

# Chapter One

## ELECTRIC CHARGES AND FIELDS

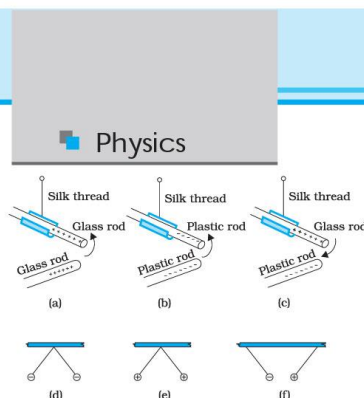


### 1.1 INTRODUCTION

All of us have the experience of seeing a spark or hearing a crackle when we take off our synthetic clothes or sweater, particularly in dry weather. This is almost inevitable with ladies garments like a polyester saree. Have you ever tried to find any explanation for this phenomenon? Another common example of electric discharge is the lightning that we see in the sky during thunderstorms. We also experience a sensation of an electric shock either while opening the door of a car or holding the iron bar of a bus after sliding from our seat. The reason for these experiences is discharge of electric charges through our body, which were accumulated due to rubbing of insulating surfaces. You might have also heard that this is due to generation of static electricity. This is precisely the topic we are going to discuss in this and the next chapter. Static means anything that does not move or change with time. *Electrostatics deals with the study of forces, fields and potentials arising from static charges.*

### 1.2 ELECTRIC CHARGE

Historically the credit of discovery of the fact that amber rubbed with wool or silk cloth attracts light objects goes to Thales of Miletus, Greece, around 600 BC. The name electricity is coined from the Greek word *elektron* meaning *amber*. Many such pairs of materials were known which



**FIGURE 1.1** Rods and pith balls: like charges repel and unlike charges attract each other.

on rubbing could attract light objects like straw, pith balls and bits of papers. You can perform the following activity at home to experience such an effect. Cut out long thin strips of white paper and lightly iron them. Take them near a TV screen or computer monitor. You will see that the strips get attracted to the screen. In fact they remain stuck to the screen for a while.

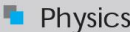
It was observed that if two glass rods rubbed with wool or silk cloth are brought close to each other, they repel each other [Fig. 1.1(a)]. The two strands of wool or two pieces of silk cloth, with which the rods were rubbed, also repel each other. However, the glass rod and wool attracted each other. Similarly, two plastic rods rubbed with cat's fur repelled each other [Fig. 1.1(b)] but attracted the fur. On the other hand, the plastic rod attracts the glass rod [Fig. 1.1(c)] and repel the silk or wool with which the glass rod is rubbed. The glass rod repels the fur.

If a plastic rod rubbed with fur is made to touch two small pith balls (now-a-days we can use polystyrene balls) suspended by silk or nylon thread, then the balls repel each other [Fig. 1.1(d)] and are also repelled

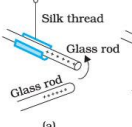
common example of electric discharge is the lightning that we see in the sky during thunderstorms. We also experience a sensation of an electric shock either while opening the door of a car or holding the iron bar of a bus after sliding from our seat. The reason for these experiences is discharge of electric charges through our body, which were accumulated due to rubbing of insulating surfaces. You might have also heard that this is due to generation of static electricity. This is precisely the topic we are going to discuss in this and the next chapter. Static means anything that does not move or change with time. *Electrostatics deals with the study of forces, fields and potentials arising from static charges.*

## 1.2 ELECTRIC CHARGE

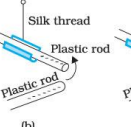
Historically the credit of discovery of the fact that amber rubbed with wool or silk cloth attracts light objects goes to Thales of Miletus, Greece, around 600 BC. The name electricity is coined from the Greek word *elektron* meaning *amber*. Many such pairs of materials were known which



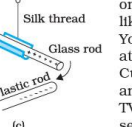
# Physics



(a)



(b)



(c)

on rubbing could attract light objects like straw, pith balls and bits of papers. You can perform the following activity at home to experience such an effect. Cut out long thin strips of white paper and lightly iron them. Take them near a TV screen or computer monitor. You will see that the strips get attracted to the screen. In fact they remain stuck to the screen for a while.


It was observed that if two glass rods rubbed with wool or silk cloth are brought close to each other, they repel each other [Fig. 1.1(a)]. The two strands of wool or two pieces of silk cloth, with which the rods were rubbed, also repel each other. However, the glass rod and wool attracted each other. Similarly, two plastic rods rubbed with cat's fur repelled each other [Fig. 1.1(b)] but attracted the fur. On the other hand, the plastic rod attracts the glass rod [Fig. 1.1(c)] and repel the silk or wool with which the glass rod is rubbed. The glass rod repels the fur.

