6 Static Electricity

In your previous class, you have learnt about the nature of electricity, its sources and its uses. Most of this was about electric currents caused by the flow of charges through conductors. Thus, you know about the effects of charges in motion.

In this chapter, we will discuss static electricity, or the properties and effects of charges which are at rest. You may remember that charges are of two types—positive and negative. You may also remember that a charged body carries an excess of one type of charge and exerts electrostatic force on bodies near it. We will now learn how bodies get charged and the kind of force they exert on other charged bodies.

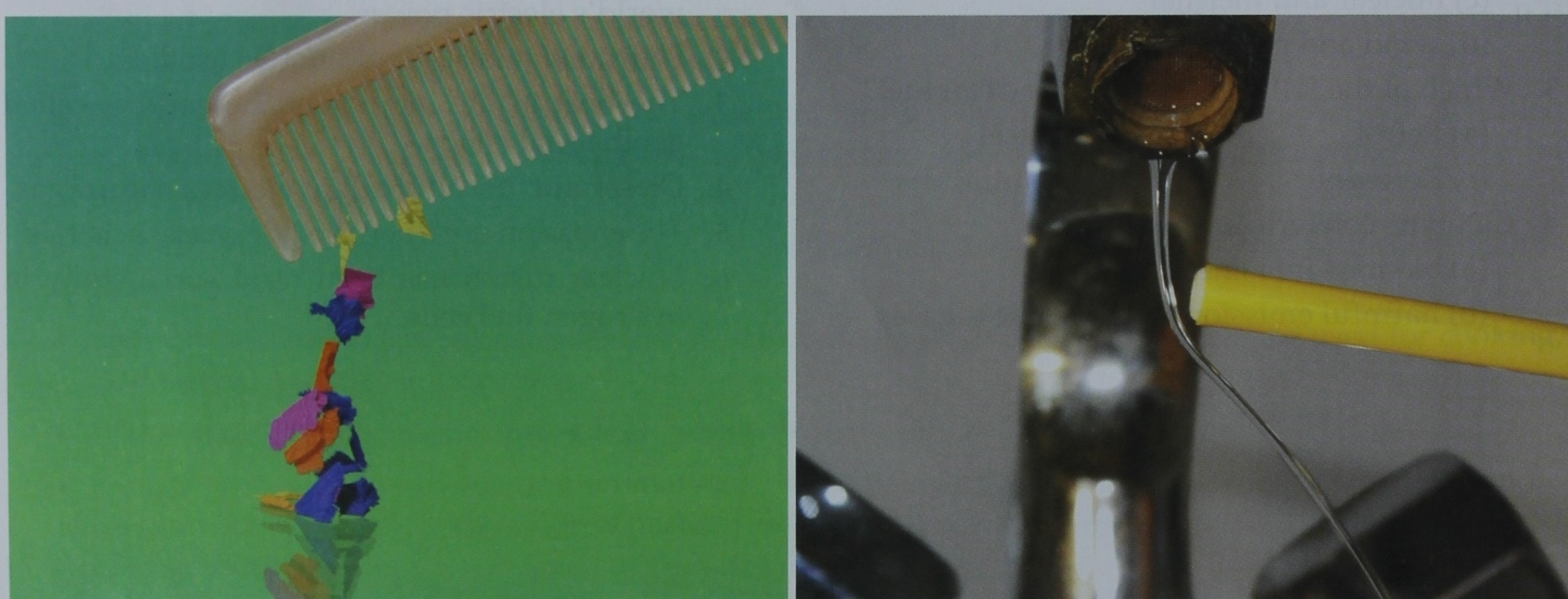


Fig. 6.1 A comb rubbed against dry hair and a plastic pen rubbed against wool or paper get charged. They exert electrostatic force on bits of paper and a stream of water.

ATOMS, CHARGES AND ELECTRICITY

You have learnt that all matter is made up of atoms. However, each atom is not a single particle in itself. It is made up of smaller particles. The structure of an atom is somewhat like that of the solar system. Almost the entire mass of the atom is concentrated at the centre, which is called the nucleus. Negatively charged particles called electrons move around the nucleus, the way planets move around the sun. The nucleus itself is made up of two types of particles packed close together. These are positively charged particles called protons and neutral (uncharged) particles called neutrons.

Protons and neutrons have almost the same mass and are much heavier than electrons. The charge on a proton is equal and opposite to the charge on an electron. Normally, an atom contains the same number of (positively charged) protons and (negatively charged) electrons. Hence, an atom is usually electrically neutral, or uncharged.

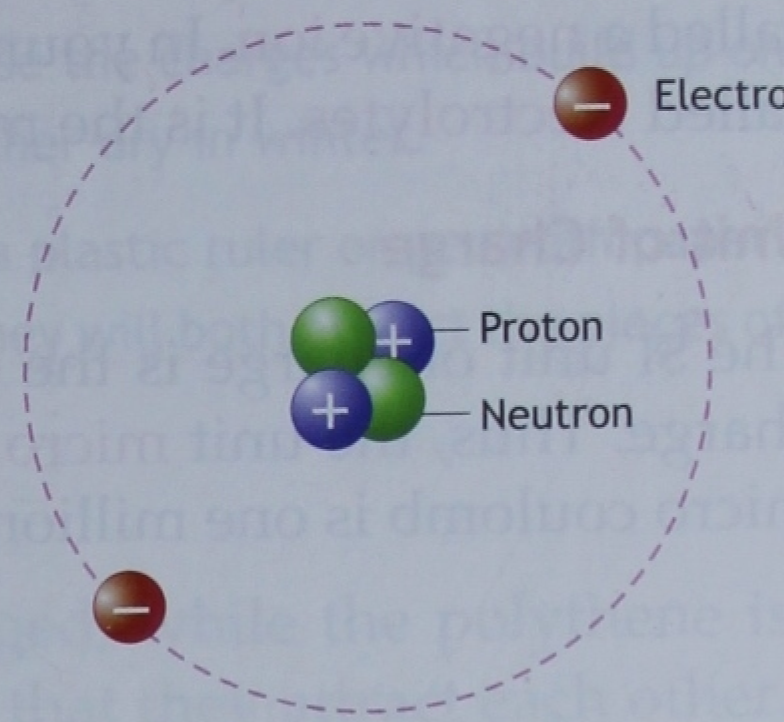


Fig. 6.2 Structure of an atom

Free Electrons

The protons and neutrons of an atom are bound very tightly and cannot normally break away. Some of the electrons moving around an atom, however, can break loose. These are called free electrons, and can move about freely inside a material. It is these charged particles, called charge carriers, that are responsible for all electrical processes. A body may gain or lose free electrons and become charged. As long as such charges in a body are at rest, we study their effects under static electricity.

