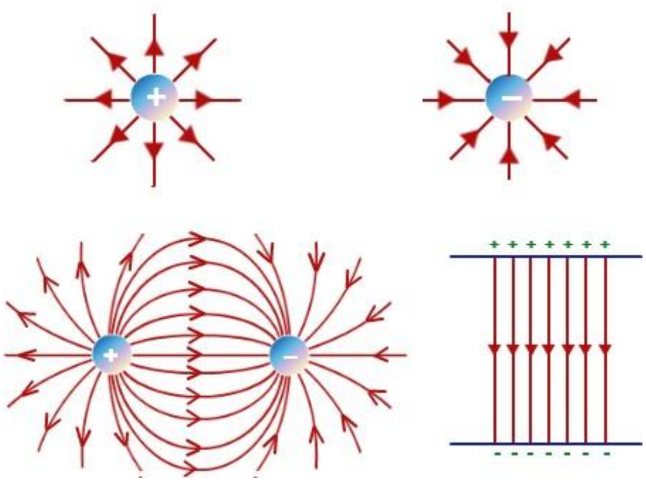
**Physical significance of electric field**

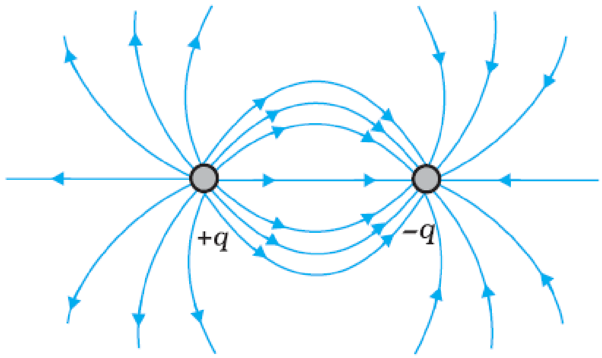
Electric field is an elegant way of characterising the electrical environment of a system of charges. Electric field at a point in the space around a system of charges tells you the force a unit positive test charge would experience if placed at that point (without disturbing the system). Electric field is a characteristic of the system of charges and is independent of the test charge that you place at a point to determine the field.
Suppose we consider the force between two distant charges $q_1$,$q_2$ in accelerated motion.There will be some time delay between the effect(force on $q_2$) and the cause (motion of $q_1$).
The field picture is, the accelerated motion of charge $q_1$ produces electromagnetic waves, which then propagate with the speed 'c', reach $q_2$and cause a force on $q_2$. The notion of field elegantly accounts for the time delay.

**Properties of electric field lines**



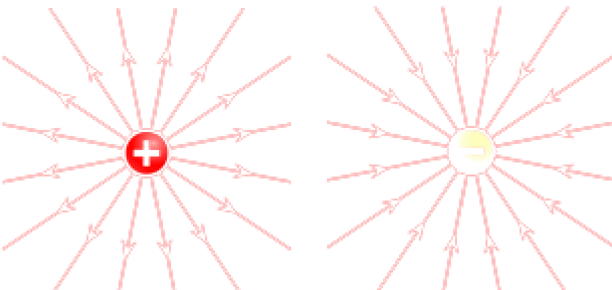
The field lines follow some important general properties:
(i) Field lines start from positive charges and end at negative charges. If there is a single charge, they may start or end at infinity.
(ii) In a charge-free region, electric field lines can be taken to be continuous curves without any breaks.
(iii) Two field lines can never cross each other. (If they did,the field at the point of intersection will not have a unique direction, which is absurd.)
(iv) Electrostatic field lines do not form any closed loops.

**Electric field lines**



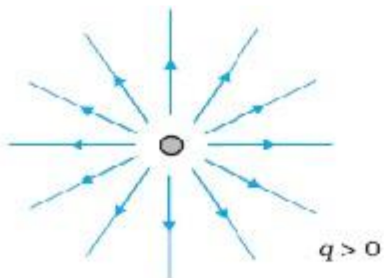

An electric field line is, in general, a curve drawn in such a way that the tangent to it at each point is in the direction of the net field at that point. An arrow on the curve is obviously necessary to specify the direction of electric field from the two possible directions indicated by a tangent to the curve. A field line is a space curve, i.e., a curve in three dimensions.

**Electric Field due to point charges**

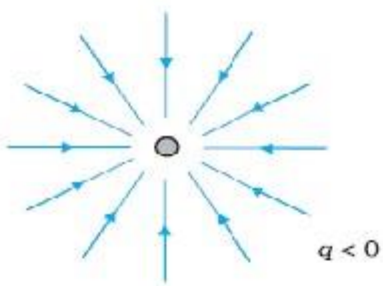


These pattern of **lines**, sometimes referred to as **electric field lines**, **point** in the direction that a positive test **charge** would accelerate if placed upon the **line**. As such, the **lines** are directed away from positively **charged** source **charges** and toward negatively **charged** source **charges**

