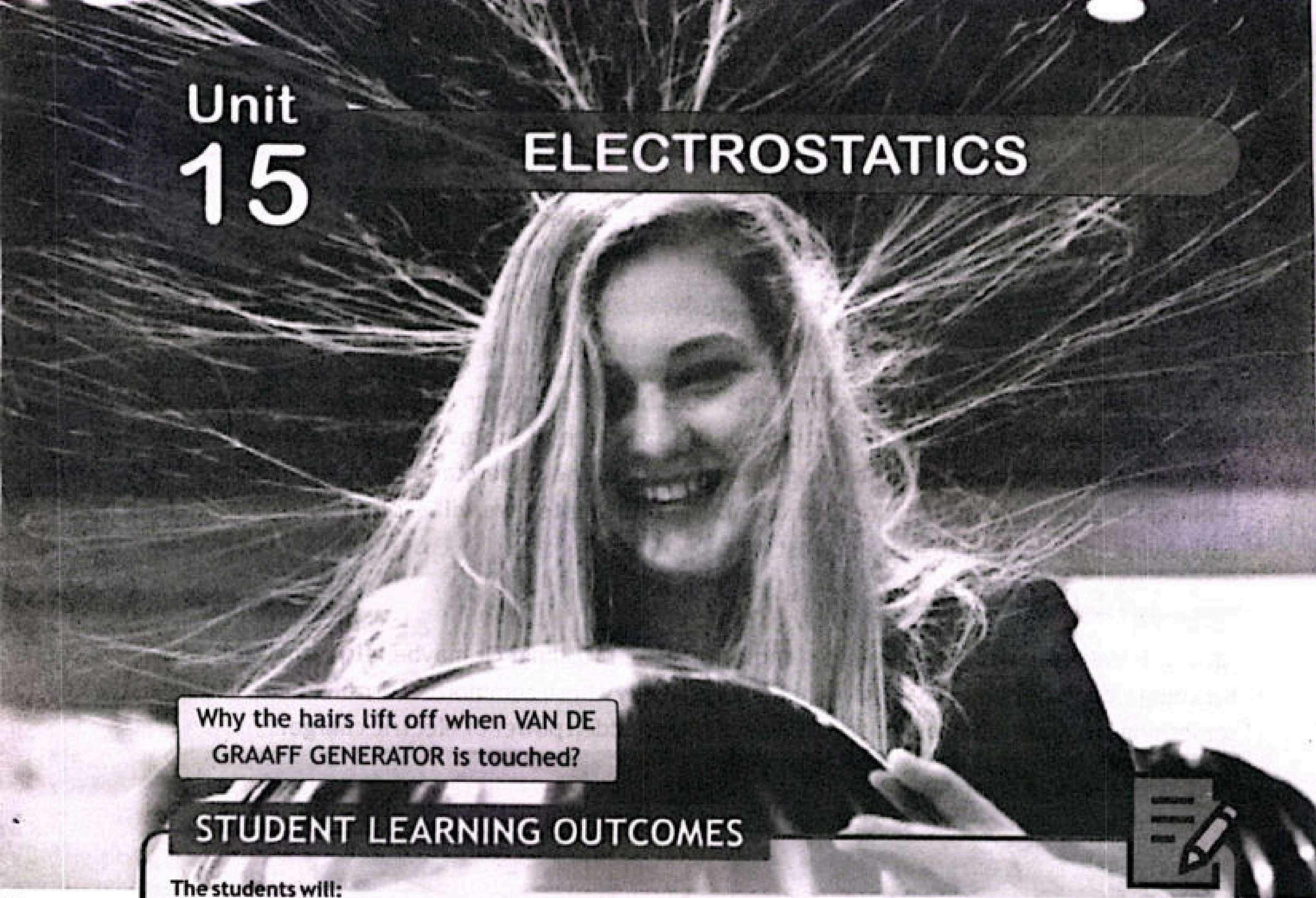


Unit 15 ELECTROSTATICS

Why the hairs lift off when VAN DE GRAAFF GENERATOR is touched?

STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-E-01] State that there are positive and negative charges.
- ✓ [SLO: P-10-E-02] State that unlike charges attract and like charges repel.
- ✓ [SLO: P-10-E-03] Describe experiments to show electrostatic charging by friction.
- ✓ [SLO: P-10-E-04] Explain that charging of solids by friction involves only a transfer of negative charge (electrons).
- ✓ [SLO: P-09-E-05] Explain how and why an insulator can be discharged by (a) putting it above a flame, and (b) exposing it to damp conditions.
- ✓ [SLO: P-10-E-06] Explain how a conductor can be charged by electric induction and then "earthing".
- ✓ [SLO: P-10-E-07] Describe examples where charging could be a problem e.g. lightning.
- ✓ [SLO: P-10-E-08] Suggest how charging and discharging is used in the application of various devices.
- ✓ [SLO: P-10-E-09] Describe an electric field as a region in which an electric charge experiences a force.
- ✓ [SLO: P-10-E-10] 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.
- ✓ [SLO: P-10-E-11] Analye and illustrate simple electric field patterns.
- ✓ [SLO: P-10-E-12] State examples of electrical conductors and insulators.
- ✓ [SLO: P-10-E-13] Describe an experiment to distinguish between electrical conductors and insulators.
- ✓ [SLO: P-10-E-14] state and use a simple electron model to explain the difference between electrical conductors and insulators.

- ✓ [SLO: P-10-E-15] Explain how a lightning rod can protect humans.
- ✓ [SLO: P-10-E-16] Explain electrical breakdown.
- ✓ [SLO: P-10-E-17] State that Corona discharge and Lichtenberg figures are visible examples of electrical breakdown.
- ✓ [SLO: P-09-E-18] Explain how lightning is generated.
- ✓ [SLO: P-10-E-19] State that there are many kinds of atmospheric lightning.

Electricity and magnetism are the governing forces behind everything we observe in the physical world. These electromagnetic forces control the structure of atoms and all materials. We are surrounded by light and other electromagnetic waves. The understanding of these forces is a remarkable achievement in the field of science. In this chapter, we will explore charges that are not moving and hence the name electrostatics.

15.1 STATIC CHARGE

Have you ever experienced your hair standing up after brushing? Or maybe felt a small jolt when touching a doorknob after leaving your car? Surprisingly, these common occurrences are all due to something known as electrostatic force, which is the hidden power of electric charge.

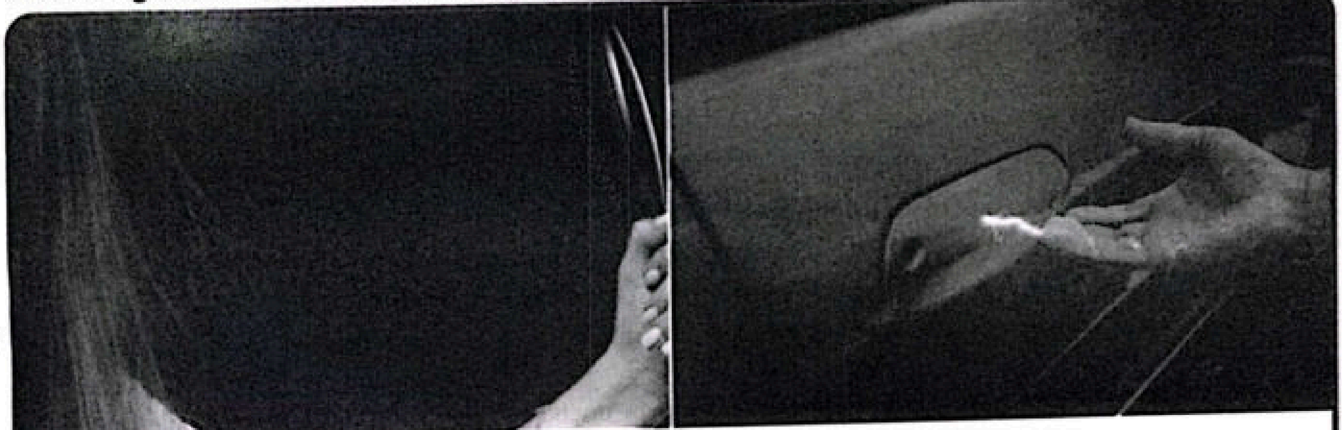


FIGURE 15.1 Electrostatic phenomena

Charge is measured in coulombs (C), named for the French physicist Charles A. de Coulomb (1736-1806), who discovered a relationship between electric force and charge.

