An atom is said to be electrically neutral when the number of positive charges (protons at the nucleus) is equal to the number of negative charges (electrons orbiting around the nucleus).
- Conductors: These are the materials in which the charges can move freely through them, e.g., metals, human bodies, electrolytes, etc.
- Insulators: These are the materials in which the charges cannot move freely, e.g., wood, rubber, plastic, etc.
- Semiconductors: These are materials whose electric conductivities are intermediate between conductors and insulators, e.g., silicon and germanium, etc.
- Materials that are oppositely charged attract each other, while those with the same charges repel each other. In other words, unlike charges attract each other, while like charges repel each other.
- Charges are said to be quantized because they exist as integral multiples of the charge of a fundamental particle.
- The principle of conservation of charges states that charges cannot be created or destroyed.
- Charging by induction is the process by which a charged body is brought closer to an uncharged body. Hence, the uncharged cannot become charged after being earthed.
- Coulomb's Law states that the force between two charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between the two charges.