Conductors have a large number of free electrons or charge carriers, while insulators have very few of them. This explains the difference between the electrical properties of conductors and insulators. Normally, the free electrons inside a conductor move about randomly, or not in any particular direction. However, when a conductor is connected to a source of electricity, or a potential difference is created between the two ends of a conductor, the free electrons flow in a particular direction. This is what gives rise to an electric current. As electrons carry negative charge, and an electric current is defined as the transfer of positive charge, the direction of conventional current is opposite to the direction of the flow of electrons.

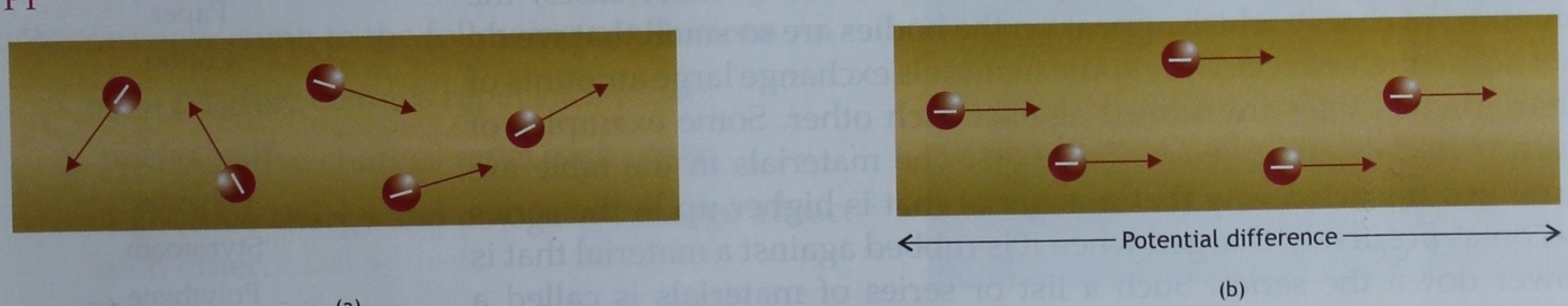


Fig. 6.3 (a) The free electrons in a conductor are normally in random motion. (b) When a potential difference is created across the conductor, they flow in a regular direction.

Charge on a Body

All objects around us normally have equal amounts of positive and negative charges. Thus, they are uncharged, or electrically neutral. (This should be obvious since they are made up of atoms, and atoms are electrically neutral.) However, sometimes a body may either lose or gain some charge. Then it becomes charged, or is no longer electrically neutral. Remember that when we speak of the charge on a body we mean the imbalance of charges, and not the actual amount of charges present in it.

1. If a body gains Q amount of positive charge, the charge on it is $+Q$.
2. If a body gains Q amount of negative charge, the charge on it is $-Q$.
3. If a body loses Q amount of positive charge, the charge on it is $-Q$.
4. If a body loses Q amount of negative charge, the charge on it is $+Q$.

Atoms can also become charged. When an atom loses electrons, its net charge becomes positive, and it is called a positive ion. When an atom gains electrons, its net charge becomes negative, and it is called a negative ion. In your previous class you have learnt that liquids which conduct electricity are called electrolytes. It is the movement of ions within such liquids that helps to conduct electricity.

Unit of Charge

The SI unit of charge is the coulomb, with the symbol C. One coulomb is a very large amount of charge. Thus, the unit micro coulomb, with the symbol μ C, is widely used in static electricity. One micro coulomb is one millionth of a coulomb, or 10^{-6} C.

CHARGING A BODY

A body can be charged by three methods—by friction, by conduction and by induction. We will discuss each of these methods in some detail.

Charging by Friction

When two bodies rub against each other, some charge usually moves from one to the other. Both the bodies then acquire equal and opposite charge. For example, suppose a body A rubs against a body B and Q amount of negative charge moves from A to B. Then B will have $-Q$ charge and A will have $+Q$ charge.

This process of transfer of charge occurs all the time, whenever bodies rub against each other, for example, when shoes rub against the floor or a pencil rubs against paper. However, in most cases, the amounts of charge which appear on the bodies are so small that we do not notice their effects. Only some materials exchange large amounts of charge when they are rubbed against each other. Some examples of such materials are given in Table 6.1. The materials in the table are arranged in such a way that a material that is higher up in the series becomes positively charged when it is rubbed against a material that is lower down the series. Such a list or series of materials is called a triboelectric series.

Table 6.1 Triboelectric series

Glass
Human hair
Nylon
Wool
Silk
Aluminium
Paper
Cotton
Amber (a resin)
Hard rubber
Polyester
Styrofoam
Polythene

ACTIVITY Let us try to charge different sets of materials by friction and observe their behaviour. Remember that

Fig. 6.4 The Styrofoam and polythene attract bits of paper. They also attract each other.

simple experiments on static electricity work best in winter. This is because the charges which build up on bodies usually leak away through the moisture in the air, and the air is rather dry in winter.

Rub a piece of Styrofoam with a strip of polythene. (Alternatively, rub a plastic ruler or pen with paper, wool or nylon.) Bring the Styrofoam and polythene close to bits of paper. They will both attract the pieces of paper, showing that both have been charged by friction.

Force between charges

A look at Table 6.1 will tell you that the Styrofoam is positively charged, while the polythene is negatively charged. If you bring them close to each other, you will find that they attract each other. This is always true, and we say that unlike charges attract each other. You can see examples of this all around you, especially in winter. For example, when you brush past a curtain made of synthetic material, it sticks to you. Nylon sweaters and socks cling to you when you try to take them off. Pulses packed in plastic bags stick to the bags and strands of hair get drawn to your comb while you comb your hair.

ACTIVITY This activity will help you observe the behaviour of similar or like charges. Blow up two balloons and attach strings to them. Rub the balloons with wool. According to Table 6.1, both the balloons should get negatively charged. Hold the strings together. You will notice that the balloons move apart, showing that like charges repel each other.