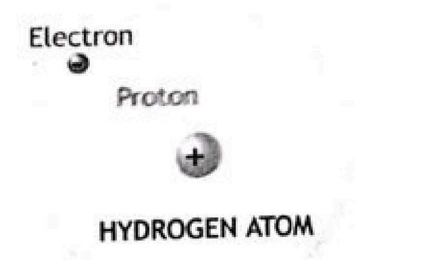


FIGURE 15.2 Structure of atom

Everything surrounding you, from your hair to your clothes and even the doorknob, is composed of minuscule building blocks called atoms. Inside these atoms are even tinier particles - some with a positive charge (+) inside nucleus known as protons, and others with a negative charge (-)

clouding around nucleus called electrons, whereas, neutrons with no charge are also found inside the nucleus. Refer to figure 15.2 and Table 15.1 for more details.

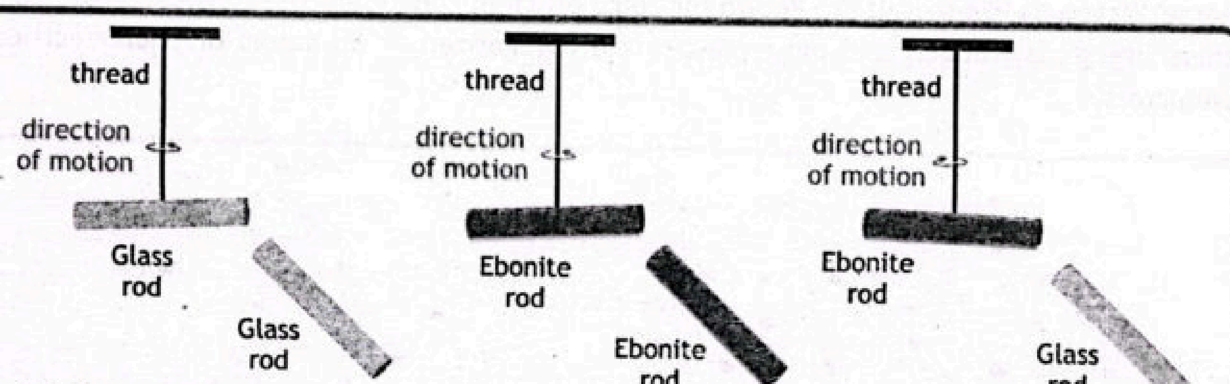
How do we know that charges are of two types? When you rub a glass rod vigorously with a silk cloth and hang it up, then bring another glass rod rubbed with silk close to it, the glass rods will push away from each other. The same goes for ebonite (hard rubber) rods rubbed with fur - when you hang one up and bring another close, they will also repel.

TABLE 15.1: BASIC PARTICLES AND THEIR CHARGES

Particle	Charge (C)	Mass (kg)
electron	-1.6×10^{-19}	9.109×10^{-31}
proton	$+1.6 \times 10^{-19}$	1.673×10^{-27}
neutron	0	1.675×10^{-27}

Now, if you hang a glass rod rubbed with silk and bring an ebonite rod rubbed with fur near it, they will be attracted to each other. The same thing happens when you hang an ebonite rod rubbed with fur and bring a glass rod rubbed with silk close - they will attract.

This experiment proves that there are two types of charges: like charges repel, while opposite charges attract as shown n figure 15.3. According to Newton's third law of motion, the repulsive and attractive forces are balanced and act on different objects.



(a) Glass rod rubbed with silk cloth brought near another suspended glass rod rubbed with silk cloth. Repulsion is observed.

(b) Ebonite rod rubbed with animal fur brought near another suspended Ebonite rod rubbed with animal fur. Repulsion is observed.

(c) Glass rod rubbed with silk cloth brought near a suspended Ebonite rod rubbed with animal fur. Attraction is observed.

FIGURE 15.3 Experimental demonstration of like charges repel and opposite charges attract

15.1.1 CHARGE IS CONSERVED

Charge cannot be created or destroyed, so how does an object get charged? When objects are charged, electric charge is not actually created; instead, charges are simply transferred between the objects, which is known as electrification. The excess charge is most commonly produced by a transfer of electrons, not protons. Protons are bound in the nucleus and, under most common situations, stay fixed.

When a glass rod is rubbed with a silk cloth, both the glass rod and silk cloth become charged. The electrons from the glass rod move to the silk cloth, making the glass rod positively charged. At the same time, the silk cloth gains electrons and becomes negatively charged. This silk cloth will repel a hanged rubber rod rubbed with fur just like as it was repelled by another rubber rod rubbed with fur. Similarly, when a rubber rod is rubbed with animal fur, both materials become charged. Electrons move from the animal fur to the rubber rod, giving the rubber rod a negative charge and the animal fur a positive charge.

When you charge an object, you either add or remove electrons. If you remove electrons, the object will have a positive charge; if you add electrons, it will have a negative charge. The number of protons in the object remains constant in both cases. The change in charge is a result of gaining or losing electrons. The net charge in solids is due to an excess or deficiency of electrons.

15.2 CONDUCTORS AND INSULATORS

Conductors are distinguished from insulators by their capacity to conduct or transmit electric charge. Materials like metals are known for being efficient conductors of electric charge, while others like glass, rubber, and most plastics are categorized as insulators or poor electrical conductors.