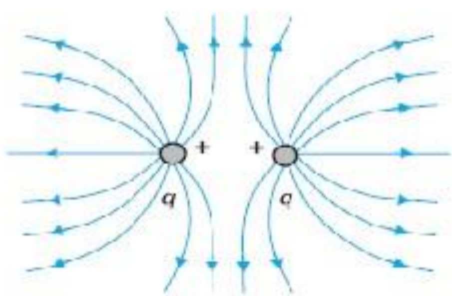
**Electric field lines of simple configurations**



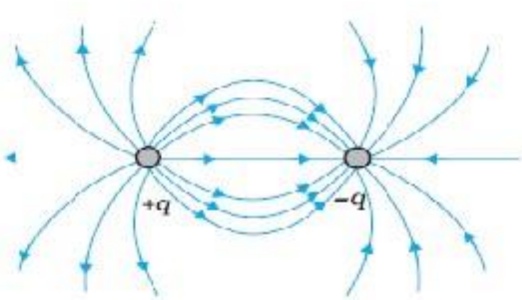

(a)



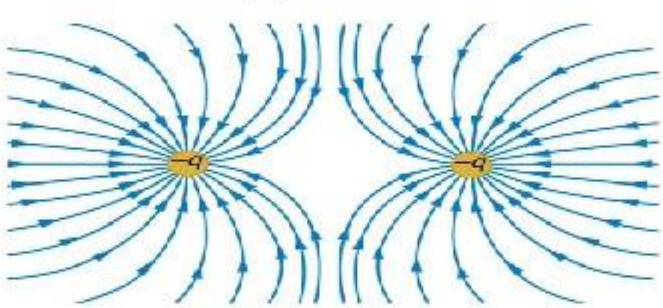

(b)



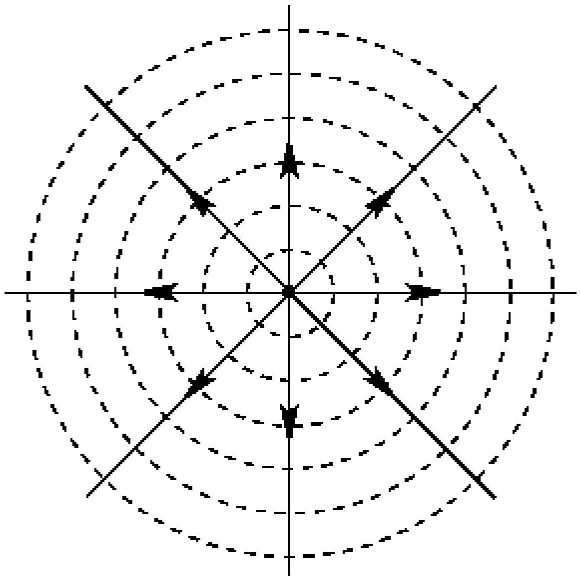

(c)




(d) .



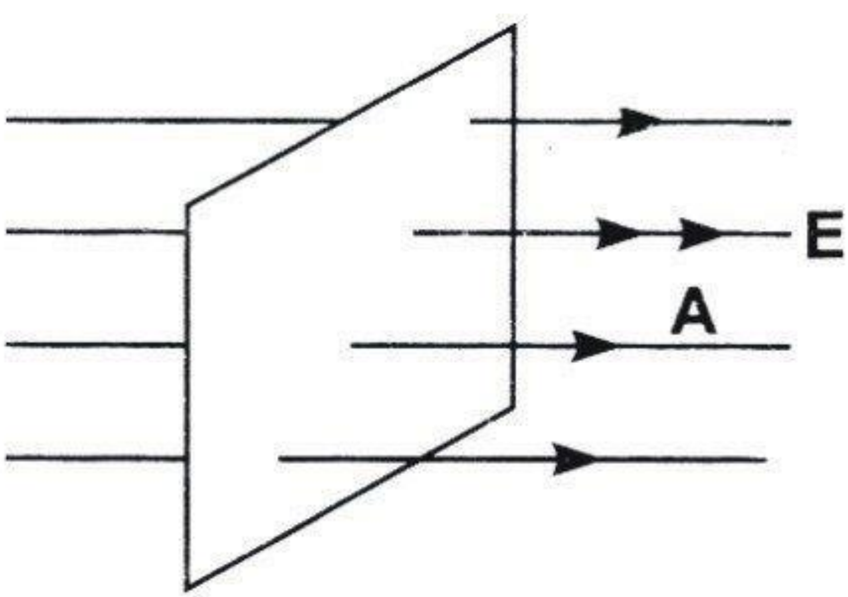
**Density of electric field lines**



Magnitude of electric field strength is higher where density of electric field lines in space is more. The attached figure shows the electric field lines due to a positive point charge. Its field lines are directed radially outwards from the point charge and the dotted lines show the locus of points with same magnitude of electric field.