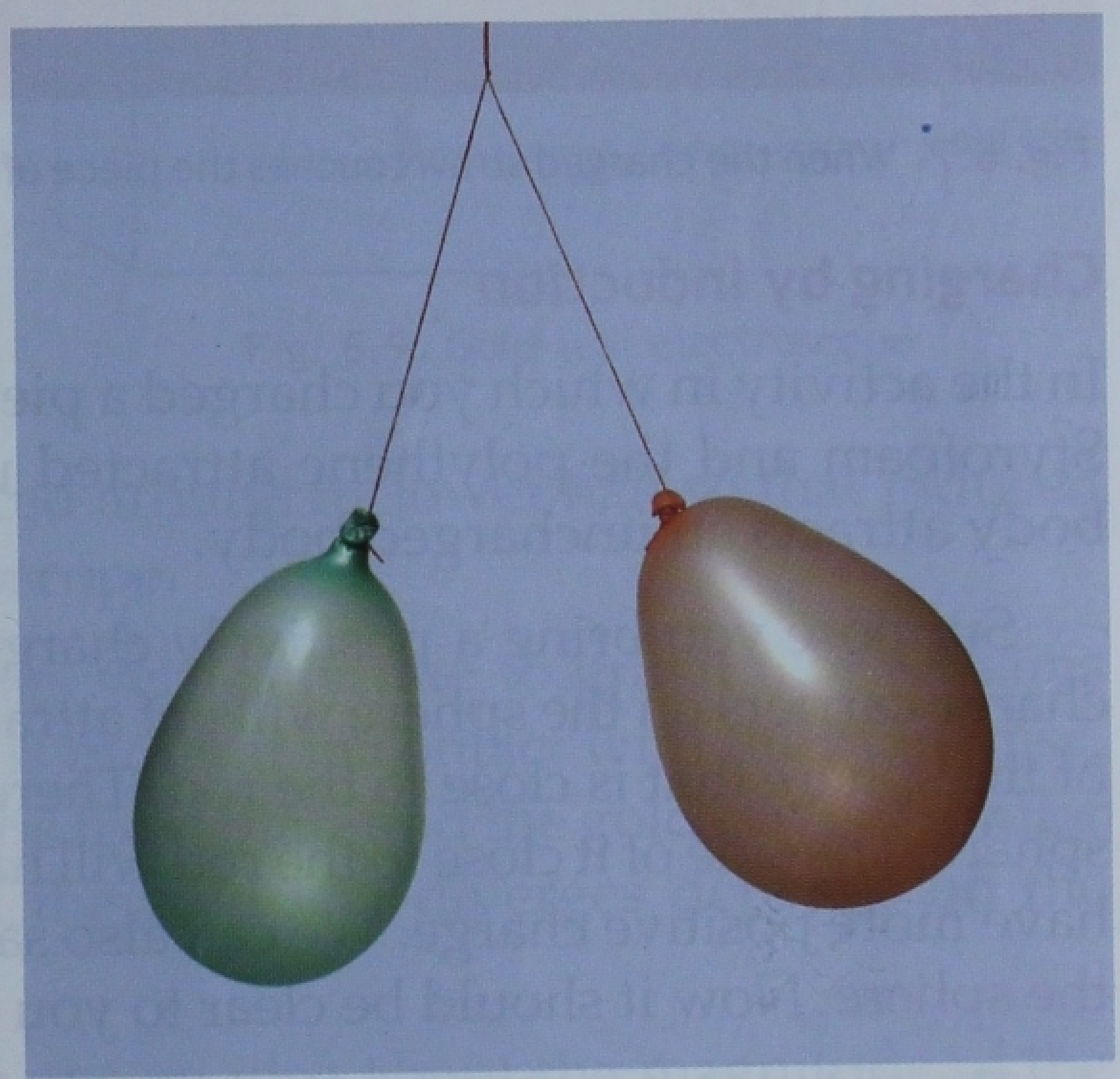


Fig. 6.5 The balloons carry similar charges, so they repel each other.

We can now come to the following conclusions.

1. Two positive charges repel each other.
2. Two negative charges repel each other.
3. A positive charge and a negative charge attract each other.

The magnitude (strength) of the force between charges depends on the magnitude (amount) of the charges. The greater the charges, the greater is the force between them. The force exerted by charges also depends on the distance between them. The greater the distance between the charges, the smaller is the force between them.

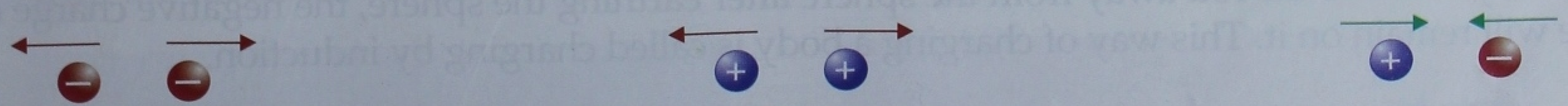


Fig. 6.6 Like charges repel, unlike charges attract.

Charging by Conduction

When an uncharged body comes in contact with a charged body, charge flows from the charged body to the uncharged one. Suppose a charged body X carrying Q charge comes in contact with an identical uncharged body Y. Charge will flow from X to Y until they both have $Q/2$ charge. This process of charging an uncharged body by bringing it in contact with a charged body is called charging by conduction.

ACTIVITY Suspend a small piece of paper by a string. Charge a drinking straw by rubbing it with another piece of paper and bring it close to the suspended piece of paper. This paper will get attracted to the straw and finally stick to it. Move the straw away and bring it near the paper again. This time the paper, which has been charged by conduction, will get repelled.