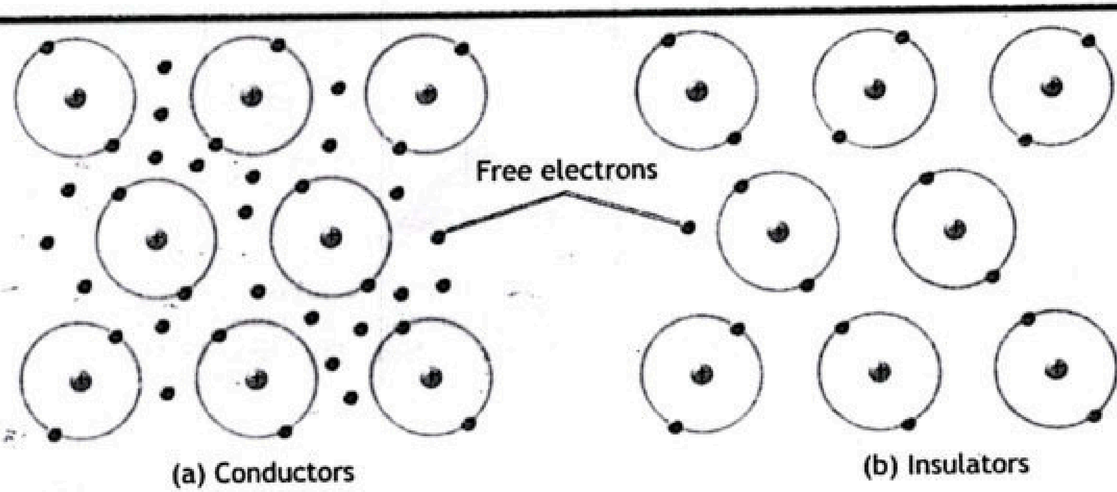


FIGURE 15.4 Free electron model for conductors and insulators

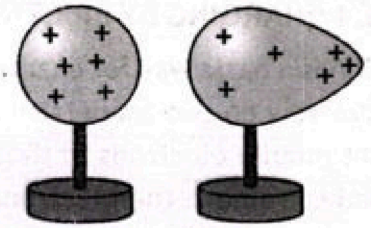
In conductors, the valence electrons, which are the electrons in the outermost atomic orbits, are loosely bound to their atoms. This loose binding allows the electrons to be easily detached from the atom, enabling them to move freely within the conductor or even leave the conductor entirely as shown in figure 15.4 (a).

Unlike in other materials, the presence of these mobile electrons, known as free electrons, is significant in conductors. As a result, conductors can efficiently transfer electric charge.

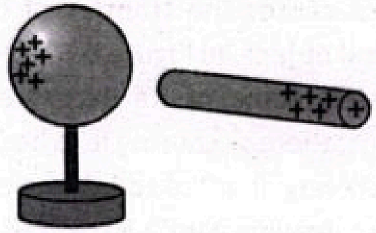
On the other hand, in insulators, even the least tightly bound electrons are firmly attached to their atoms. As a result, these electrons cannot move freely, preventing charge from flowing through the material. This strong attachment means that electric charge cannot be easily redistributed or removed from an insulator, making it ineffective for conducting electric charge compared to conductors as shown in figure 15.4 (b).

When a charge is placed on a spherical conductor, it spreads out evenly across its surface. However, on other shapes, charges have a tendency to repel each other and move towards the more pointed areas as shown in figure 15.5 (a).

However, insulators on the other hand, do not allow charges to move easily, therefore the charge will remain in the spot where it is introduced as shown in figure 15.5 (b).



(a) On a spherical conductor, the charge spreads out evenly. On other shapes of conductors, the charges tend to repel one another toward the more pointed surfaces.



(b) On an insulator, the charge remains in the spot where it was introduced.

FIGURE 15.5 Charge distribution

This means that when you create a charge on one part of an insulator, such as rubbing wool on a plastic rod, the charge will stay in that area while the rest remains neutral due to the restricted movement of charges in insulators.

15.3 CHARGING AND DISCHARGING

Sliding across a car seat results in the transfer of electrons between materials, leading to an accumulation of negative charges on your body. This static charge remains stationary and is known as an electrostatic charge. Friction between surfaces generates this charge, which persists until the electrons can disperse due to their repulsion. Typically, when you reach for a metal doorknob, the electrons find an escape route, resulting in a spark. Metal doorknobs, being good electrical conductors, allow electrons to freely move within the material. Conversely, if you touch plastic or wood, you won't experience a shock. There are three main ways to charge objects: through friction, contact, and induction.

15.3.1 CHARGING BY FRICTION

Friction is a basic way for charge transfer between objects. The direction and amount of charge transfer rely on two properties of atoms: ionization energy and electron affinity. Atomic nuclei attract mobile electrons in their outer orbitals. The stronger the attraction, the more energy needed to remove the electrons. Removing electrons ionizes the atom. The energy needed to remove the outermost electron is called ionization energy.

15.3.2 CHARGING BY CONTACT (CONDUCTION)

When a charged object comes into contact with a neutral object, the excess or deficit of electrons in the charged object causes the transfer of charge to the previously neutral object. In Figure 8.6, a negatively charged object transfers some of its excess electrons to the neutral object, thereby causing it to become negatively charged. A positively charged rod draws electrons out of a neutral object, leaving it with an overall positive charge.

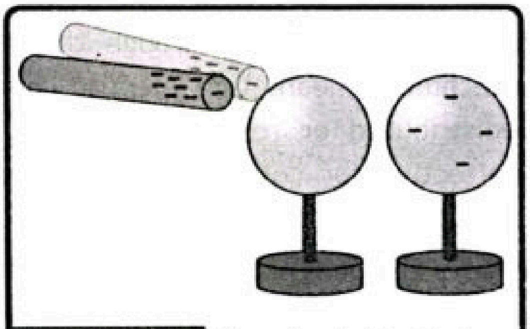


FIGURE 15.6 Charging by Contact.

15.3.3 CHARGING BY INDUCTION

Imagine a negatively charged rubber strip near an insulated metal sphere labeled 'X' as shown in Figure 15.7 (a). The negative charge in the strip repels the electrons in sphere 'X', pushing them towards the far side of the connected sphere labeled 'Y'. This creates a temporary separation of charge within 'Y', with an excess of negative charge on the far side. Importantly, there's no transfer of electrons between the objects.

If we separate spheres X and Y while the charged strip remains nearby as shown in Figure 15.7 (b), the separated charges are "frozen" in place. Sphere X, which lost electrons, becomes positively charged. Sphere Y, with the repelled electrons concentrated on its side, becomes negatively charged. This demonstrates how electrostatic induction can be used to separate charges and

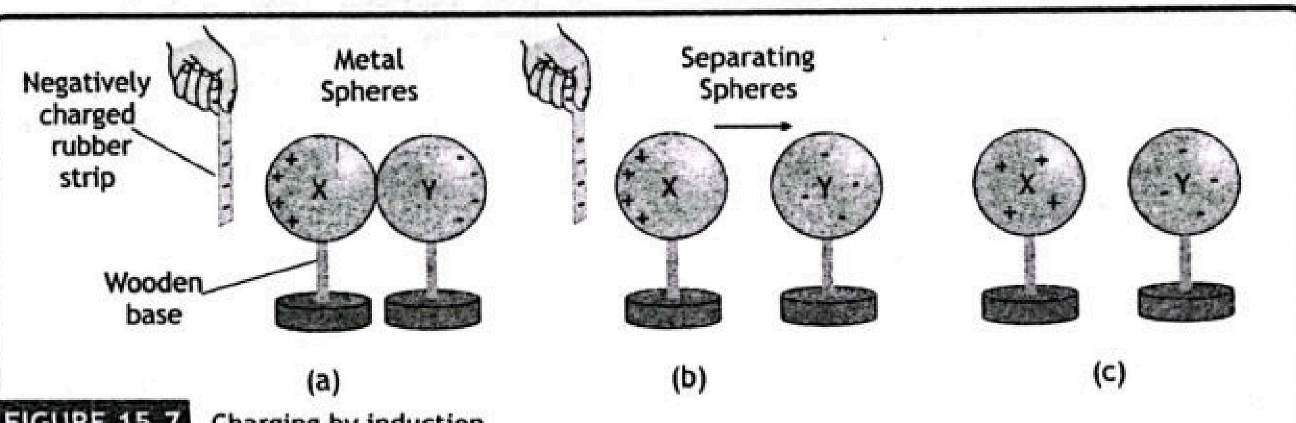
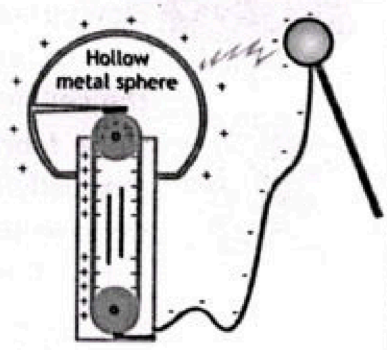


FIGURE 15.7 Charging by induction.