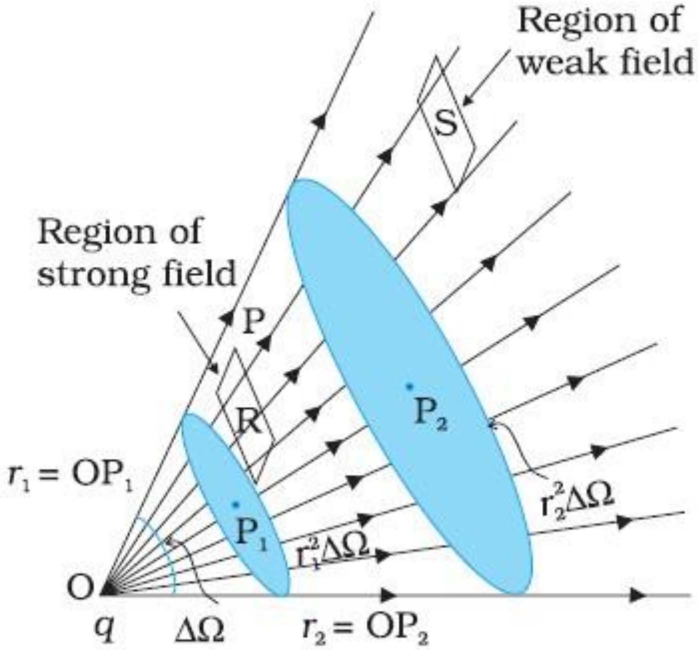
Since, $E \propto \frac{1}{r^2}$ for a point charge, it is larger near the charge. This behaviour is consistent in the electric field lines of point charge.

**Electric flux**



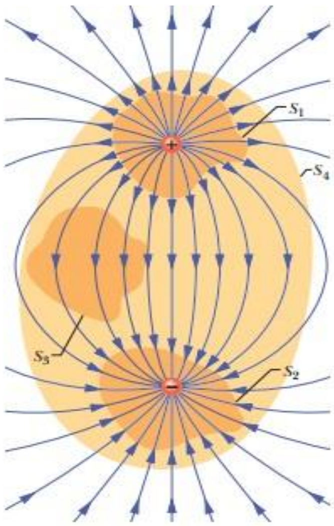
**Electric flux** is the measure of flow of the **electric** field through a given area. **Electric flux** is proportional to the number of **electric** field lines going through a normally perpendicular surface.

**Relation between electric field lines and flux across a surface**




The field lines carry information about the direction of electric field at different points in space. Having drawn a certain set of field lines, the relative density (i.e., closeness) of the field lines at different points indicates the relative strength of the electric field at those points. The field lines are crowded where the field is strong and are spaced apart where it is weak.
While electric flux is the measure of the flow of the electric field through a given area. It is proportional to the number of electric field lines passing normally through a perpendicular surface.

**Application of Gauss law**




Two charges, equal in magnitude but opposite in sign, and the field lines that represent their net electric field. Four Gaussian surfaces are shown in cross section. Surface $S_1$ encloses the positive charge. Surface $S_2$ encloses the negative charge. Surface $S_3$ encloses no charge. Surface $S_4$ encloses both charges and thus no net charge.

Fig, which shows two particles, with charges equal in magnitude but opposite in sign, and the field lines describing the electric fields the particles set up in the surrounding space. Four Gaussian surfaces are also shown, in cross section. Let us consider each in turn

**Surface 1 -** The electric field is outward for all points on this surface. Thus, the flux of the electric field through this surface is positive, and so is the net charge within the surface, as Gauss law requires.

**Surface 2** - The electric field is inward for all points on this surface.Thus, the flux of the electric field through this surface is negative and so is the enclosed charge, as Gauss law requires.

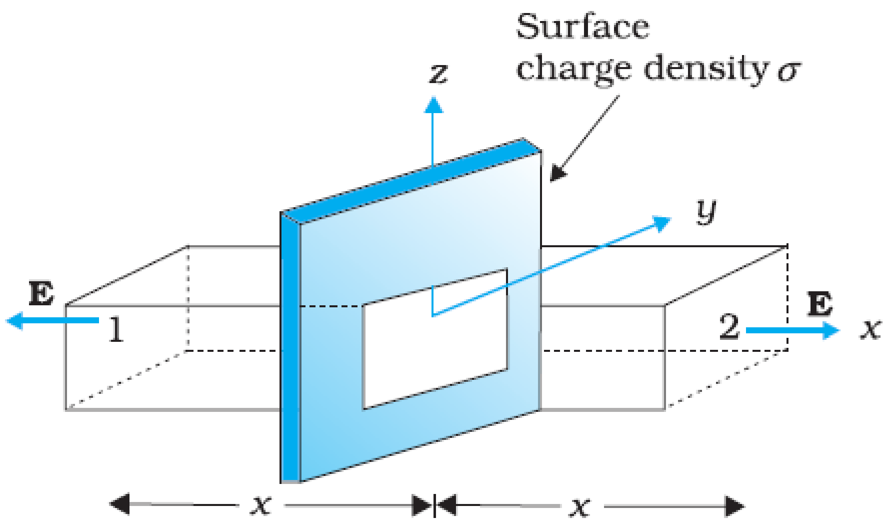
**Surface 3** - This surface encloses no charge, and thus$q_{enclosed}=0$. Gauss law requires that the net flux of the electric field through this surface be zero. That is reasonable because all the field lines pass entirely through the surface, entering it at the top and leaving at the bottom.

**Surface 4** - This surface encloses no net charge, because the enclosed positive and negative charges have equal magnitudes. Gauss law requires that the net flux of the electric field through this surface be zero. That is reasonable because there are as many field lines leaving surface $S_4$ as entering it.