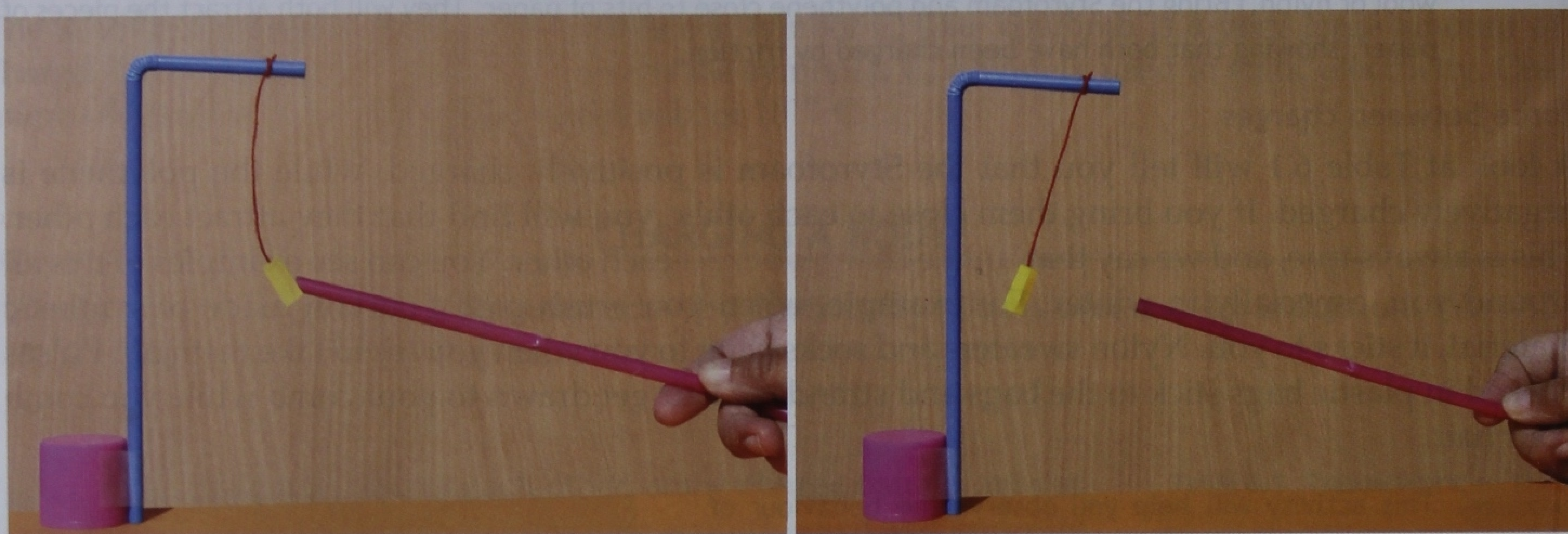


Fig. 6.7 When the charged straw touches the piece of paper, the latter gets charged by conduction. It then gets repelled by the straw.

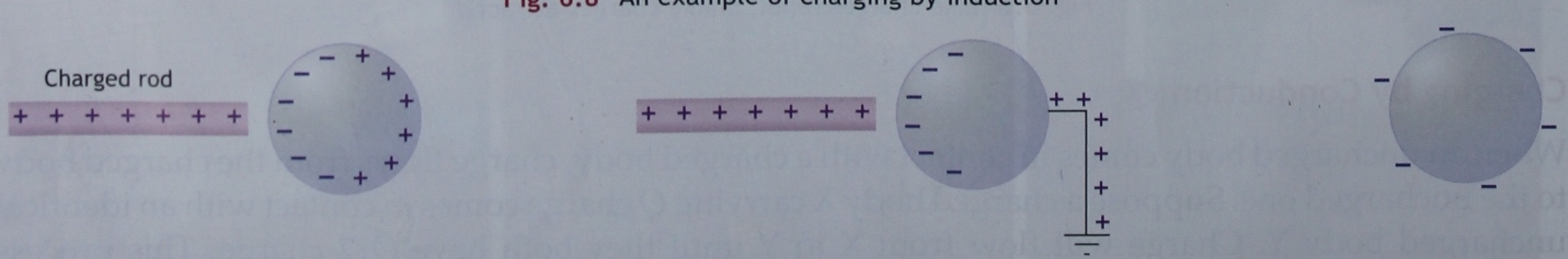
Charging by Induction

In the activity in which you charged a piece of Styrofoam and a strip of polythene by friction, both the Styrofoam and the polythene attracted uncharged pieces of paper. Let us find out how a charged body attracts an uncharged body.

Suppose you bring a positively charged rod close to an uncharged metallic sphere. The negative charge carriers on the sphere will get attracted to the positive charge on the rod and move to the side of of the sphere that is close to the rod. There will, thus, be a temporary rearrangement of charges on the sphere. The side of it close to the rod will have more negative charge and the side away from the rod will have more positive charge. We can also say that induced negative and positive charges will appear on the sphere. Now it should be clear to you why an uncharged body gets attracted to a charged body.

The induced charges on the sphere will disappear as soon as you move the rod away. However, if you earth the sphere, or connect it to the earth, without moving the rod away from it, the positive charges will flow to the earth, leaving the sphere with a net negative charge. (You may remember that earthing a body means connecting it to the earth to allow charges on it to flow to the earth). The negative charges remain on the sphere and do not flow to the earth because they are attracted or 'bound' by the positive charges on the rod. If you move the rod away from the sphere after earthing the sphere, the negative charge on the sphere will remain on it. This way of charging a body is called charging by induction.

Fig. 6.8 An example of charging by induction



1. Negative charges are attracted towards the rod and get bound.
2. When the sphere is earthed, the unbound positive charges flow to the earth.
3. The remaining charges make the sphere negatively charged.

COMPARING CHARGES

An electroscope is an instrument used to detect and compare charges. We can use it to find

1. whether a body is charged,
2. whether the charge on a body is small or large, and
3. the nature (positive or negative) of the charge on a body.

Gold-Leaf Electroscope

This is one of the earliest instruments to be devised to detect and compare charges. It consists of a brass rod with a brass disc at the top and two plates at the bottom. The rod is fixed inside a closed glass jar, as shown in Figure 6.9. One of the plates is fixed, while the other, which is a very thin gold plate, is hinged at its upper end and can move. The electroscope gets its name from the thin gold plate, which is called a gold leaf. Although the movable plate can be made of any conductor, gold is preferred because it can be beaten into a very thin leaf. A thin leaf is light and moves easily, which improves the sensitivity of the instrument. The glass jar protects the plates from air currents. Earthed conducting sheets are placed around its lower half so that induced charges are earthed and improve the working of the electroscope.