UNIT OPENER?

Why the hairs lift off when Van de Graaff generator is touched?

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.



Van de Graaf Generator

It was invented by American physicist Robert J. Van de Graaff in 1929. A pulley drives an insulating belt by a sharply pointed metal comb which has been given a positive charge by a power supply. Electrons are removed from the belt, leaving it positively charged. A similar comb at the top allows the net positive charge* to spread to the dome.

The strands of their hair all have the same net charge and therefore repel each other strongly, making them to lift off.

create charged objects as shown in Figure 15.7 (c).

From the above two activities, we can conclude that bodies can be charged by a process called electrostatic induction. ***A change in distribution of electrical charge in an object, caused by the influence of nearby charges is called electrostatic induction.***

One way to charge by induction is through grounding. This involves connecting a neutral object to the ground temporarily to let extra charges escape. For instance, if a negatively charged object is brought close to a neutral conductor like a metal sphere, the positive charges in the neutral sphere will be drawn towards the negatively charged object and negative charge will be pushed to side of the object. This causes the electrons in the sphere to move away from the side facing the charged object. Earthing or grounding is giving charge a path to escape into the ground; therefore, by briefly grounding the sphere with a finger, extra electrons can flow into the ground, resulting in the sphere having a net positive charge as shown in figure 15.8.

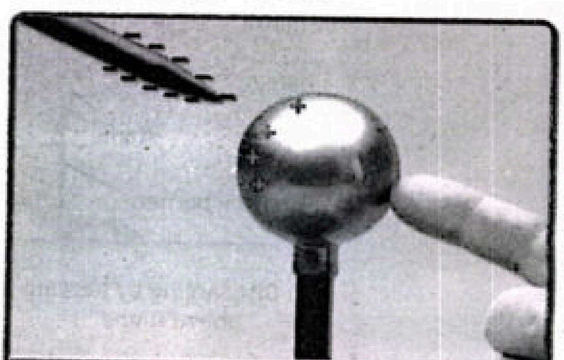
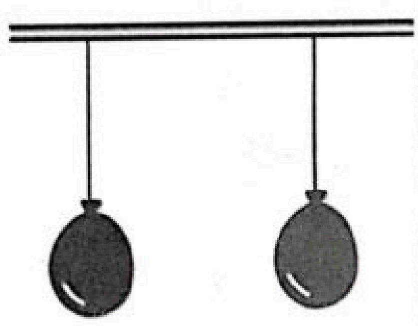


FIGURE 15.8 Using finger as ground

MINI LAB

Blow up two latex balloons, attach a light string to each, and hang them about 1 ft apart from the ceiling or a rod. Rub both balloons with a furry fabric or your hair to charge them. Gradually bring the balloons closer together. Observe for signs of an electric force. If you notice the force, clarify whether it is attractive or repulsive. Also, identify the two key factors influencing the strength of the electric force.

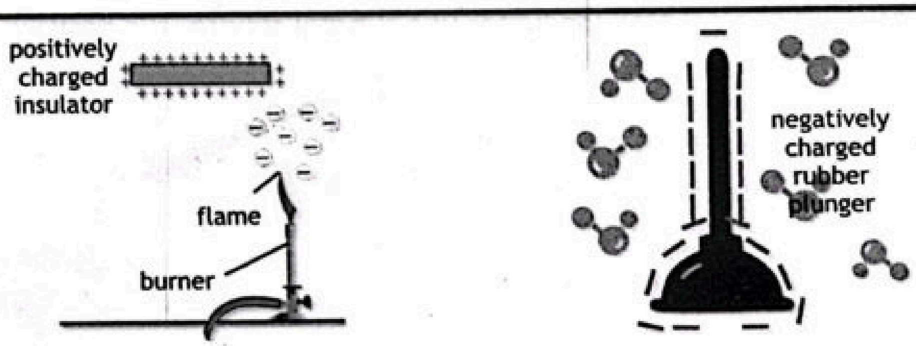


15.3.4 METHODS TO DISCHARGE INSULATORS

Electrical discharging is the process of neutralizing or dissipating electric charges on a material or surface. In conductors, this occurs when excess charge is redistributed or flows away through a conductive path, returning the material to a neutral state. Conductors can be discharged by grounding or applying an opposite charge. Conversely, insulators, which resist electric charge flow, can also be discharged under certain conditions.

Discharging insulators typically requires altering the material's environment to enable charge movement or neutralization. Two effective techniques for discharging insulators include heating them over a flame and exposing them to humid conditions.

- **A. Heating above flame:** When an insulator is heated with a flame, the heat excites the electrons and can make the surrounding air conductive, aiding in charge neutralization. Additionally, the heat can temporarily enhance the surface conductivity of the insulator, allowing static charges to move and discharge as shown in figure 15.9 (a).



(a) Discharging by heating above flame

(b) Discharging by exposing to humid conditions

FIGURE 15.9 Techniques for Discharging Insulators

- **B. Exposing to Humid Conditions:** Placing an insulator in damp conditions promotes discharge by allowing water molecules to adhere to its surface. These polar molecules interact with charged areas, creating a thin conductive layer that facilitates charge movement. Moreover, the ions present in humid air assist in neutralizing static charges on the insulator's surface, making this an effective discharging method as shown in figure 15.9 (b).

15.3.5 A SURFACE CHARGE CAN BE INDUCED ON INSULATORS BY POLARIZATION

Imagine running a plastic comb or brush through your hair. As you rub, some electrons from your hair transfer onto the comb, giving it a negative charge. Now, envision small pieces of paper nearby. These pieces of paper typically have a balanced charge, but when brought close to the negatively charged comb, these pieces of paper fly towards the comb. How is this possible? Why attraction of uncharged objects not repulsion?

The paper pieces start off with an equal number of positive and negative charges. However, when you run a comb through your hair, electrons transfer from your hair to the comb, making the comb negatively charged. This negatively charged comb creates an electric field around it as it approaches the paper. The negative charge on the comb repels the negative charges in the paper, but it also attracts the positive charges. Since positive charges are more mobile within an atom, they move closer to the comb while the negative charges are pushed away. In the end, the attractive force between the negatively charged comb and the positively charged side of the paper becomes stronger than the repulsive force between the comb and the negative charges.

This net attraction pulls the paper pieces towards the comb. The induced movement of positive charges towards the comb creates a stronger overall attraction, like a coordinated team in a tug-of-war winning the battle and bringing the paper closer. The same effect can be seen with a plastic (or amber) rod rubbed with fur, as shown in figure 15.10 (a) and (b). Similarly, a balloon rubbed against hair can attract a falling stream of water as shown in figure 15.10 (c) and (d).