What would happen if we were to bring an enormous charge Q up close to surface $S_4$ in Fig.? The pattern of the field lines would certainly change, but the net flux for each of the four

Gaussian surfaces would not change. Thus, the value of Q would not enter Gauss law in any way, because Q lies outside all four of the Gaussian surfaces that we are considering.

**Gaussian surface**




Gaussian surface for a
uniformly charged infinite plane sheet.

The surface that we choose for the application of Gauss's law is called the Gaussian surface.The Gaussian surface doesn't pass through any discrete charge. This is because electric field due to a system of discrete charges is not well defined at the location of any charge.However, the Gaussian surface can pass through a continuous charge distribution.

**Explain continuous distribution of charges**

In a continuous charge distribution, all the charges are closely bound together i.e. having very less space between them. But this closely bound system doesnt means that the electric charge is uninterrupted. It clears that the distribution of separate charges is continuous, having a minor space between them.

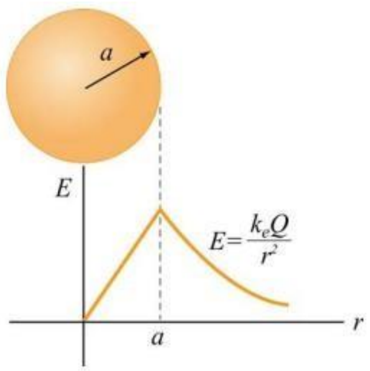
**Uniform Charge distribution**

When the charge is not accumulated in some part but is spread uniformly then it is called uniform charge distribution

**Non uniform charge distribution**

If charge is non uniformly spread over the surface then it is non uniform distribution of charges.

**Electric field intensity vs distance for a charged non-conducting sphere**




Electric field due to a uniformly charged sphere as a function of $r$

**Equipotential surfaces**

Surfaces having same potential are termed as equipotential surfaces
The properties of equipotential surfaces can be summarized as follows:

The electric field lines are normal to the equipotentials and are directed from higher to lower potentials.
By symmetry, the equipotential surfaces produced by a point charge form a family of concentric spheres, and for a constant electric field, a family of planes normal to the field lines.
The tangential component of the electric field along the equipotential surface is zero, otherwise non-vanishing work would be done to move a charge from one point on the surface to the other.
Work done in moving a particle along an equipotential surface is zero.

**Electric dipole**
An electric dipole is a pair of equal and opposite point charges -q and q, separated by a distance 2a. The direction from q to -q is said to be the direction of the dipole.
$p=q\times 2a$
where $p$ is the electric dipole moment pointing from the negative charge to the positive charge.

**Electrostatic field is zero inside a conductor**

Consider a conductor, neutral or charged. There may also be an external electrostatic field. In the static situation, when there is no current inside or on the surface of the conductor, the electric field is zero everywhere inside the conductor. This fact can be taken as the defining property of a conductor.

A conductor has free electrons. As long as electric field is not zero, the free charge carriers would experience force and drift. In the static situation, the free charges have so distributed themselves that the electric field is zero everywhere inside. Electrostatic field is zero inside a conductor.

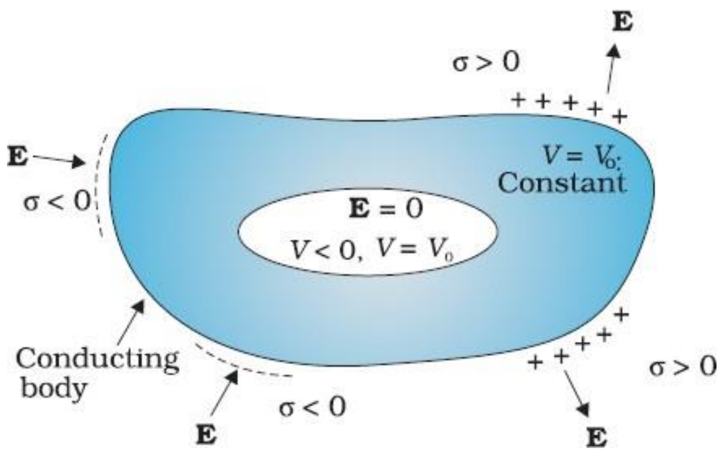
**At the surface of a charged conductor, electrostatic field must be normal to the surface at every point**

If E were not normal to the surface, it would have some non-zero component along the surface. Free charges on the surface of the conductor would then experience force and move. In the static situation, therefore,E should have no tangential component. Thus electrostatic field at the surface of a charged conductor must be normal to the surface at every point. (For a conductor without any surface charge density, field is zero even at the surface.)

**The interior of a conductor can have no excess charge in the static situation**

A neutral conductor has equal amounts of positive and negative charges in every small volume or surface element. When the conductor is charged,the excess charge can reside only on the surface in the static situation.This follows from the Gauss's law. Consider any arbitrary volume element v inside a conductor. On the closed surface S bounding the volume element v, electrostatic field is zero. Thus the total electric flux through S is zero. Hence, by Gauss's law, there is no net charge enclosed by S. But the surface S can be made as small as you like, i.e., the volume v can be made vanishingly small. This means there is no net charge at any point inside the conductor, and any excess charge must reside at the surface.