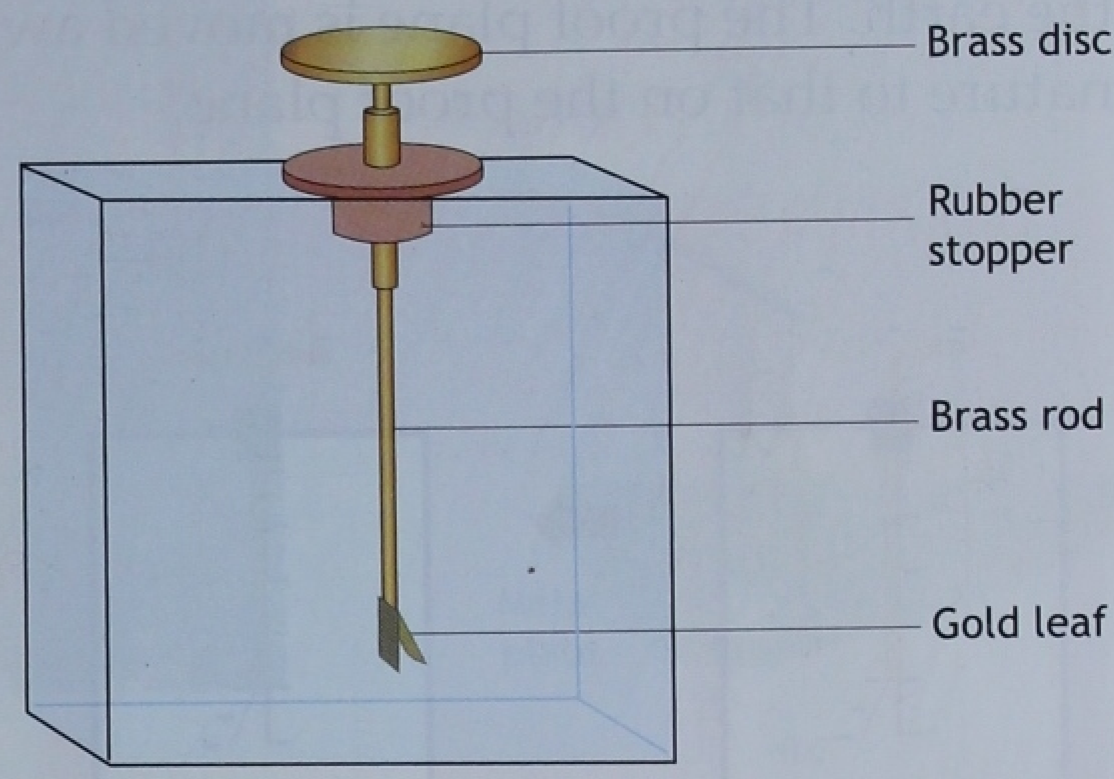


Fig. 6.9 Gold-leaf electroscope

When the electroscope is uncharged, the gold leaf hangs vertically due to gravity, or remains parallel to the fixed plate. However, when a charged body is brought in contact with the brass disc, the gold leaf moves apart, or diverges. This is because both the fixed plate and the gold leaf get similar charges and hence repel each other. The extent to which the gold leaf diverges depends on the magnitude of the charge.

Noting the extent to which the gold leaf diverges gives one an idea about the magnitude of the charge being tested but not about its nature. To determine the nature of the charge, the electroscope has to be charged with a known charge initially. Suppose the electroscope is given a positive charge. Then the divergence of the gold leaf will increase if a positive charge is brought in contact with the metal disc. On the other hand, the divergence will decrease if a negatively charged body is brought in contact with the metal disc.

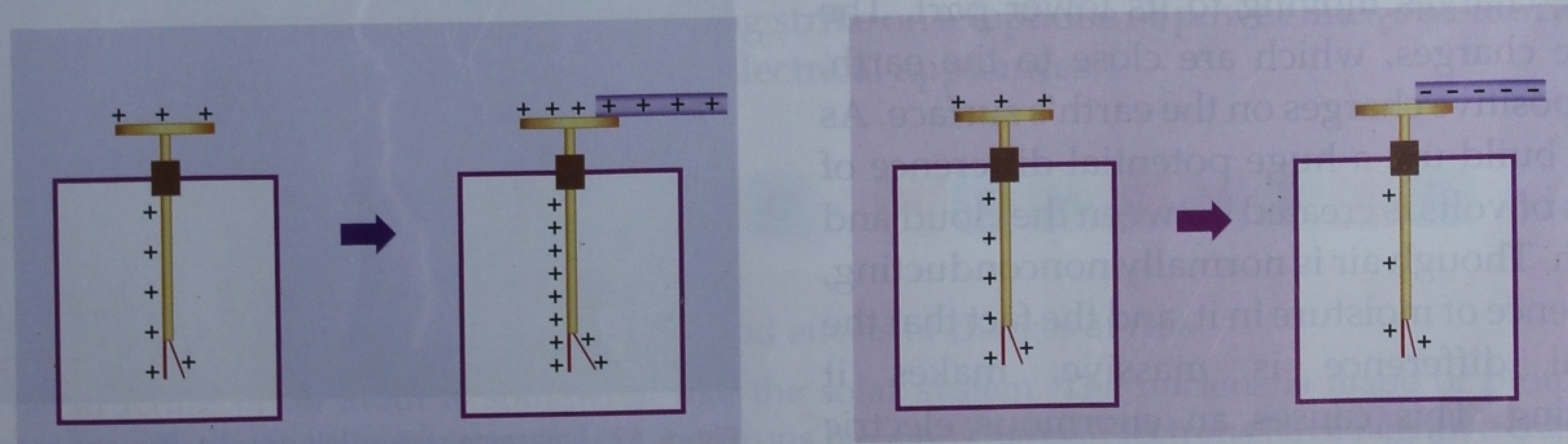


Fig. 6.10 The divergence increases if the test charge is similar in nature to the charge on the eletroscope. The divergence decreases if the test charge is opposite in nature to the charge on the electroscope.

Charging an electroscope

An electroscope can be charged by conduction or induction. To charge an electroscope by conduction, a brass disc with an insulating handle, called a proof plane, is used. The proof plane is first made to touch a charged body and then brought in contact with the metal disc of the electroscope. The electroscope then gets charge of the same nature as the charged body.

To charge an electroscope by induction, the charged proof plane is brought near the disc of the electroscope. Bound charges (of the opposite sign) then appear on the disc and free charges (of the same sign) appear on the plates. The disc is then earthed by touching it, so that the free charges flow to the earth. The proof plane is moved away from the electroscope, leaving it with a charge opposite in nature to that on the proof plane.