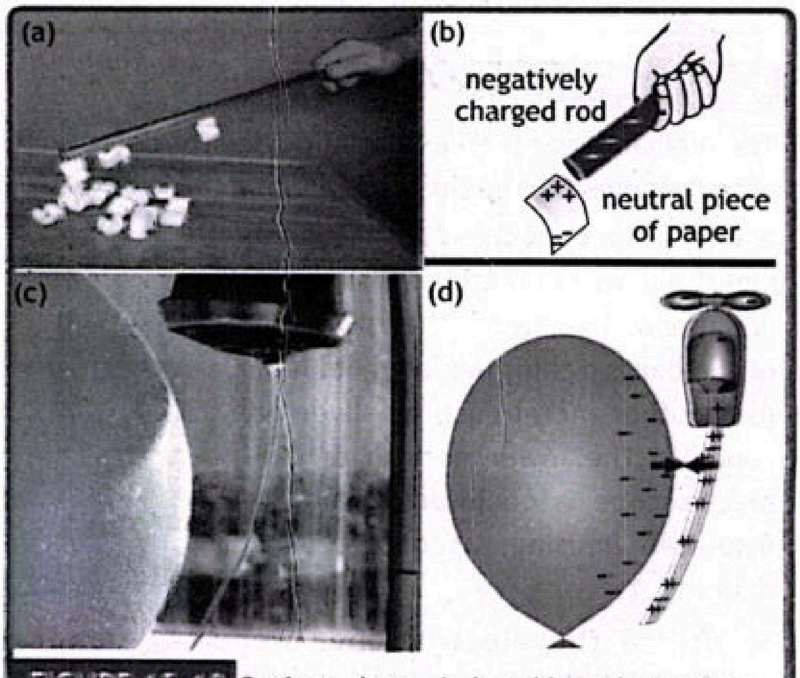
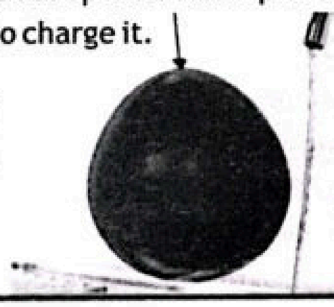


FIGURE 15.10 Surface charge induced by polarization

MINI LAB

Materials required: Baloon and water faucet

Activity: Turn on a water faucet and adjust the flow to create a small but steady stream. The stream should be slow enough to remain continuous, without breaking into individual droplets. Rub a plastic rod, latex balloon, or plastic comb with wool or fur to charge it.



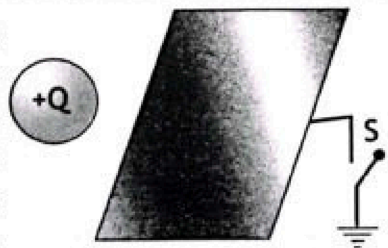
Hold the charged end of the balloon close to the stream of water, but make sure the balloon does not touch the water.

Observation: What happens to the stream of water?

Question: What might be causing this to happen?

CAN YOU TELL?

A metal plate is connected by a conductor to a ground through a switch. The switch is initially closed. A charge +Q is brought close to the plate without touching it, and then the switch is opened. After the switch is opened, the charge +Q is removed. What is the charge on the plate then?



15.4 ELECTROSCOPE

The electroscope is an essential device for detecting and analyzing the charge present on an object. It operates on the principle that like charges repel and vice versa.

A basic electroscope consists of a metal bar with a metallic disk at its upper end. Attached to the lower end of the bar is a thin, flexible gold leaf (or another metal such as silver or copper). The lower portion of the electroscope is enclosed within an insulated housing, as depicted in figure 15.11.

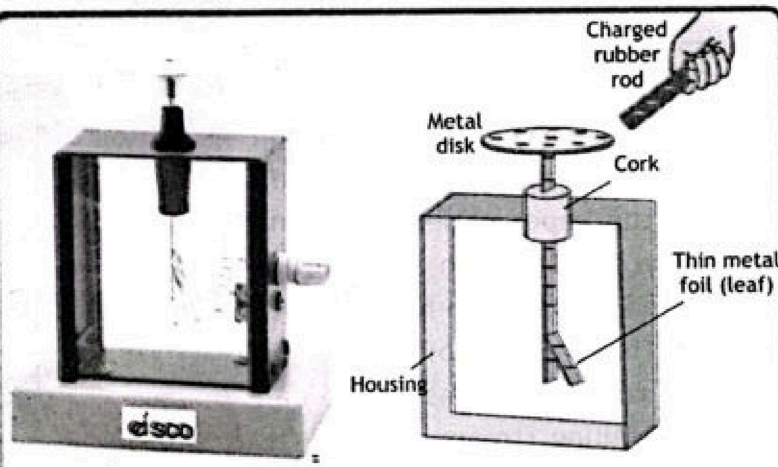


FIGURE 15.11 Gold-leaf electroscope.

To utilize the electroscope, we simply touch the metal disk with the object we wish to examine in order to detect its charge. For instance, if we touch the disk with a negatively charged plastic rod, some of the rod's excess electrons will transfer to the disk. These electrons will then disperse throughout the metal bar and the gold foil due to the phenomenon of electrostatic induction. The similar charge on the metal rod will cause the flexible metal leaf to repel and move away from the rod, rising higher. Likewise, if a positively charged rod is brought near the metallic disk, it will attract electrons from the electroscope, resulting in a net positive charge on the disk. Once again, the foil will rise.

When a charged rod is brought near an electroscope, it shows that the rod is charged, but it doesn't indicate the charge's sign. However, if the electroscope is first given a known type of charge, the sign can be determined. For instance, if electrons are transferred to the electroscope from a negatively charged object, the electrons in the rod will repel each other and some will transfer to the electroscope.

As a result, the leaf of the electroscope will diverge from the metal, indicating that it has been charged as shown in figure 15.12 (a). If a negatively charged rod is brought close to the already negatively charged electroscope, the leaf will diverge even further as more electrons are repelled as shown in figure 15.12 (b). On the other hand, a positively charged rod will attract electrons up to the bulb and away from the leaf area, causing the leaf to collapse as shown in figure 15.12 (c).

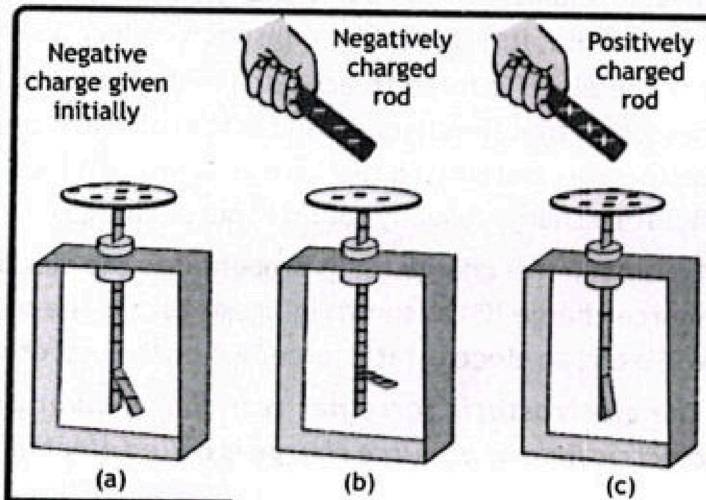


FIGURE 15.12 Determination of sign of charge

It is possible to create a positively charged electroscope using a negatively charged rubber rod through charging by induction. By grounding the electroscope with a finger, electrons can escape from the bulb to the ground as shown in Figure 15.13. When a negatively charged rod is brought close to the bulb, electrons are repelled through the finger and body to the Earth. Removing the finger while keeping the charged rod nearby results in a net positive charge on the electroscope.