**Electrostatic potential is constant throughout the volume of the conductor and has the same value (as inside) on its surface**




Since E = 0 inside the conductor and has no tangential component on the surface, no work is done in moving a small test charge within the conductor and on its surface. That is, there is no potential difference between any two points inside or on the surface of the conductor. Hence, the result. If the conductor is charged,electric field normal to the surface exists; this means potential will be different for the surface and a point just outside the surface.In a system of conductors of arbitrary size, shape and charge configuration, each conductor is characterised by a constant value of potential, but this constant may differ from one conductor to the other.

**Describe the uses of Van de Graaff Generator**

Small Van de Graaff machines are produced for entertainment, and in physics education to teach electrostatics; larger ones are displayed in science museums.

**Electrostatic shielding**

Whatever be the charge and field configuration outside, any cavity in a conductor remains shielded from outside electric influence: the field inside the cavity is always zero. This is known as electrostatic shielding.

**Van de Graff generator**

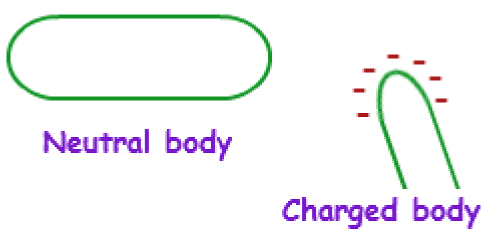
A Van de Graaff generator is an electrostatic generator which uses a moving belt to accumulate electric charge on a hollow metal globe on the top of an insulated column, creating very high electric potentials. It produces very high voltage direct current (DC) electricity at low current levels.

A simple Van de Graaff generator consists of a belt of rubber (or a similar flexible dielectric material) running over two rollers of differing material, one of which is surrounded by a hollow metal sphere. Two electrodes, in the form of comb-shaped rows of sharp metal points, are positioned near the bottom of the lower roller and inside the sphere, over the upper roller. One comb is connected to the sphere, and another comb to ground. The method of charging is based on the triboelectric effect, wherein simple contact of dissimilar materials causes the transfer of some electrons from one material to the other.

**Uses of Van de Graff generator**

The **Van de Graff** generator was developed as a particle accelerator in physics research, its high potential is used to accelerate subatomic particles to high speeds in an evacuated tube. It was the most powerful type of accelerator in the 1930s until the cyclotron was developed. Today it is still used as an accelerator to generate energetic particle and x-ray beams in fields such as nuclear medicine.

**Introduction to Charged and Uncharged Bodies**




**Charged Body :**

A body which possess charge is called charged body. But this charge may be either positive or negative.

Depending upon the nature of charge, a charged body may be classified as follow :

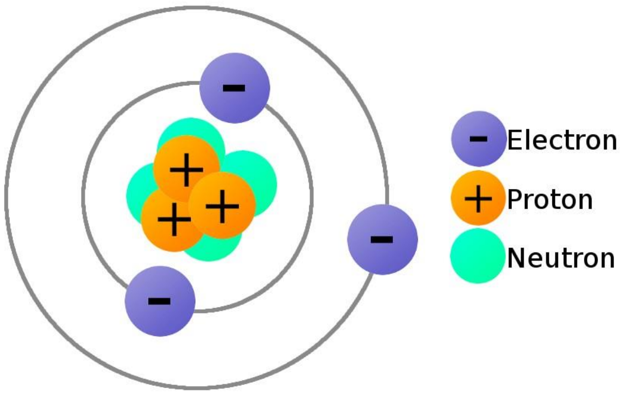
**Positively Charged Body :** A body with more number of proton is known as positively charged body.

**Negatively Charged Body :** A body with more number of electrons is known as negatively charged body

**Uncharged Body :**

A body which is electrically neutral is called as an uncharged body. They have equal negative and positive charge. As a result, they remain neutral.

**Electrons, Protons and Neutrons**




The atom is made of 3 types of particles. They are:

(i) electrons (ii) protons (iii) neutrons. The electron is negatively charged, the proton is positively charged and the neutron has no charge, it is neutral.

**Comparision Between Electron, Proton and Neutron**

Properties of Subatomic Particles

| Name | Location | Charge (C) | Unit Charge | Mass (amu) | Mass (g) |
|---|---|---|---|---|---|
| electron | outside nucleus | $-1.602 \times 10^{-19}$ | 1− | 0.00055 | $0.00091 \times 10^{-24}$ |
| proton | nucleus | $1.602 \times 10^{-19}$ | 1+ | 1.00727 | $1.67262 \times 10^{-24}$ |
| neutron | nucleus | 0 | 0 | 1.00866 | $1.67493 \times 10^{-24}$ |

**Simple Electrostatic Phenomenon From Our Daily Life**

The attraction of plastic wrap to our hand after we remove it from a package.