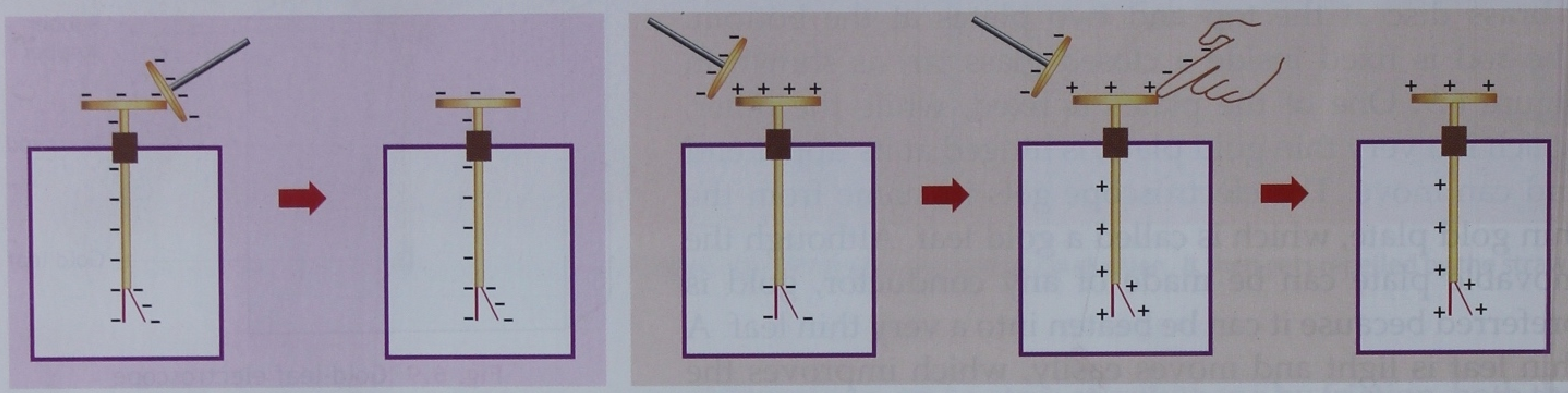


Fig. 6.11 Charging an electroscope by (a) conduction and (b) induction

LIGHTNING

During the rainy season you must have seen flashes of lightning followed by the loud sound of thunder. Lightning is caused by the accumulation and separation of charges in clouds.

Thunderclouds normally have huge amounts of positive and negative charges. Sometimes, these charges separate, with the positive charges moving to the upper part of a cloud and the negative charges moving to its lower part. The negative charges, which are close to the earth, induce positive charges on the earth's surface. As charges build up, a huge potential difference of millions of volts is created between the cloud and the earth. Though air is normally nonconducting, the presence of moisture in it, and the fact that the potential difference is massive, makes it conducting. This causes an enormous electric current to pass from the cloud to the earth, which creates brilliant streaks of light.

Fig. 6.12 Lightning strikes kill people, damage property and cause forest fires.

A potential difference between clouds can cause an electric current to pass from one cloud to another. However, when we speak of a lightning strike, we mean a sudden passage of large amounts of charge between a cloud and the earth. The sound of thunder accompanying flashes of lightning is caused by the sudden expansion of air due to the heat released by the passage of electricity.

Lightning Conductor

The enormous amount of energy released during a lightning strike can damage buildings, burn down trees and kill people. Some buildings are provided with lightning conductors to protect them from damage from lightning strikes. A lightning conductor consists of a set of metal spikes fitted at the top of a building and connected by a metal strip to a copper plate buried in the earth. When negative charges build up in a cloud, positive charges from the earth travel through the lightning conductor and the air to meet the charges in the cloud and neutralise them. And if lightning does strike, despite the action of the lightning conductor, the current passes through the conductor into the earth without damaging the building.