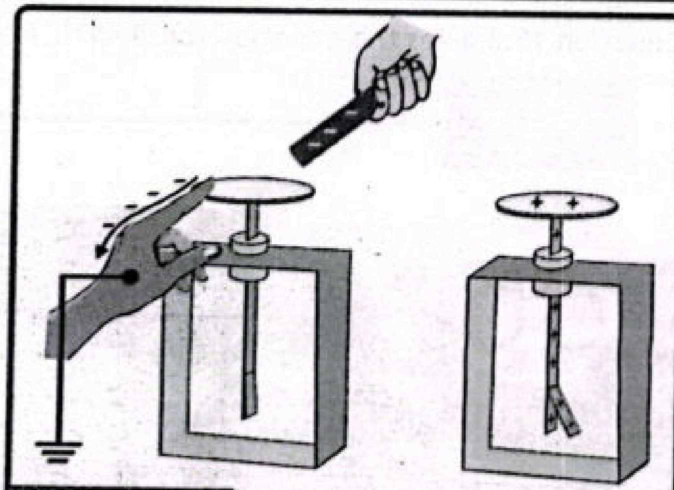


FIGURE 15.13 Induced charge on electroscope

15.5 ELECTRIC FIELD

CAN YOU TELL?

Why on dry days, static electricity is much more noticeable compared to humid or rainy days?

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. The region around a charge where it can attract or repel another charge is described by the concept of the electric field.

An electric field is defined as the region around a charge where it exerts a force on other charges. The electric field strength decreases with distance from the charge, following an inverse square law for point charges. Thus, while the electric field is theoretically present everywhere, its influence diminishes with increasing distance.

For the electric force to act upon a charge particle, it is not necessary that the charges will come in physical contact. It will be there as and when a test charge is brought into the electric field of a charge (usually called a source charge).

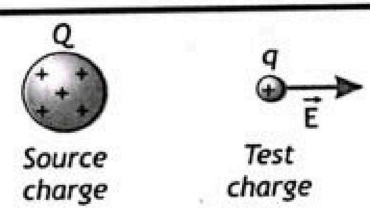


FIGURE 15.14 Electric field Intensity

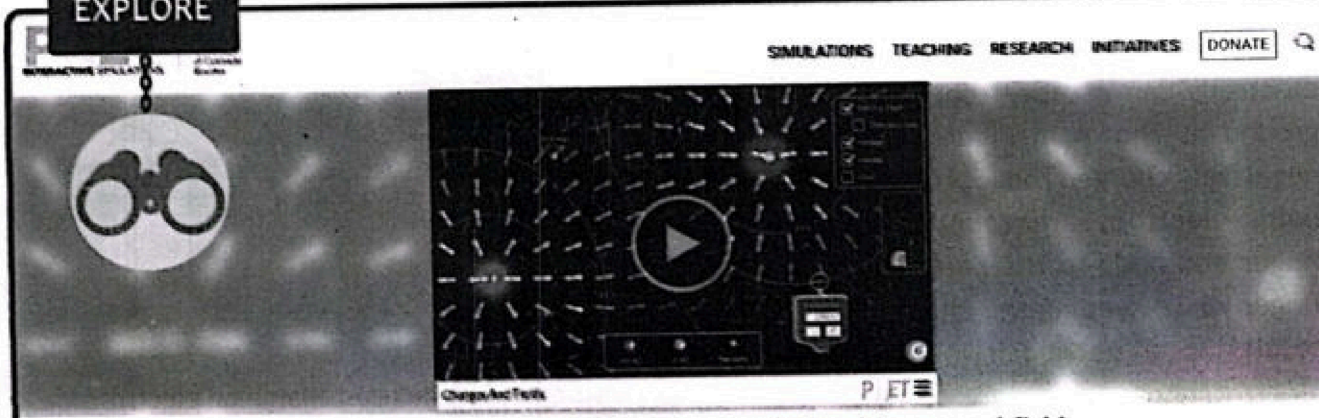
Consider a test charge 'q_0' is brought into the electric field of a source charge 'Q' as shown in figure 15.14. The source charge will exert an electrostatic force "F_E" on the test charge.

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,

$$E = \frac{F_E}{q_0} \qquad (15.2)$$

Equation 15.2 gives the equation for electric field intensity. Its S.I unit is N/C.

EXPLORE



https://phet.colorado.edu/en/simulations/charges-and-fields

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.

Example 15.1

A positive charge of magnitude + 2.2 × 10^{6} C experiences a force of 0.40 N from a source charge 'Q' at certain distance 'r'. What is the field strength at this position??

GIVEN

Force 'F' = 0.40 N

Test charge 'q_o' = + 2.2 × 10^{6} C

REQUIRED

Electric field strength 'E' = ?

Solution:

The electric field intensity is: $E = \frac{F}{q_o}$ putting values $E = \frac{0.40\text{ N}}{2.2 \times 10^{6}\text{ C}}$

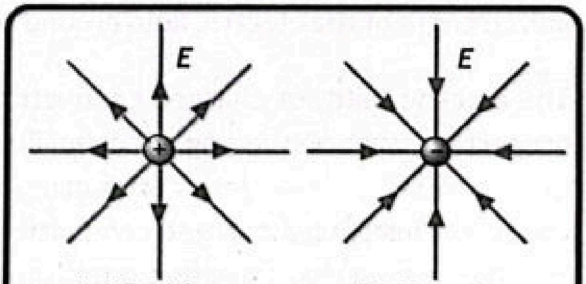
Therefore, $\boxed{E = 1.8 \times 10^{-5}\ \text{N/C}}$ **ANSWER**

The field strength at this point will be 1.8 × 10^{5} N/C.

15.5.1 ELECTRIC FIELD LINES

To visualize electric field around a source charge, the direction of force on positive test charge is represented by a line which give direction of electric field intensity at that point or region. That is why these lines are called as electric field lines.

These lines were first introduced by Michael Faraday. These lines are imaginary and have no physical existence.

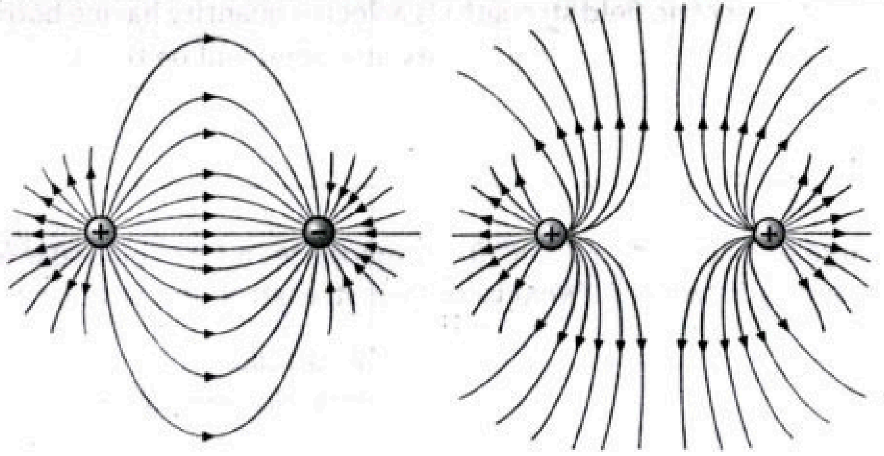


(a) Positive (b) Negative

FIGURE 15.15 Electric field around a single charge

For positive charge, the electric field lines or shortly field lines are directed away from positive charge because a positive charge will repel positive test charge as shown in figure 15.15 (a). For negative charge, the field lines are directed towards the charge as it will attract a positive test charge when brought to its field as shown in figure 15.15 (b).