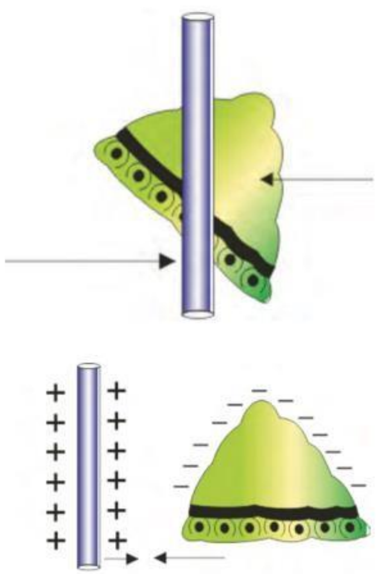
**Simple Electrostatic Phenomenon From Our Daily Life**

Charging of a plastic comb after combing.

**Common electrostatic phenomenon**

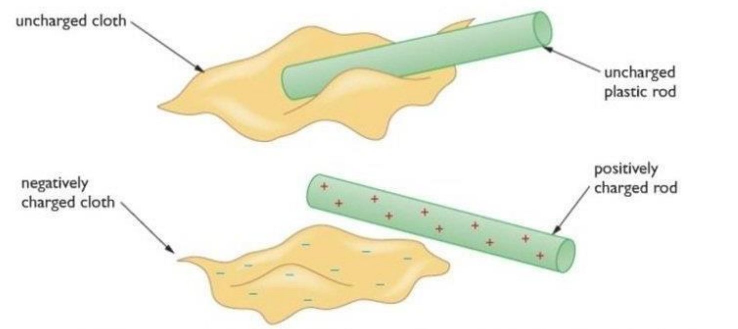
Lightning

**Charging By Friction**




When an object is rubbed with another object, the atoms in the objects get rubbed and a transfer of electrons takes place between the atoms of the two objects. One object loses electrons, while the other gains electrons. Thus, the gain of electrons or loss of electrons makes both the objects charged.

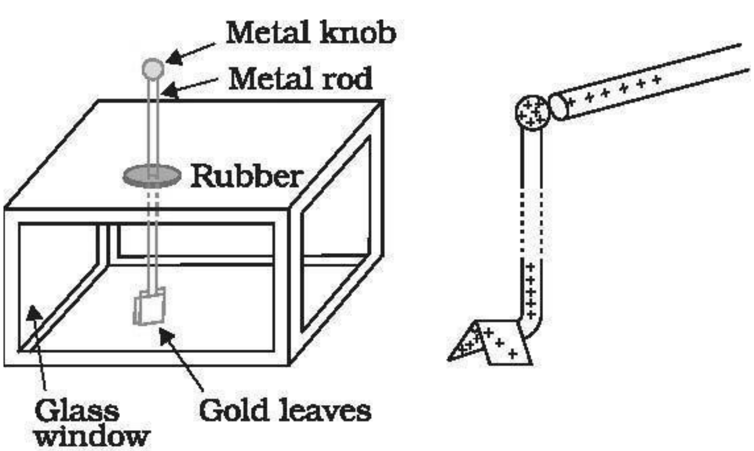
**Charging by friction**




*Rubbing a neutral rod with a neutral piece of cloth can result in them both becoming charged.*

By using the method of friction, positive charge is developed on one of the bodies and negative charge on the other. When these two bodies are brought close, they attract.
Some objects have tendency to gain positive charge (example glass and ebonite rod) while some objects have the tendency to gain negative charge(example silk).

**Construction and Working of Gold Leaf Electroscope**




**Gold Leaf Electroscope :**
It is a simple device to detect the presence of charge on any body.
**Construction :**
It consists of a metal rod which is fitted in an insulating box. Metal rod has a metal knob at its top. Two gold leaves are also attached at the bottom end of the rod.
**Working :**
Since electroscope is used to detect the presence of charge. So through it we can find whether a

body is charged or uncharged.
Therefore the body to be detected is brought close enough to the metal knob. When a charged object touches the knob at the top of the rod, charge flows through the rod on to the leaves.
Both the gold leaves will have same charge and hence as a result they will repel and diverge.
The degree of divergence is an indicator of the amount of charge i.e., more the charge, more will be the divergence.

#### Applications of Gold Leaf Electroscope

These are some of the applications of Gold Leaf Electroscope :

**1.Detect charge :**

Body under test is touched with the metal cap. If the leaves diverge, the body is charged and if there is no effect on leaves, then the body is uncharged.

**2.To identify the nature of charge :**

The electroscope is charged by a known body(say positively charged body) and then the body is removed. Next, the body under test is brought in contact with the metal cap. If the leaves diverge further, the body has same charge(positive) and if the leaves come closer to each other, the body has opposite charge(negative).