If a plastic rod rubbed with fur is made to touch two small pith balls (now-a-days we can use polystyrene balls) suspended by silk or nylon thread, then the balls repel each other [Fig. 1.1(d)] and are also repelled by the rod. A similar effect is found if the pith balls are touched with a glass rod rubbed with silk [Fig. 1.1(e)]. A dramatic observation is that a pith ball touched with glass rod attracts another pith ball touched with plastic rod [Fig. 1.1(f)].


These seemingly simple facts were established from years of efforts and careful experiments and their analyses. It was concluded, after many careful studies by different scientists, that there were only two kinds of an entity which is called the *electric charge*. We say that the bodies like glass or plastic rods, silk, fur and pith balls are electrified. They acquire an electric charge on rubbing. The experiments on pith balls suggested that there are two kinds of electrification and we find that (i) *like charges repel* and (ii) *unlike charges attract* each other. The experiments also demonstrated that the charges are transferred from the rods to the pith balls on contact. It is said that the pith balls are electrified or are charged by contact. The property which differentiates the two kinds of charges is called the *polarity* of charge.

When a glass rod is rubbed with silk, the rod acquires one kind of charge and the silk acquires the second kind of charge. This is true for any pair of objects that are rubbed to be electrified. Now if the electrified glass rod is brought in contact with silk, with which it was rubbed, they no longer attract each other. They also do not attract or repel other light objects as they did on being electrified.


Thus, the charges acquired after rubbing are lost when the charged bodies are brought in contact. What can you conclude from these observations? It just tells us that unlike charges acquired by the objects



(d)



(e)



(f)

**FIGURE 1.1** Rods and pith balls: like charges repel and unlike charges attract each other.

Interactive animation on simple electrostatic experiments:  
<http://physics.physics.ucla.edu/travoltage/HTML/>




# Electric Charges and Fields

neutralise or nullify each other's effect. Therefore the charges were named

## Electric Charges and Fields

neutralise or nullify each other's effect. Therefore the charges were named as *positive* and *negative* by the American scientist Benjamin Franklin. We know that when we add a positive number to a negative number of the same magnitude, the sum is zero. This might have been the philosophy in naming the charges as positive and negative. By convention, the charge on glass rod or cat's fur is called positive and that on plastic rod or silk is termed negative. If an object possesses an electric charge, it is said to be electrified or charged. When it has no charge it is said to be neutral.

### UNIFICATION OF ELECTRICITY AND MAGNETISM

In olden days, electricity and magnetism were treated as separate subjects. Electricity dealt with charges on glass rods, cat's fur, batteries, lightning, etc., while magnetism described interactions of magnets, iron filings, compass needles, etc. In 1820 Danish scientist Oersted found that a compass needle is deflected by passing an electric current through a wire placed near the needle. Ampere and Faraday supported this observation by saying that electric charges in motion produce magnetic fields and moving magnets generate electricity. The unification was achieved when the Scottish physicist Maxwell and the Dutch physicist Lorentz put forward a theory where they showed the interdependence of these two subjects. This field is called *electromagnetism*. Most of the phenomena occurring around us can be described under electromagnetism. Virtually every force that we can think of like friction, chemical force between atoms holding the matter together, and even the forces describing processes occurring in cells of living organisms, have its origin in electromagnetic force. Electromagnetic force is one of the fundamental forces of nature.

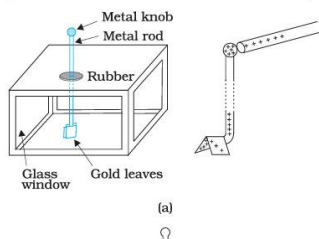
Maxwell put forth four equations that play the same role in classical electromagnetism as Newton's equations of motion and gravitation law play in mechanics. He also argued that light is electromagnetic in nature and its speed can be found by making purely electric and magnetic measurements. He claimed that the science of optics is intimately related to that of electricity and magnetism.

The science of electricity and magnetism is the foundation for the modern technological civilisation. Electric power, telecommunication, radio and television, and a wide variety of the practical appliances used in daily life are based on the principles of this science. Although charged particles in motion exert both electric and magnetic forces, in the frame of reference where all the charges are at rest, the forces are purely electrical. You know that gravitational force is a long-range force. Its effect is felt even when the distance between the interacting particles is very large because the force decreases inversely as the square of the distance between the interacting bodies. We will learn in this chapter that electric force is also as pervasive and is in fact stronger than the gravitational force by several orders of magnitude (refer to Chapter 1 of Class XI Physics Textbook).

