# CHAPTER 15

# ELECTROSTATICS



## Student's learning outcomes (SLOs)

**After studying this chapter, students will be able to:**

- state that there are positive and negative charges [and charge is measured in coulombs].
- state that unlike charges attract and like charges repel.
- describe experiments to show electrostatic charging by friction.
- explain that charging of solids by friction involves only a transfer of negative charge (electrons).
- explain how a conductor can be charged by electrostatic induction and then "earthing."
- suggest how charging and discharging is used in the application of various devices (e.g., photocopier and electrostatic precipitator).
- describe an electric field as a region in which an electric charge experiences a force.
- state that the direction of an electric field line at a point is the direction of the force on a positive charge at that point.
- discuss and illustrate simple electric field patterns (including the direction of the field):
  - (a) around a point charge
  - (b) around a charged conducting sphere
  - (c) between two oppositely charged parallel conducting plates (end effects will not be examined).
- state examples of electrical conductors and insulators.
- describe an experiment to distinguish between electrical conductors and insulators.

- state and use a simple electron model to explain the difference between electrical conductors and insulators.
- explain how a lightning rod can protect humans.
- explain electrical breakdown (it occurs when a strong electric field passes through a gas and causes its atoms to ionize).
- state that corona discharge and Lichtenberg figures are visible examples of electrical breakdown.

Electrostatics is a branch of physics which deals with the study of charges at rest. It focuses on understanding the interaction between charges and electric field they create. Electrostatics plays an important role in everyday life. In this chapter, we will cover topics such as electric charge and its properties, electrostatic induction, applications of electrostatics, Coulomb's law and electric field. In addition to this, we will also learn about the practical applications and safety precautions related to the electrostatics.

## 15.1 Electric Charge

When a plastic comb (or rod) is rubbed through dry hair and is brought near small pieces of paper, it attracts them (Fig. 15.1). Similarly, amber rod when rubbed with silk attracts small pieces of paper. We often experience a shock when we touch a metal doorknob, after sliding across a car seat or walking on a synthetic carpet. In each of these cases, the electrostatic force, resulting from electric charges, is in action. This phenomenon of attraction or repulsion between objects is due to a property called electric charge. We have already learnt that an object's mass is an inherent property. Objects with smaller mass have less inertia than those with larger mass. Similarly, another intrinsic property of an object is its electrical charge. There are two types of electric charges, known as positive and negative, which can be

Fig. 15.1: Comb rubbed with dry hair attracts small pieces of paper

demonstrated through a simple experiment (Fig. 15.2). The SI unit of charge is the coulomb (C).

Figure. 15.2 shows electrostatic interactions between glass and plastic rods after being charged by friction. In the first scenario (a), two glass rods that have been rubbed with silk cloth are brought close to each other. Since both rods acquire a positive charge, they repel each other due to the fundamental principle that like charges repel. In the second scenario (b), two plastic rods, likely rubbed with wool or fur, are placed near each other. Both rods gain a negative charge, leading to repulsion, as similar charges push away from each other. Lastly, in scenario (c), a positively charged glass rod (rubbed with silk) is brought near a negatively charged plastic rod (rubbed with fur or wool). Unlike the previous cases, attraction is observed because opposite charges attract. This set of experiments clearly demonstrates the basic electrostatic rule that like charges repel while opposite charges attract.

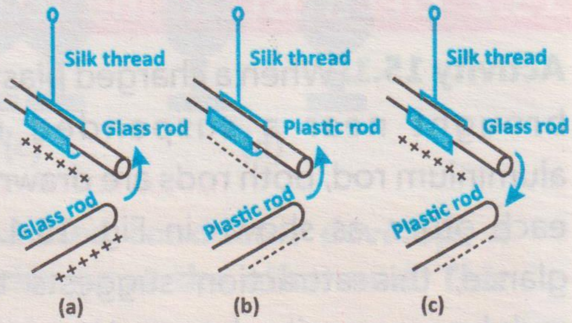

Fig. 15.2: Electrostatic interactions between glass rods and plastic rods after being charged by friction

## Properties of Charges

Matter is composed of atoms, which consist of subatomic particles. Among these, protons are positively charged particles located in the nucleus, while electrons are negatively charged particles that orbit around the nucleus (Fig.15.3). Since everything is composed of atoms, every material carries either a positive charge, a negative charge, or neutral. Charge is an essential property of materials that causes them to either attract or repel . Charge can be transferred between objects through various processes, including rubbing, direct contact, or induction. The total amount of charge in an isolated system remains constant.