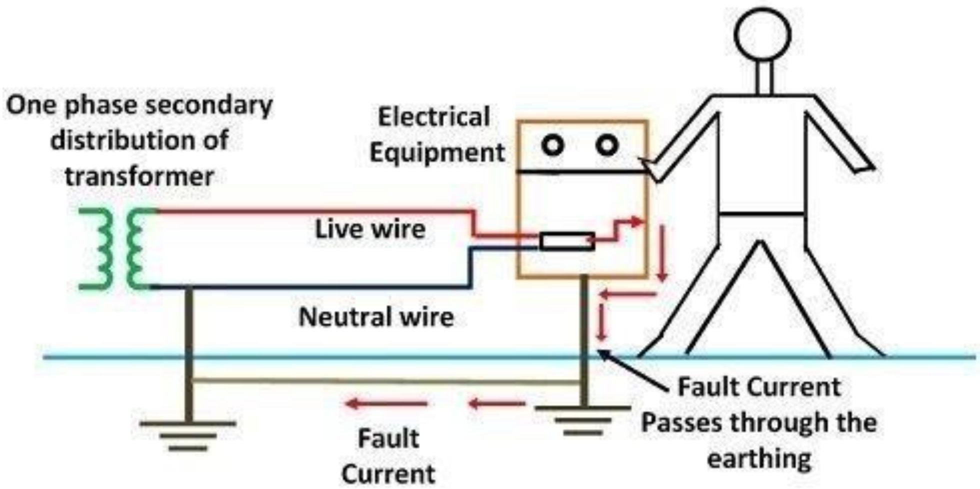
**3.Identify a body as conductor or insulator :**

Take two electroscopes. Charge one of the electroscopes so that its leaves will diverge. Then, connect the two electroscopes by the object under test. If the leaves of other electroscope diverge, the body is a conductor and if there is no effect on the electroscopes, the body is an insulator.

#### Discharging

When a charged body comes into contact with a body which is not charged, the electric charges jump from the charged body to the uncharged body till the charges on both the bodies become equal. This process is called **discharging**.

**Process of Earthing and its Advantages**



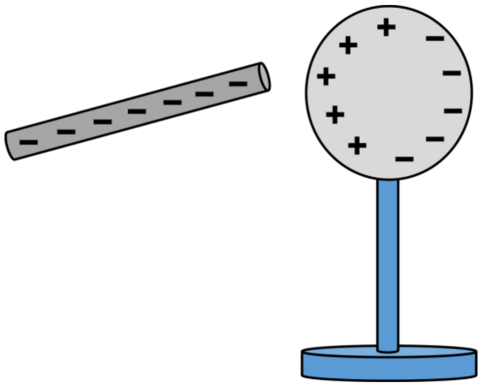

Electrical System With Earthing

When we bring a charged body in contact with the earth, all the excess charge on the body disappears by causing a momentary current to pass to the ground through the connecting conductor (such as our body). This process of sharing the charges with the earth is called grounding or earthing.

Earthing provides a safety measure for electrical circuits and appliances. A thick metal plate is buried deep in the earth and thick wires are drawn from this plate. These are used in buildings for the purpose of earthing near the mains supply.

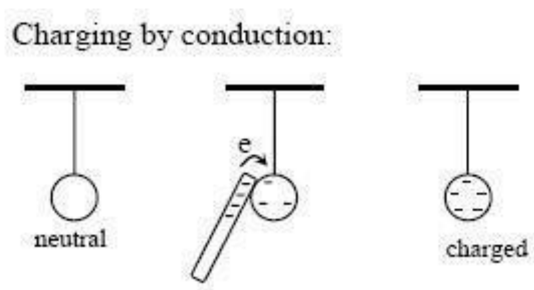
The electric wiring in our houses has three wires: live, neutral and earth. The first two carry electric current from the power station and the third is earthed by connecting it to the buried metal plate. Metallic bodies of the electric appliances such as electric iron, refrigerator, TV are connected to the earth wire. When any fault occurs or live wire touches the metallic body, the charge flows to the earth without damaging the appliance and without causing any injury to the humans; this would have otherwise been unavoidable since the human body is a conductor of electricity.

**Electrostatic Induction**



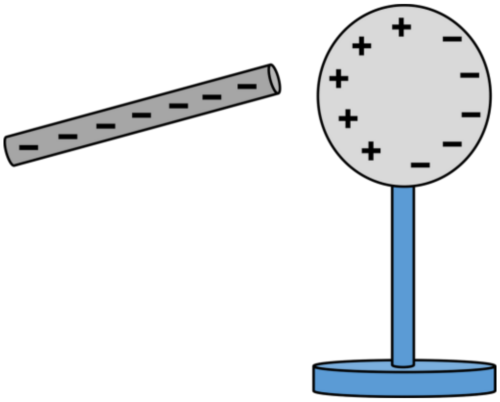
When an uncharged object is placed very close to a charged conductor without touching, the nearer end acquires a charge opposite to the charge on the charged conductors and the two bodies attract. This is called charging by induction. The net charge on the bodies remains the same and body is charged until they are kept close or brought in contact.

**Charging by Conduction**




Charging by conduction involves the contact of a charged object to a neutral object. Hence when an uncharged conductor is brought in contact with a charged conductor, charge is shared between the two conductors and hence the uncharged conductor gets charged.
During charging by conduction, both objects acquire the same type of charge.