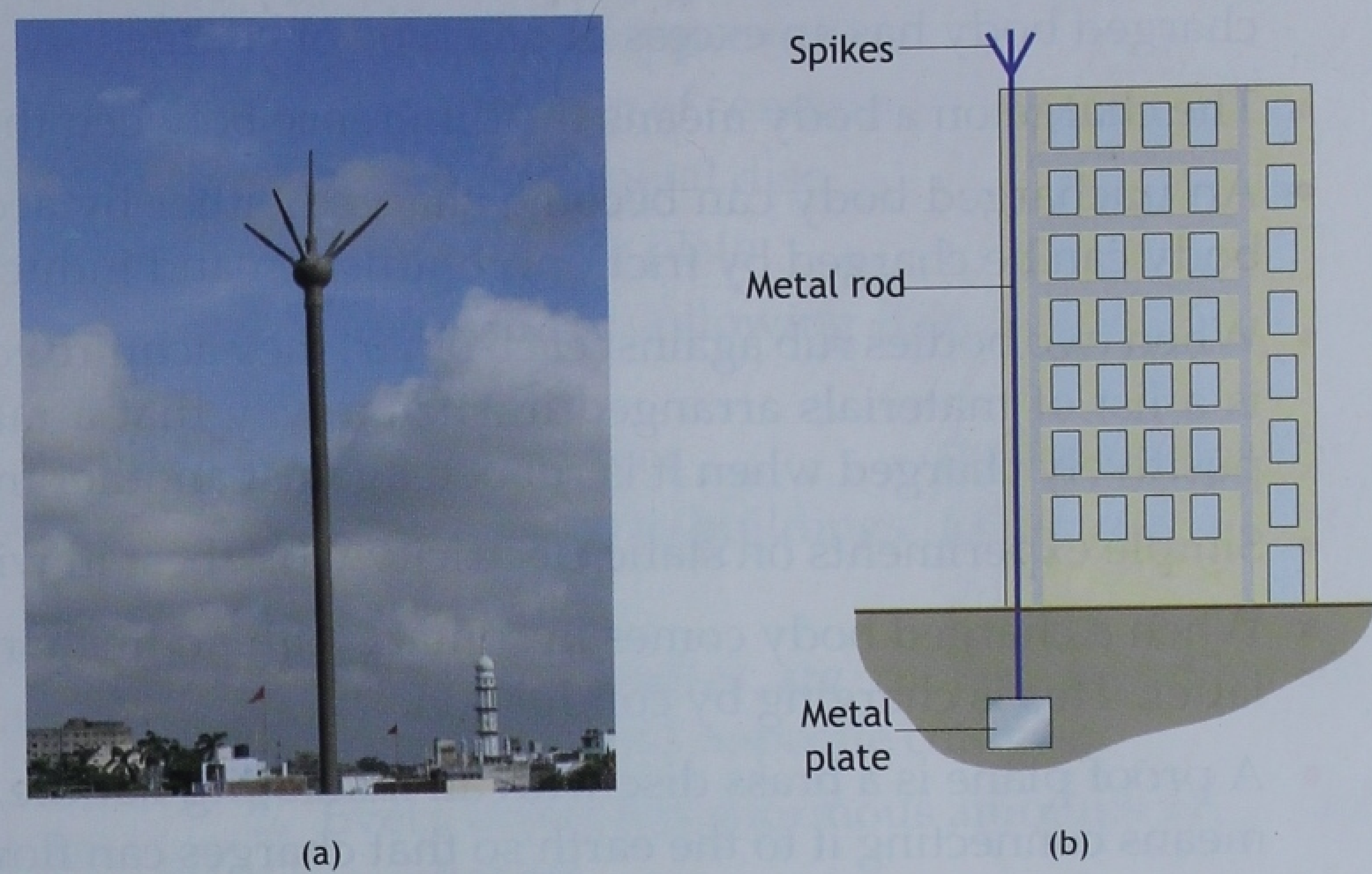


Fig. 6.13 Lightning conductor

Safety

Lightning strikes can kill people or leave them with lifelong disabilities. Here are some precautions you can take to protect yourself during a thunderstorm.

1. It is best to stay indoors during a thunderstorm.
2. If you happen to be outdoors, take shelter inside a vehicle (with a hard top) and roll up the windows. If that is not possible, crouch down on the balls of your feet and make as little contact as possible with the ground. Avoid high ground, water bodies, trees, fences, power and telephone lines, bicycles, motorcycles, metallic farm equipment, or anything that can act as a path for a lightning strike.
3. If you are indoors, stay away from windows. Do not use electrical appliances, computers and telephones with cords because a lightning strike on telephone or power lines outside can induce shocks indoors. If possible, turn off all electrical appliances.

POINTS TO REMEMBER

- Electrostatics is the study of the properties and effects of charges at rest.
- The structure of an atom is somewhat like the solar system. The nucleus is made of protons and neutrons. Protons have positive charge, neutrons have no charge. Electrons have negative charge and move around the nucleus. Protons and neutrons are much heavier than electrons.

- Electric current is caused by the motion of free electrons, called charge carriers or carriers. Conductors have a large number of carriers while insulators have very few carriers. In static electricity, we assume that all the carriers inside a body are static (at rest).
- The SI unit of charge is the coulomb, with the symbol C. One micro coulomb (μ C) is equal to 10^{-6} C, or one millionth of a coulomb.
- Normally a body has equal amounts of positive and negative charges, or is electrically neutral. A charged body has an excess of one type of charge.
- The charge on a body means the difference between the positive and negative charges on it.
- An uncharged body can become charged either by acquiring some charge or losing some charge. A body can be charged by friction, conduction and induction.
- When two bodies rub against each other, they acquire equal and opposite charges. A triboelectric series is a list of materials arranged in such a way that a material that is higher up in the series becomes positively charged when it is rubbed against another material lower down the series.
- Simple experiments on static electricity work best in winter because the atmosphere is dry.
- When a charged body comes in contact with an uncharged body, charge flows from the former to the latter. This is charging by conduction.
- A proof plane is a brass disc with an insulating handle, used for transferring charge. Earthing a body means connecting it to the earth so that charges can flow to the ground.
- Any two charges exert forces on each other. Like charges repel, unlike charges attract. The force between charges depends on the magnitude of the charges and the distance between them.
- When a charged body comes close to an uncharged body, induced charges appear on the latter. If the uncharged body is earthed in the presence of the chargd body, it gets a charge that is opposite in nature to that on the uncharged body. This is called charging by induction.
- An electroscope can detect and compare charges. The gold-leaf electroscope has a brass rod with a disc at the top and two conducting plates at its lower end. One of the plates is a gold leaf, hinged at its upper end. When the disc has some charge, the fixed plate and the gold leaf repel each other and the gold leaf diverges from the fixed plate.
- The working of a gold-leaf electroscope improves when conducting, earthed sheets are placed around its lower half.
- It is charged by conduction, or induction when it is used to detect the nature of a charge.
- Lightning and thunder are caused by the accumulation and separation of charges in the clouds. Damages to a building due to lightning can be reduced to a large extent by a lightning conductor. It has a set of metal spikes connected by a thick metal strip to a large copper plate buried in the earth.
- It is safest to be indoors during a thunderstorm. If you are outdoors, crouch down on the balls of your feet making as little contact with the ground as possible. Stay away from anything that can act as a target for a lightning strike.

EXERCISE

Short-Answer Questions

1. What is meant by the 'charge on a body'?
2. Name some materials which can be charged by friction.
3. What is a triboelectric series?
4. Describe the nature of the forces which exist between charged bodies.
5. Explain the statement "if two uncharged bodies are rubbed against each other, they acquire equal and opposite charges."

6. What is the SI unit of charge? Which unit of charge is widely used in electrostatics and why?
7. Why should earthed conducting sheets be placed around the lower half of a gold-leaf electroscope?

Long-Answer Questions

1. Describe the structure of an atom. What are free electrons and what role do they play in electrical processes?
2. Name the different ways in which a body can be charged. Describe each of them briefly.
3. Describe a gold-leaf electroscope and explain its working.
4. Explain how thunder and lightning occur in nature.
5. What is a lightning conductor? Explain how it reduces both the risk of a lightning strike and the possible damage from lightning.
6. Mention three precautions we should take to protect ourselves from a lightning strike.

Objective Questions

Choose the correct option.