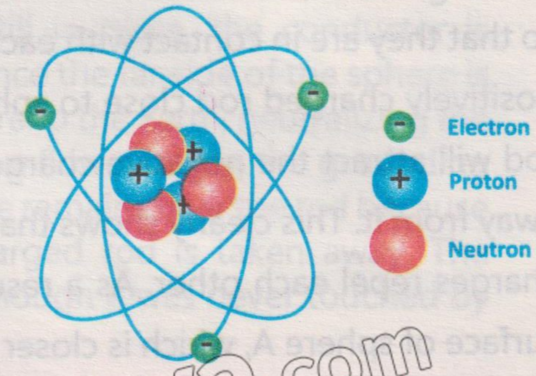

Fig. 15.3: Structure of an atom

## 15.2 Electrostatic induction

**Do You Know?**

When a charged rod is brought near a conductor without touching it, the conductor still gets charged. That is the amazing effect of electrostatic induction.

**Activity 15.1:** When a charged plastic rod is brought near a suspended neutral aluminium rod, both rods are drawn toward each other, as shown in Fig. 15.4. At first glance, this attraction suggests that the rods have opposite charges. However, this is not the case. The charged plastic rod causes a redistribution of positive and negative charges within the neutral aluminium rod, leading to the attraction. Despite this, the total charge on the aluminium rod remains zero. This indicates that attraction alone is not a reliable method to determine if an object is charged. The observed behaviour is an example of a phenomenon known as electrostatic induction.

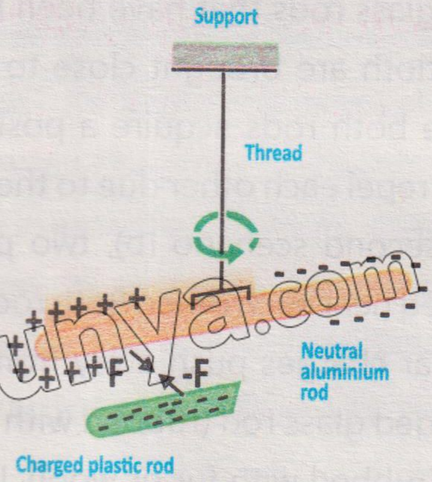


Fig. 15.4: Charged plastic rod attracts neutral aluminium rod

**Activity 15.2:** Take two metal spheres, A and B, and place them on insulated stands so that they are in contact with each other, as shown in Fig. 15.5(a). Now bring a positively charged rod close to sphere A, as shown in Fig. 15.5(b). The charged rod will attract the negative charges towards it and repel the positive charges away from it. This clearly shows that unlike charges attract each other, while like charges repel each other. As a result, negative charge accumulates on the left surface of sphere A, which is closer to the rod, while positive charge appears on the right surface of sphere B.

Now separate the spheres while keeping the charged rod near sphere A. Upon testing the two spheres, we will find that they are oppositely charged, as shown in Fig. 15.5(c). After removing the rod, the charges are evenly distributed across the surfaces of the spheres, as seen in Fig. 15.5(d). In this process, equal and opposite charges appear on each sphere. This phenomenon is known as charging by induction.

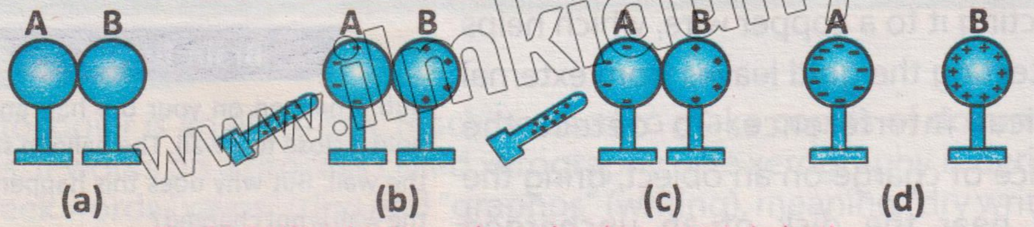


Fig. 15.5: Charging two spheres by electrostatic induction

**In the presence of a charged object, an insulated conductor develops a positive charge at one end and a negative charge at the other end. This process is known as electrostatic induction.**

## Charging by Induction and Earthing

Charging by induction is a method of charging a conductor without directly touching it with a charged object. It involves the redistribution of electric charges within a conductor when exposed to a nearby electric field. Suppose we bring a negatively charged rod near a neutral metal sphere (conductor).The presence of the negatively charged rod causes free electrons in the conductor to move away due to repulsion, leaving the side near the rod positively charged and the far side negatively charged. This separation of charges is called electrostatic induction.