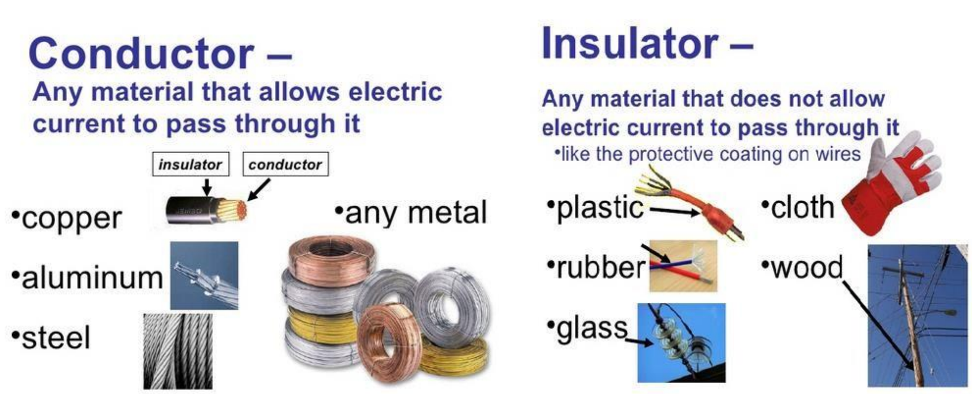
**Charging by Induction**



In this process, a charged object is brought near but not touched to a neutral conducting object. The presence of a charged object near a neutral conductor will induce (force) electrons within the conductor to move.

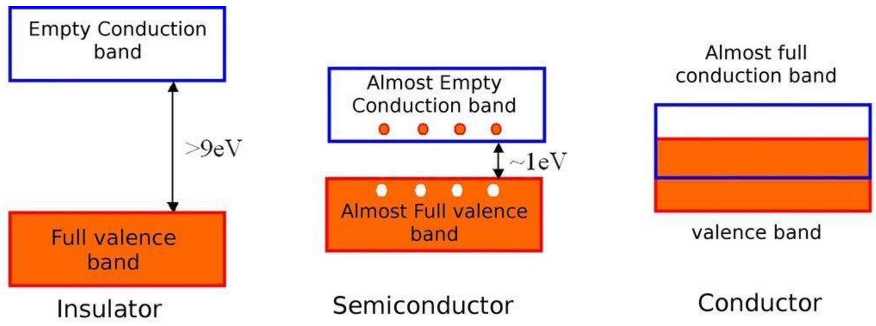
The movement of electrons leaves an imbalance of charge on opposite sides of the neutral conductor. While the overall object is neutral (i.e., has the same number of electrons as protons), there is an excess of positive charge on one side of the object and an excess of negative charge on the opposite side of the object.

**Examples of conductors and insulators**




Examples of conductors are metals(silver, copper and aluminium, etc), mercury, earth, etc. Examples of insulators are non-metals (plastic, glass, pure water, sulphur, etc). Some exceptions that are non-metals but not insulators are graphite and tap water.

**Band Gap For Conductor, Semiconductor and Insulator**



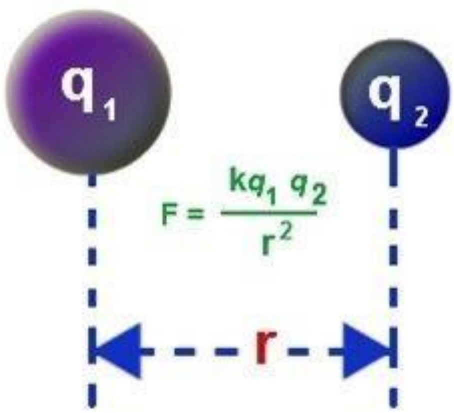

**Comparision Between Conductors, Insulators and Semiconductors**

| S.No | Conductors | Semiconductors | Insulators |
|---|---|---|---|
| 1 | Easily conducts the electrical current. | Conducts the electric current less than conductor and greater than insulator. | Does not conduct any current. |
| 2 | Has only one valence electron in its outermost orbit. | Has four valence electron in its outermost orbit. | Has eight valence electron in its outermost orbit. |
| 3 | Conductor formed using metallic bonding. | Semiconductors are formed due to covalent bonding. | Insulators are formed due to ionic bonding. |
| 4 | Valence and conduction bands are overlapped. | Valence and conduction bands are separated by forbidden energy gap of 1.1eV. | Valence and conduction bands are separated by forbidden energy gap of 6 to 10eV. |
| 5 | Resistance is very small | Resistance is high | Resistance is very high |
| 6 | It has positive temperature coefficient | It has negative temperature coefficient | It has negative temperature coefficient |
| 7 | Ex: copper,aluminium,etc | Ex: silicon, germanium, etc | Ex: Mica, Paper, etc |

**Conductors, insulators and semiconductors**

| Conductors | Insulators | Semiconductors |
|---|---|---|
| There are no band gaps. | Large gap between the lower energy levels (the valence band) and the upper conduction band. | The gap between the valence band and conduction band is smaller. |
| Electrons can move easily using a continuous, partially filled conduction band. | The valence band is full as no electrons can move up to the conduction band which is empty as a result.The material can't conduct as only the electrons in a conduction band can move easily. | At room temperature there is sufficient energy available to move some electrons from the valence band into the conduction band allowing some conduction to take place. |

**Electrostatic force**




Electrostatic force is the force between two charged particles. It is more when the amount of charge on bodies is more and when distance between the charges is small.
Similar charges repel each other while opposite charges attract each other.