In Figure 15.16 (a), the symmetric electric field lines for a pair of point charges with equal magnitude but opposite signs are shown, forming an electric dipole. The lines originate from the positive charge and terminate at the negative charge. The concentrated lines between the



(a) Oposite charges (b) Similar charges

FIGURE 15.16 2-dimensional drawing of electric field lines of two charges placed near each other.

charges indicate a powerful electric field in that region, particularly between the charges. Figure 15.16 (b) shows two particles with the same type of charge (both positive), they repel each other. This repulsion can be visualized using electric field lines, which show the direction and strength of the electric field around the charges.

The electric fields of charged conductors have interesting properties. When studying electric fields, analyzing the field around a charged conducting sphere provides important insights. A charged conducting sphere generates an electric field that spreads out uniformly if it is positively charged as shown in figure 15.17, or inward if it is negatively charged.

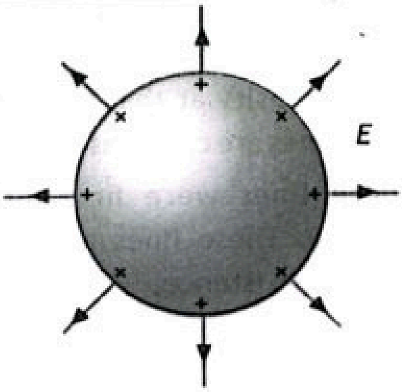


FIGURE 15.17
Electric field of a positively charged spherical conductor

Outside the sphere, the electric field behaves similarly to that of a point charge, decreasing with distance according to the inverse square law. However, inside the sphere, the electric field is zero because the charges distribute themselves evenly on the surface, creating a balanced field within. In contrast, a point charge generates an electric field that spreads out from a single point and decreases with the inverse square of the distance, without any interior region.

When studying electric fields, an important example is two parallel plates that are oppositely charged. One plate has a positive charge, and the other has a negative charge. The electric field between these plates is shown in Figure 15.18.

The positive plate has a uniform positive charge, while the negative plate has a uniform negative charge, both created by connecting the plates to a battery. The electric field in this region is uniform, which means that both the strength and direction of the electric field remain constant throughout the space between the plates. The electric field lines move in straight paths from the positive plate to the negative plate, showing the direction in which a positive charge would move.

This uniformity is a significant characteristic of the electric field created by parallel plates, as it simplifies calculations and predictions regarding the behavior of charged particles within the field.

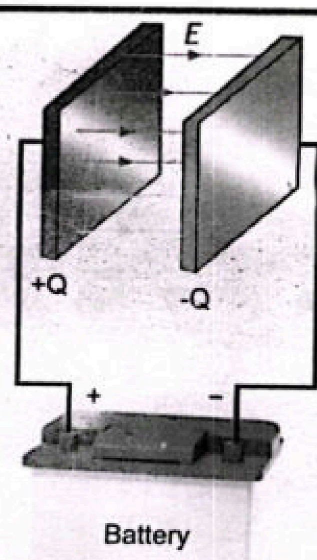
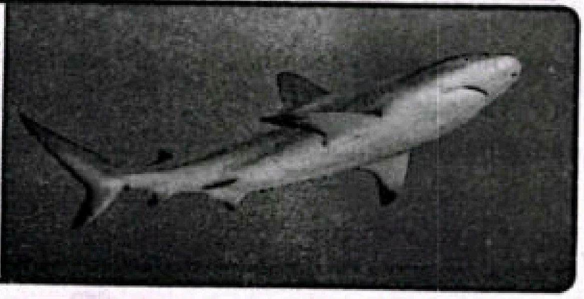


FIGURE 15.18

Electric field of oppositely charged conducting plates

SCIENCE TIDBITS

Sharks are sensitive to the small electric field surrounding possible prey, such as fish. Experiments have shown that a shark will attack an artificial electric field and ignore a piece of food.



15.6 APPLICATIONS OF ELECTROSTATICS

Electrostatic have a number of applications in our daily life.

15.6.1. ELECTROSTATIC PRECIPITATOR AND DUST EXTRACTION

Electrostatic precipitator and dust extractor works on the principle of electrostatics. To reduce air pollution, coal burning power stations uses electrostatic precipitation phenomena to extract dust from the smoke in chimneys before releasing it to the environment as shown in figure 15.19. Air mixed with dust enters the device across a positively charged mesh. The airborne particles become positively charged when they make contact with the mesh. Then they pass through a second, negatively charged mesh. The electrostatic force of attraction

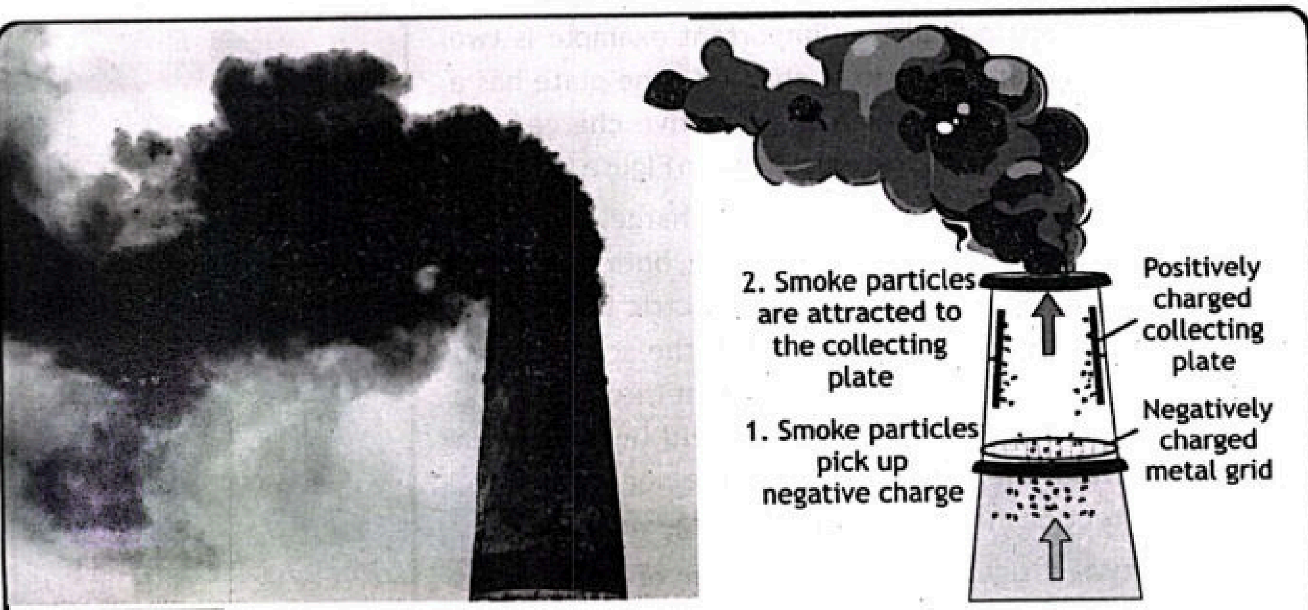


FIGURE 15.19 Electrostatic precipitator and dust extractor

between the positively charged particles in the air and the negatively charged mesh causes the particles to precipitate out on the surface of the mesh.

15.6.2. PHOTOCOPIER MACHINE

Most photocopy machines use an electrostatic process called xerography, derived from the Greek words "xeros" for dry and "graphos" for writing. The major steps in this process include charging the photoconducting drum, transferring an image, creating a positive charge duplicate, attracting toner to the charged parts of the drum, and transferring the toner to the paper as shown in figure 15.20.