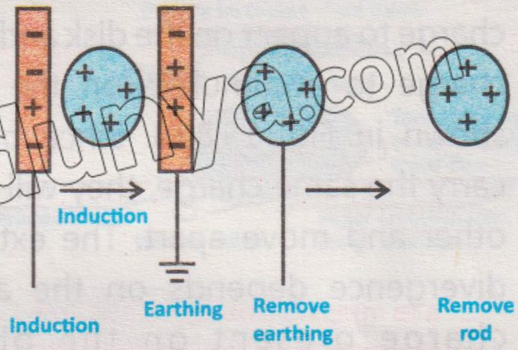


Fig. 15.6: Charging a conductor by induction and earthing

Earthing is the process of connecting a conductor to the Earth using a conducting wire. While the charged rod is still in place, the conductor is connected to the Earth using a wire (Fig. 15.6). Since the far side of the sphere is negatively charged, electrons flow from the sphere to the Earth, neutralizing the negative charge. After the unwanted charges have flowed away, the grounding connection is removed. The excess positive charge remains near the rod because the negative charges have left. Finally, the charged rod is taken away. The conductor now has a net positive charge, even though it was never touched by the rod.

## Electroscope

The gold leaf electroscope is a sensitive device which is used to detect electric charges. It consists of a brass rod with a brass disk at the top and two thin gold leaves suspended at the bottom, as shown in Fig. 15.7. The rod passes through an insulating material, which holds it in place. Charges can move freely from the disk to the leaves via rod. Additionally, a thin aluminum foil is attached to the lower part of the inside of the jar. This aluminum foil is typically grounded by connecting it to a copper wire, which helps in protecting the gold leaves from external electrical interference. To detect the presence of charge on an object, bring the object near the disk of an uncharged electroscope. If the object is neutral, there will be no deflection of the leaves, as shown in Fig. 15.8(a). However, if the object is charged either positively or negatively the leaves of the electroscope will diverge. For example, if the object is negatively charged, electrostatic induction will cause a positive charge to appear on the disk and a negative charge to accumulate on the leaves, as shown in Fig. 15.8(b). Since both leaves carry the same charge, they will repel each other and move apart. The extent of the divergence depends on the amount of charge present on the object. An electroscope can also serve to distinguish between conductors and insulators. To perform this test, bring a charged object near the disk of the electroscope without allowing contact. If the leaves collapse from their previously diverged position, it indicates that the material is a good conductor, as charge can flow.

**Brain Teaser**

Rub a balloon on your dry hair and then hold it close to a wall. The balloon sticks to the wall. But why does this happen when the wall is not charged?

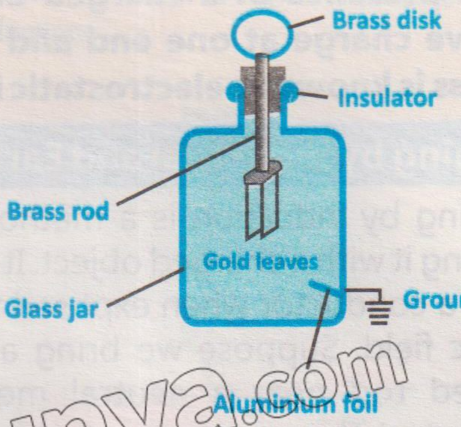

Fig. 15.7: Uncharged electroscope

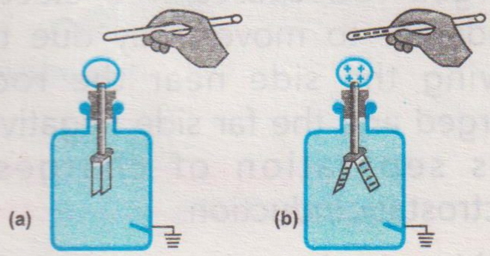

Fig. 15.8: Detecting charge using a gold leaf electroscope

**Brain Teaser**

Why do the leaves of an electroscope diverge when a charged object is brought near, even if the object does not touch the electroscope?

## 15.3 Applications of Electrostatics

There are many application of electrostatics with conductors, as shown in Fig 15.9. Charging and discharging are fundamental processes in the operation of various devices, such as photocopiers and electrostatic precipitators, which rely on electrostatic principles.