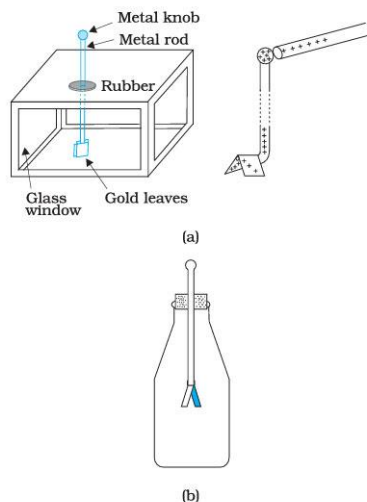
A simple apparatus to detect charge on a body is the *gold-leaf electroscope* [Fig. 1.2(a)]. It consists of a vertical metal rod housed in a box, with two thin gold leaves attached to its bottom end. When a charged object touches the metal knob at the top of the rod, charge flows on to the leaves and they diverge. The degree of divergence is an indicator of the amount of charge.

3

## Physics



Students can make a simple electroscope as follows [Fig. 1.2(b)]: Take a thin aluminium curtain rod with ball ends fitted for hanging the curtain. Cut out a piece of length about 20 cm with the ball at one end and flatten the cut end. Take a large bottle that can hold this rod and a cork which will fit in the opening of the bottle. Make a hole in the cork sufficient to hold the curtain rod snugly. Slide the rod through the hole in the cork with the cut end on the lower side and ball end projecting above the cork. Fold a small, thin aluminium foil (about 6 cm in length) in the middle and attach it to the flattened



**FIGURE 1.2** Electroscopes: (a) The gold leaf electroscope, (b) Schematics of a simple electroscope.

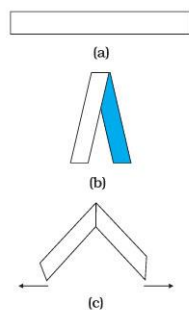
Students can make a simple electroscope as follows [Fig. 1.2(b)]: Take a thin aluminium curtain rod with ball ends fitted for hanging the curtain. Cut out a piece of length about 20 cm with the ball at one end and flatten the cut end. Take a large bottle that can hold this rod and a cork which will fit in the opening of the bottle. Make a hole in the cork sufficient to hold the curtain rod snugly. Slide the rod through the hole in the cork with the ball end projecting above the cork. Fold a small, thin aluminium foil (about 6 cm in length) in the middle and attach it to the flattened end of the rod by cellulose tape. This forms the leaves of your electroscope. Fit the cork in the bottle with about 5 cm of the ball end projecting above the cork. A paper scale may be put inside the bottle in advance to measure the separation of leaves. The separation is a rough measure of the amount of charge on the electroscope.

To understand how the electroscope works, use the white paper strips we used for seeing the attraction of charged bodies. Fold the strips into half so that you make a mark of fold. Open the strip and iron it lightly with the mountain fold up, as shown in Fig. 1.3. Hold the strip by pinching it at the fold. You would notice that the two halves move apart.

This shows that the strip has acquired charge on ironing. When you fold it into half, both the halves have the same charge. Hence they repel each other. The same effect is seen in the leaf electroscope. On charging the curtain rod by touching the ball end with an electrified body, charge is transferred to the curtain rod and the attached aluminium foil. Both the halves of the foil get similar charge and therefore repel each other. The divergence in the leaves depends on the amount of charge on them. Let us first try to understand why material bodies acquire charge.

You know that all matter is made up of atoms and/or molecules. Although normally the materials are electrically neutral, they do contain charges; but their charges are exactly balanced. Forces that hold the molecules together, forces that hold atoms together in a solid, the adhesive force of glue, forces associated with surface tension, all are basically electrical in nature, arising from the forces between charged particles. Thus the electric force is all pervasive and it encompasses almost each and every field associated with our life. It is therefore essential that we learn more about such a force.

To electrify a neutral body, we need to add or remove one kind of charge. When we say that a body is charged, we always refer to this excess charge or deficit of charge. In solids, some of the electrons, being less tightly bound in the atom, are the charges which are transferred from one body to the other. A body can thus be charged positively by losing some of its electrons. Similarly, a body can be charged negatively



**FIGURE 1.3** Paper strip experiment.



## Electric Charges and Fields

by gaining electrons. When we rub a glass rod with silk, some of the electrons from the rod are transferred to the silk cloth. Thus the rod gets positively charged and the silk gets negatively charged. No new charge is created in the process of rubbing. Also the number of electrons, that are transferred, is a very small fraction of the total number of electrons in the material body. Also only the less tightly bound electrons in a material body can be transferred from it to another by rubbing. Therefore, when a body is rubbed with another, the bodies get charged and that is why we have to stick to certain pairs of materials to notice charging on rubbing the bodies.