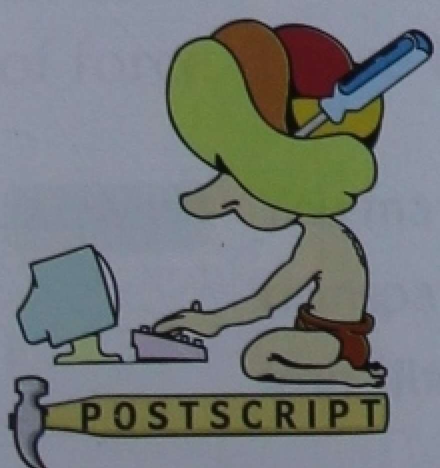
1. In the language of electrostatics, the charge on a body means
   (a) the total amount of positive charges on it
   (b) the average charge on it
   (c) the difference between the positive and negative charges on it
   (d) the total charge of the free electrons present in it
2. A body an be charged
   (a) only by conduction
   (b) only by induction
   (c) only by friction
   (d) by all of the above processes
3. On which of the following principles does the gold-leaf electroscope work?
   (a) Similar charges repel each other.
   (b) Dissimilar charges attract each other.
   (c) Gold is a very good conductor of electricity.
   (d) Glass is a very poor conductor of electricity.
4. A lightning conductor at the top of a high building is
   (a) a thick copper wire
   (b) a number of conductors with sharp points
   (c) a wide metal disc
   (d) a copper plate
5. Which of the following does not occur due to lightning?
   (a) Forest fires (b) Heavy rainfall
   (c) Damage to buildings (d) Injury or death

Fill in the blanks.

1. When two bodies are rubbed together, they acquire ...... and opposite charges.
2. Every object has enormous amounts of ...... and ...... charges.
3. The structure of an atom is somewhat like the ...... system.
4. Gold is used in an electroscope because it can be beaten into very ...... sheets.
5. A lightning conductor can gradually ...... the clouds above it.

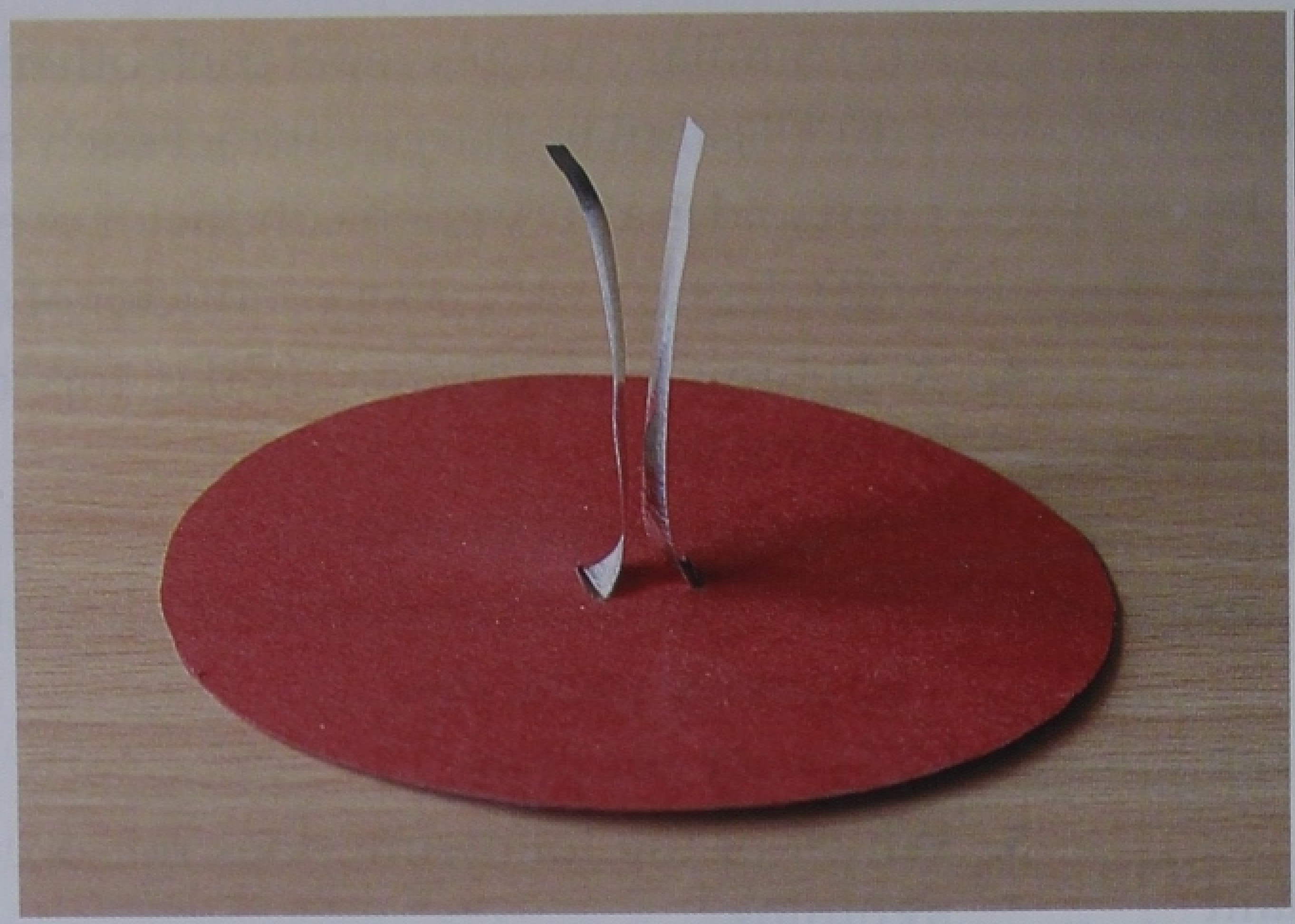
Write true or false.

1. A body cannot have charges of only one type.
2. Conducting materials have a larger number of free electrons.
3. The force between two charges is proportional to their magnitudes.
4. A gold-leaf electroscope can detect only negative charges.
5. A lightning conductor can reduce the charges on the clouds above it.
6. When atoms lose or gain electrons they are called ions.



Making an Electroscope

Cut a strip of metal foil (for example, a chocolate wrapper). Fold it in half. Make two slits on a circular piece of cardboard and pass the metal foil through the slits, as shown, so that you have two metal leaves hanging freely. Place the cardboard over the mouth of a glass jar. Rub a comb or plastic ruler with a nylon sock. Bring the comb close to the cardboard. The metal leaves should move apart.



Producing a Little Lightning

Charge a Styrofoam plate by rubbing it with wool or paper. Clamp a plastic clothes pin on an aluminium-foil bowl. Hold the bowl by this handle. Darken the room and bring your finger close to the top of the bowl. You will hear a crackling sound (thunder), see a small flash (lightning) and feel a mild shock, as charges travel from the bowl to the ground through your body.

❑