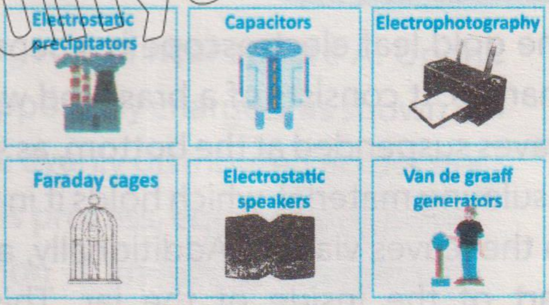

Fig. 15.9: Applications of electrostatics

## Photocopier

A photocopier is an electronic machine used to make copies of documents and images. It works on a process called xerography. The xerography is derived from the Greek words "xeros" (dry) and "graphos" (writing), meaning "dry writing."

The central part of the photocopier machine contains a rotating drum which is composed of aluminium and coated with a layer of selenium. Aluminium is a good conductor of electricity, while selenium is a photoconductor, it behaves like an insulator in the dark but conducts electricity when exposed to light.

The process of photocopier begins by applying a positive charge to the drum. In the dark, this charge stays on the surface of the drum because selenium does not allow current to pass. When light falls on the drum, electrons from the aluminium move through the selenium and remove the positive charge from those areas. When the image of the document is projected on the drum, the bright (light) areas lose their charge, and the dark areas remain positively charged. This creates an invisible electrostatic image on the drum. A fine, dry black powder called toner is given a negative charge and spread over the drum. It sticks only to the positively charged image areas. A neutral sheet of paper passes under the drum with a slightly positive roller behind it, which pulls the toner onto the paper. Finally, the paper goes through heated rollers that melt and press the toner into the paper, making the image permanent.

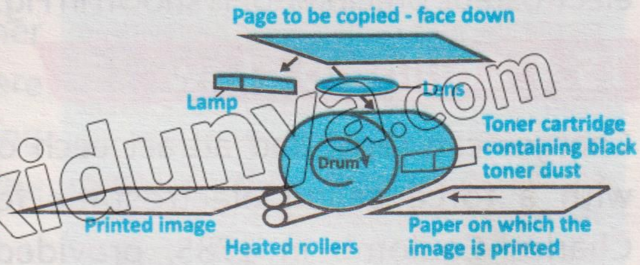


Fig. 15.10: Labelled diagram of a multifunction photocopier machine

## Electrostatic Precipitator

An electrostatic precipitator (ESP) is a device used to remove particulate matter from industrial exhaust gases. Charging and discharging are critical to its operation. Corona discharge is an electrical phenomenon where a high-voltage ionizes the air around a conductor (e.g., a thin wire), creating a plasma region that releases electrons. These electrons attach to nearby gas molecules, forming negative ions. The device charges the particles in the gas stream by passing them through a corona discharge, which imparts a negative charge to the particles. These charged particles are then attracted to positively charged collection plates, where they adhere and are removed from the gas stream. Periodically, the collection plates are discharged to remove the accumulated particles, which fall into a hopper for disposal. This process ensures efficient removal of pollutants from the air, making electrostatic precipitators essential in reducing industrial emissions. Both applications demonstrate how controlled charging and discharging can be harnessed for practical and environmentally beneficial purposes. The diagram of an electrostatic precipitator is shown in Fig. 15.11.

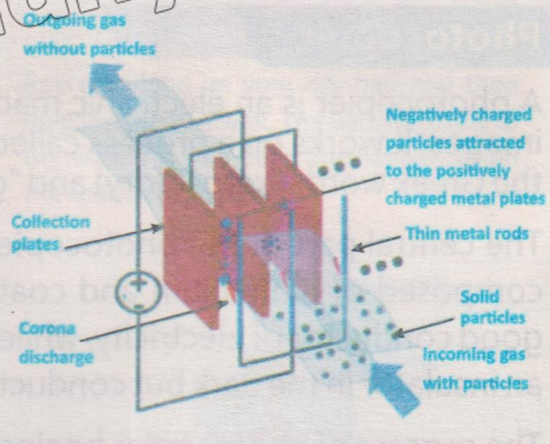

Fig. 15.11: Electrostatic precipitator

## 15.4 Coulomb's Law

Charges can repel and attract each other with a force called electrostatic force. Charles Coulomb in 1785, provided an experimental law to explain the nature and magnitude of electrostatic force between the charges. Coulomb's law states that;

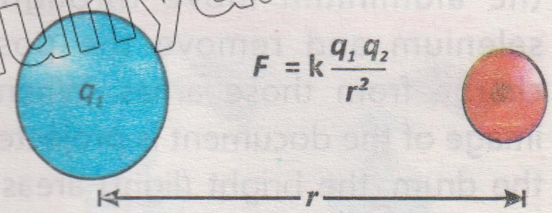

Fig. 15.12: Coulomb's law

**The magnitude of the electrostatic force between two point charges is directly proportional to the product of magnitude of these charges and inversely proportional to the square of the distance between them.**

Consider two charges $q_1$ and $q_2$, seperated by distance $r$ (Fig.15.12).