### 1.3 CONDUCTORS AND INSULATORS

A metal rod held in hand and rubbed with wool will not show any sign of being charged. However, if a metal rod with a wooden or plastic handle is rubbed without touching its metal part, it shows signs of charging. Suppose we connect one end of a copper wire to a neutral pith ball and the other end to a negatively charged plastic rod. We will find that the pith ball acquires a negative charge. If a similar experiment is repeated with a nylon thread or a rubber band, no transfer of charge will take place from the plastic rod to the pith ball. Why does the transfer of charge not take place from the rod to the ball?

Some substances readily allow passage of electricity through them, others do not. Those which allow electricity to pass through them easily are called *conductors*. They have electric charges (electrons) that are comparatively free to move inside the material. Metals, human and animal bodies and earth are conductors. Most of the non-metals like glass, porcelain, plastic, nylon, wood offer high resistance to the passage of electricity through them. They are called *insulators*. Most substances fall into one of the two classes stated above\*.

When some charge is transferred to a conductor, it readily gets distributed over the entire surface of the conductor. In contrast, if some charge is put on an insulator, it stays at the same place. You will learn why this happens in the next chapter.

This property of the materials tells you why a nylon or plastic comb gets electrified on combing dry hair or on rubbing, but a metal article like spoon does not. The charges on metal leak through our body to the ground as both are conductors of electricity.

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 into 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

\* There is a third category called *semiconductors*, which offer resistance to the movement of charges which is intermediate between the conductors and insulators.



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.

### 1.4 CHARGING BY INDUCTION

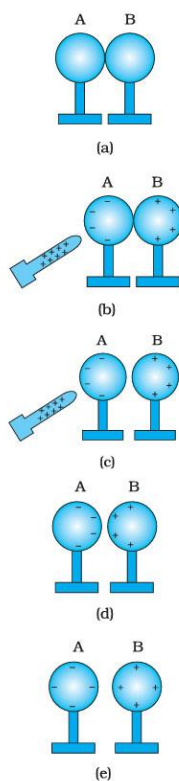


FIGURE 1.4 Charging by induction.

When we touch a pith ball with an electrified plastic rod, some of the negative charges on the rod are transferred to the pith ball and it also gets charged. Thus the pith ball is *charged by contact*. It is then repelled by the plastic rod but is attracted by a glass rod which is oppositely charged. However, why a electrified rod attracts light objects, is a question we have still left unanswered. Let us try to understand what could be happening by performing the following experiment.

- (i) Bring two metal spheres, A and B, supported on insulating stands, in contact as shown in Fig. 1.4(a).
- (ii) Bring a positively charged rod near one of the spheres, say A, taking care that it does not touch the sphere. The free electrons in the spheres are attracted towards the rod. This leaves an excess of positive charge on the rear surface of sphere B. Both kinds of charges are bound in the metal spheres and cannot escape. They, therefore, reside on the surfaces, as shown in Fig. 1.4(b). The left surface of sphere A, has an excess of negative charge and the right surface of sphere B, has an excess of positive charge. However, not all of the electrons in the spheres have accumulated on the left surface of A. As the negative charge starts building up at the left surface of A, other electrons are repelled by these. In a short time, equilibrium is reached under the action of force of attraction of the rod and the force of repulsion due to the accumulated charges. Fig. 1.4(b) shows the equilibrium situation. The process is called *induction of charge* and happens almost instantly. The accumulated charges remain on the surface, as shown, till the glass rod is held near the sphere. If the rod is removed, the charges are not acted by any outside force and they redistribute to their original neutral state.
- (iii) Separate the spheres by a small distance while the glass rod is still held near sphere A, as shown in Fig. 1.4(c). The two spheres are found to be oppositely charged and attract each other.
- (iv) Remove the rod. The charges on spheres rearrange themselves as shown in Fig. 1.4(d). Now, separate the spheres quite apart. The charges on them get uniformly distributed over them, as shown in Fig. 1.4(e).

In this process, the metal spheres will each be equal and oppositely charged. This is *charging by induction*. The positively charged glass rod does not lose any of its charge, contrary to the process of charging by contact.

When electrified rods are brought near light objects, a similar effect takes place. The rods induce opposite charges on the near surfaces of the objects and similar charges move to the farther side of the object.