Mathematically;

$$F \propto q_1 q_2 \quad \text{.............} \quad (15.1)$$

and $$F \propto \frac{1}{r^2} \quad \text{.............} \quad (15.2)$$

or $$F \propto \frac{q_1 q_2}{r^2}$$

or $$F = k\frac{q_1 q_2}{r^2} \quad \text{.............} \quad (15.3)$$

where k is a constant of proportionality which quantifies the strength of the electrostatic force between two point charges. The value of k is determined by the medium between the charges. In vacuum or air, k is approximately $9 \times 10^9$ N $m^2$ $C^{-2}$. Coulomb's law is applicable primarily to point charges whose sizes are negligible compared to the distance separating them.

**Do You Know?**

***Newton Vs. Coulomb***

- Similar formulae inverse square laws
- Gravitational forces are only attractive
- Are important when dealing with large masses and distances
- Electrical forces are attractive and repulsive
- Are important when dealing with small masses and distances

## 15.5 Electric Field

One charge exerts a force on another charge. This force is present everywhere around the charge, theoretically extending to infinity. However, the strength of the force decreases with distance.

**Tidbit**

If the charges are opposite in sign (one positive and one negative), they will attract each other. If the signs are reversed, making both charges positive or both negative, they will repel each other. The magnitude of the force will remain the same, but the direction of the force will change. This is an example of how Coulomb's law works with both attraction and repulsion.

**An electric field is the region around a charge where it exerts a force on other charges.**

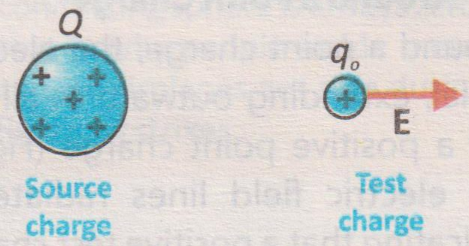


Fig. 15.13: Electric field intensity

The electric field strength decreases with distance from the charge, following an inverse square law for point charges.

Mathematically;

$$E = k\frac{q}{r^2} \quad ............. \quad (15.4)$$

Consider a test charge $q_o$ is brought into the electric field of a source charge Q as shown in Fig. 15.13. The source charge will exert an electrostatic force **F** on the test charge.

**The electrostatic force per test charge (unit positive charge) when it is brought to the electric field of a source charge is called electric field intensity.**

Mathematically;

$$\mathbf{E} = \mathbf{F}/q_o \quad ..............(15.5)$$

The SI unit of electric field intensity is newton per coulomb ($N\,C^{-1}$).

Electric field intensity (electric field strength) is a vector quantity having both magnitude and direction. The direction of electric field intensity at a point will be the direction of force on a positive test charge at that point is same as that of electric force.

> **Do You Know?**
>
> **Electric Fields**
>
> - Electric fields are represented by electric field lines. (imaginary) and show the direction of the force at that point.
> - Electric field direction is from a positive charge to a negative charge.
> - Electric field lines (also known as electric flux) do not cross each other.
> - Electric field lines represent the path that a small positive test charge would follow in an electric field.
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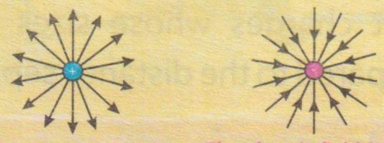
> 
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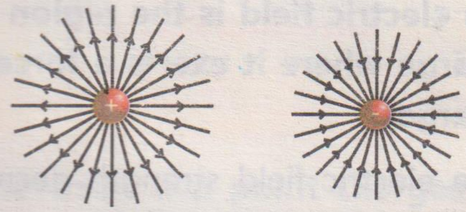
> The electric field for an isolated positive charge — The electric field for an isolated nagative charge

## Electric Field Lines

The concept of an electric field demonstrates how a charged object affects other nearby charged objects. The electric field is a vector field, which means it has both magnitude and direction. The direction of the electric field at any point is the direction in which a positive test charge would move if placed at that location. Here, we will explain and show the electric field patterns for three common situations:

### (a) Around a Point Charge

Around a point charge, the electric field is radial, extending outward in all directions. For a positive point charge (Fig. 15.14-a), the electric field lines radiate outward, indicating that a positive test charge placed nearby would be repelled. In contrast, for a negative point charge (Fig. 15.14-b), the electric field lines point inward, showing that a positive test charge would be attracted towards it. This reflects the repulsive force around positive charges and the attractive force around negative charges.



(a) (b)

**Fig. 15.14:** Electric field lines for isolated positive and negative point charges

### (b) Around a Charged Conducting Sphere

A charged conducting sphere distributes its charge evenly on its surface, and the electric field around it behaves similar to that of a point charge, but only outside the sphere. Outside, the electric field lines are radial,

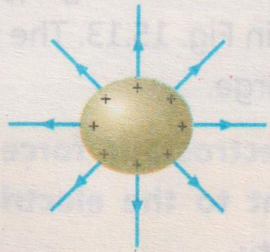


**Fig. 15.15:** Charge distribution on a positively charged sphere

radiating outward for a positively charged sphere and inward for a negatively charged one (Fig. 15.15). Inside the sphere, the electric field is zero because the charges on the surface rearrange to cancel any internal electric field.

### (c) Between Two Oppositely Charged Parallel Conducting Plates

When two large parallel conducting plates are given equal and opposite charges, a uniform electric field is created between them, commonly used in capacitors (Fig. 15.16). The electric field lines point from the positively charged plate to the negatively charged plate, and they are parallel and equally spaced, showing a uniform electric field. This uniformity means the electric field has the same magnitude and direction at all points between the plates, which is due to the plates being large and close together, minimizing edge effects.

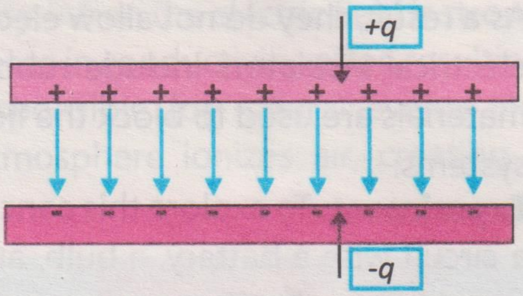



Fig. 15.16: Electric field between two oppositely charged parallel plates

**Example:** A point charge $q = 10\ \mu C$ is placed in air. Calculate the electric field at a distance of 0.5 m from the charge.

**Solution:**

Given that;

$k = 9.0 \times 10^9\ N\ m^2\ C^{-2}$

$q = 10 \times 10^{-6}\ C$

*and* $r = 0.5\ m$

To find; $E = ?$

Using the formula:

$E = kq / r^2$

Substituting the values

$E = (9.0 \times 10^9 \times 10 \times 10^{-6}) / (0.5)^2$

$E = 3.6 \times 10^5\ N\ C^{-1}$

**Do You Know?**

The electric field inside a charged conducting sphere is always zero, that is why people inside metal cars or airplanes are safe during lightning strikes.

## 15.6 Conduction of Electric Charges

### Electrical Conductors

Electrical conductors are materials that allow electric charge to flow freely through them. They have loosely bound electrons in their atomic structure, which can flow easily when a voltage is applied, creating an electric current.

Examples of electrical conductors include metals, such as copper, aluminum, and silver, as well as materials like graphite and electrolytes .

## Electrical Insulators

Eléctrical insulators are materials that resist or prevent the flow of electric charge. In insulators, electrons are tightly bound to their atoms and cannot move freely. As a result, they do not allow electric current to pass through them. Examples of electrical insulators include rubber, plastic, glass, wood, and ceramics . These materials are used to block the flow of electricity and provide safety in electrical systems.

**Experiment:** To explore this concept, we can conduct a simple experiment: Build a circuit with a battery, a bulb, and a gap to test materials. Insert objects like a metal key, a plastic spoon, or a wooden stick into the gap. If the bulb lights up, the material is a conductor; if it stays OFF, it is an insulator. This hands-on activity turns us into an electricity detective, revealing the hidden properties of everyday items.

## Free Electron Model

Electrical conductors and insulators can be explained using a simple electron model. In conductors, such as metals, the outermost electrons of atoms are loosely bound and can move freely throughout the material. These "free electrons" act like a sea of mobile charges, allowing electric current to flow easily when a voltage is applied. In contrast, insulators, like rubber or plastic, have electrons that are tightly bound to their atoms and cannot move freely. When a voltage is applied to an insulator, the electrons remain fixed, preventing the flow of electric current. This difference in electron behaviour explains why conductors allow electricity to flow while insulators block it.

# 15.7 Accumulation of Charges

The accumulation of charges, often referred to as static electricity, occurs when electrons are transferred from one object to another, leading to an imbalance of positive and negative charges. This buildup can have several consequences. In everyday life, it can cause minor shocks when touching metal objects or make clothes cling together. In industrial settings, accumulated charges can be more serious, potentially damaging electronic components, igniting flammable substances, or disrupting manufacturing processes. Proper grounding, antistatic measures, and humidity control are often employed to mitigate these risks and prevent the harmful effects of charge accumulation.

## Electrical breakdown

Electrical breakdown occurs when a strong electric field passes through a gas (or insulating material), causing its atoms to ionize. This ionization creates free electrons and ions, which can conduct electricity. When the electric field is strong enough, it can lead to a sudden, dramatic increase in conductivity, often resulting in a spark or arc. This phenomenon is responsible for natural events like lightning, where the electric field in the atmosphere ionizes air, creating a conductive path for the discharge.

### Corona discharge

Corona discharge is a visible form of electrical breakdown that occurs when a high-voltage electric field ionizes the air around a conductor, typically near sharp points or edges where the electric field is the strongest (Fig . 15.17). This ionization produces a faint glow or "corona" and is often seen around high-voltage power lines or antennas, while less intense than a full spark.

**Tidbit**

When the electric field around a high-voltage power line becomes intense, it can ionize nearby air molecules. This causes a phenomenon known as **corona discharge,** where the air gives off a faint blue or violet glow. This is why we may see a bluish light near sharp edges of electrical equipment in the dark.

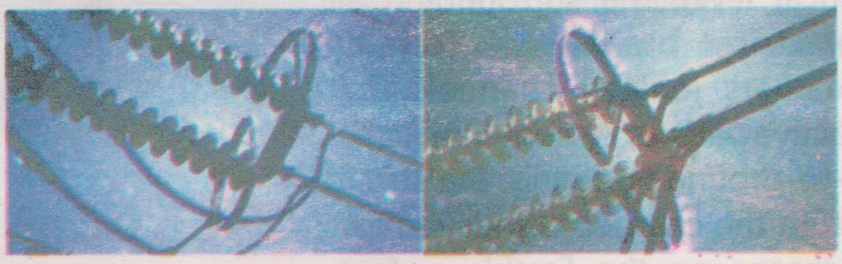


Fig. 15.17: Corona discharge

### Lichtenberg Figures

These are branching, tree-like patterns that form on insulating materials (like wood or acrylic), when a high-voltage electrical discharge passes through them as shown in Fig 15.18. The patterns result from the electrical breakdown of the material, leaving behind visible traces of the discharge path. They are named after the German physicist Georg Christoph Lichtenberg, who first documented them. Both corona discharge and Lichtenberg figures are visible examples of electrical breakdown, demonstrating how strong electric fields can ionize materials and create conductive paths.

A sequence of zooms showing the "self-similar" property of lichtenberg figures

Fig. 15.18: Self-Similarity in lichtenberg figures

## Lightning conductors

Lightning conductors, or lightning rods, are protective devices installed on tall structures to safeguard them from lightning strikes. A lightning rod provides a low-resistance path for the electrical discharge to follow, directing the massive current safely into the ground. This prevents the lightning from passing through the building, which could cause fires, structural damage, or harm to humans. By channeling the lightning's energy safely away, the rod protects both the structure and its occupant (Fig. 15.19).

Lightning is generated through a complex process involving charge separation, electric field buildup, and discharge. It begins with friction between water molecules suspended in clouds during thunderstorms or between smoke particles in volcanic plumes, leading to the accumulation of electric charge. As these charges separate within the cloud, an intense electric field develops. When this field reaches a critical level, the surrounding air undergoes electrical breakdown, forming lightning streamers ionized channels that create a conductive path for current flow. In the case of cloud-to-ground lightning, the strong electric field from the charged clouds induces an opposite charge on the Earth's surface, particularly in conductive materials. When the electric potential difference becomes large enough, it overcomes air resistance, allowing a rapid discharge of electricity between the cloud and the ground. This discharge results in the brilliant flash and thunder that characterize lightning, with some strikes occurring from cloud to cloud or even from the ground to the cloud in response to charge redistribution.

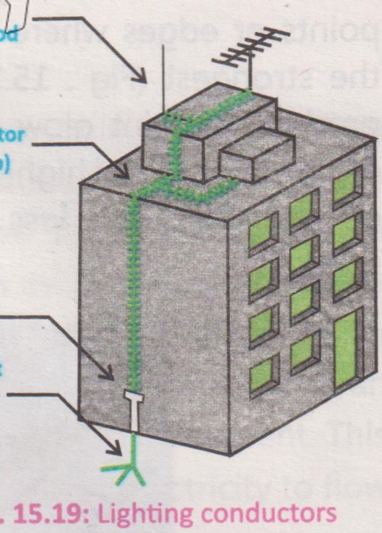



Fig. 15.19: Lighting conductors installed in building

**Do You Know?**

**Lichtenberg figures** are fern-like patterns that may appear on the skin of lightning strike victims that disappear in 24 hours.

## EXCERISE

### A. Multiple Choice Questions

**Tick (✓) the correct answer.**

15.1 Electrical breakdown is:
(a) the process of ionizing a gas due to a strong electric field
(b) the process of neutralizing a charged object
(c) the process of charging an insulator
(d) the process of discharging a conductor

15.2 Which of the following is a visible example of electrical breakdown?
(a) Corona discharge (b) Electric current
(c) Magnetic field (d) Electric potential

15.3 What happens when two unlike charges are brought close to each other?
(a) They attract (b) They repel
(c) They neutralize each other (d) Nothing happens

15.4 According to Coulomb's law, what happens to the attraction of two oppositely charged objects as their distance of separation increases?
(a) Decreases (b) Increases
(c) Remains unchanged (d) Cannot be determined

15.5 The device which works on the principle of electrostatics:
(a) electric bell (b) photocopier (c) electric heater (d) transformer

### B. Short Answer Questions

15.1 State Coulomb's law of electrostatics and write its mathematical form.
15.2 What is an electric field?
15.3 Give two examples each of electrical conductors and electrical insulators.
15.4 List some applications of electrostatics in daily life.
15.5 What happens when like charges and unlike charges are brought close to each other?
15.6 What is meant by electrical breakdown, and when does it occur?
15.7 What are the dangers of static electricity?

### C. Constructed Response Questions

15.1 Why do some materials gain electrons while others lose electrons when rubbed together? What property of the materials determines this behaviour?

15.2 A charged comb attracts small pieces of paper, but after some time, the paper pieces fall off. Why does this happen?

15.3 Why do dust particles often get attracted to television screens or computer monitors after they are turned ON?
the water bends toward the balloon. What does this tell us about the nature of water molecules?

15.4 If we rub a balloon on our dry hair and place it near a thin stream of water, the water bends toward the balloon. What does this tell us about the Nature of water molecules?

15.5 A conductor and an insulator are both placed in an electric field. How will their behaviour differ, and why?

## D. Comprehensive Questions

15.1 Discuss the working of a gold-leaf electroscope. How can it be used to determine the nature and magnitude of charge on a body?

15.2 How does Coulomb's law help in understanding the interaction between charged particles? What factors affect the force between them?

15.3 Explain the concept of electric field intensity. How can the electric field of a point charge and a parallel plate capacitor be represented using field lines?

15.4 Explain how and why electrical conductors and insulators behave differently in terms of charge transfer and movement of electrons.

15.5 Discuss how electrostatics plays a role in real-life hazards, such as dust explosions in factories and static shocks from synthetic clothing. How can these hazards be minimized?

## E. Numerical Problems

15.1 A positive test charge of 25 µC is placed in an electric field. The force on it is 0.500 N. What is the magnitude of the electric field at the location of the test charge? **[Ans: $2.0 \times 10^4$ N $C^{-1}$]**

15.2 Two point charges, $q_1$ = 8 µC and $q_2$ = 4 µC, are placed at a distance of 120 cm. What will be the Coulomb's force between them? Also, find the nature of the force. **[Ans: 0.2 N, the direction of repulsion]**

15.3 Two identical charges repel each other with a force of 0.2 N when they are 9 cm apart. Find the force between them when they are 3 cm apart. **[Ans: 1.8 N]**

15.4 A point charge $q$=10 µC is placed in air. Calculate the electric field strength at a distance of 0.5 metres from the charge. **[Ans: $3.6 \times 10^5$ N $C^{-1}$]**

15.5 Two small equally charged metal spheres having charge 3 µC are brought close together such that the distance between them is 2.0 cm. Calculate the magnitude of repulsive force that each sphere exerts on the other. **[Ans: 202.5 N]**

15.6 Two small equally charged metal spheres repel each other with a force of 0.5 N when placed 3 cm apart in the air. Calculate the charge on each sphere. **[Ans: 224 µC]**

15.7 A force of 85 N acts between two charges placed 3.2 cm apart. If one charge is 25 µC, determine the other charge. **[Ans: 3.87 µC]**