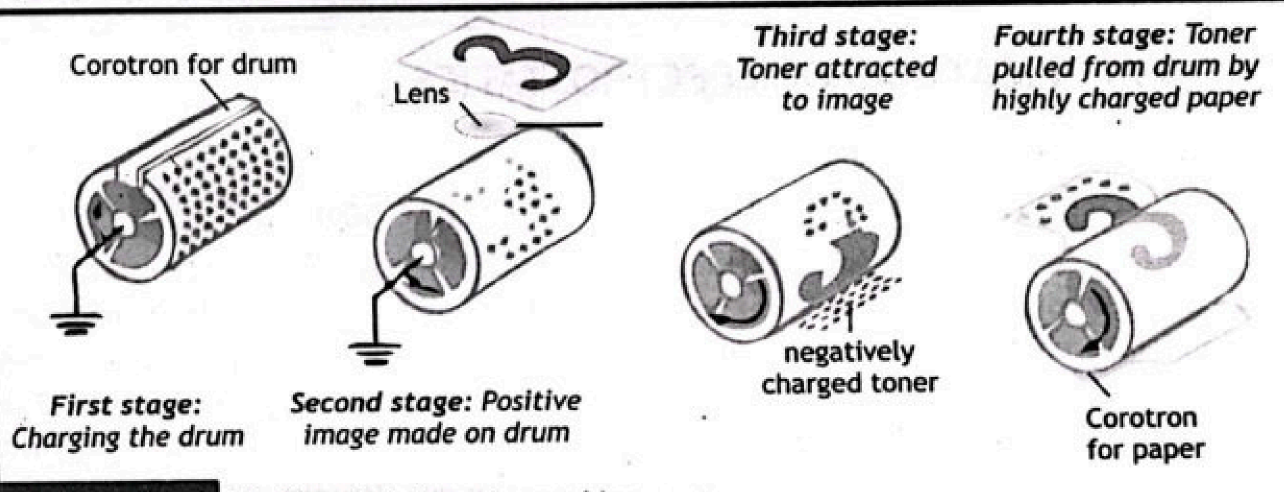
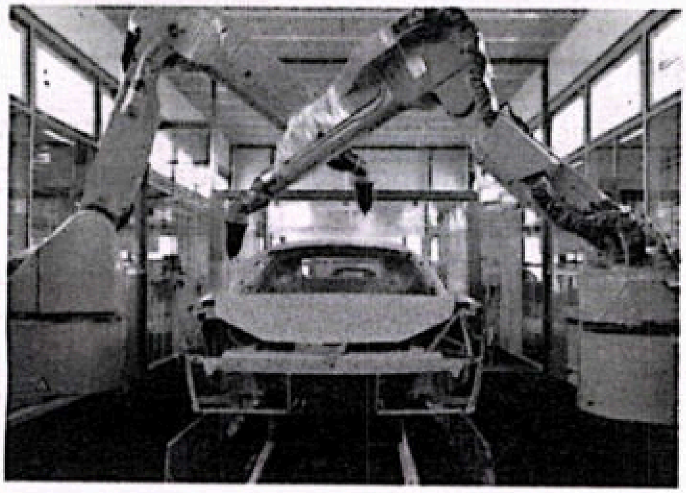
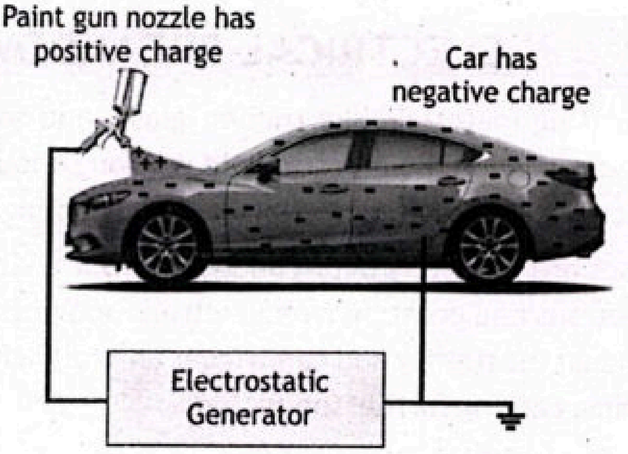


FIGURE 15.20 Working of photocopier machine.

SCIENCE TIDBITS

Automobile manufacturers use electropainting to paint new cars. The body of a car is charged and then the paint is given the opposite charge by charging the nozzle of the sprayer. Charging is either by applying a negative electric charge to the paint while it is in the container or applying the charge in the barrel of the spray painter gun.



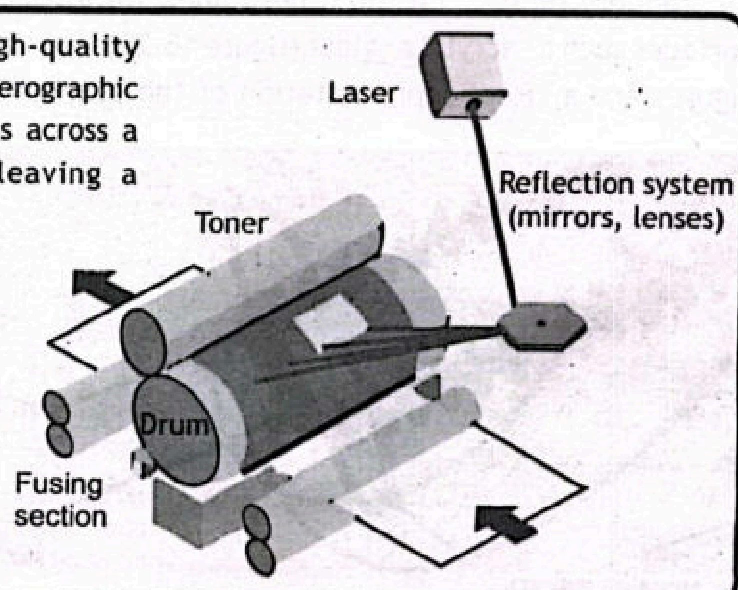


The paint is then pushed through the gun, rubbing against the side, and gaining a static electric charge as it moves. Opposite charges attract each other which helps to distribute the paint particles evenly and get uniform coverage.

SCIENCE TIDBITS

Laser printers create high-quality images on paper using the xerographic process. A laser beam scans across a photoconducting drum, leaving a positively charged image.

The drum is then charged and the image is transferred to paper, similar to xerography. Laser printers can produce high-quality images due to the precise control of laser light. They receive output from a computer and can achieve high-quality results.



The process begins with a selenium-coated aluminum drum, which is sprayed with a positive charge from a device called a corotron. Selenium acts as a photoconductor, meaning it behaves as an insulator in the dark and becomes a conductor when exposed to light. This unique property allows the drum to hold a static charge in dark areas while discharging in areas exposed to light, thereby creating a latent image on the drum's surface. Toner particles, which are oppositely charged, are then attracted to the charged areas of the drum. Finally, the toner is transferred to a piece of paper and fused using heat and pressure, producing a clear copy of the original document.

15.7 ELECTRICAL BREAKDOWN

Insulating materials like rubber, glass, and some plastics typically do not conduct electricity. However, when the electric field is strong enough, they can reach a breakdown voltage, allowing electrons to be pulled from atoms and enabling current flow.

Gases are generally poor conductors, but a strong electric field can ionize gas atoms, removing electrons and creating free electrons and positively charged ions. This process allows the gas to conduct electricity and can trigger an avalanche effect, where freed electrons collide with other atoms, causing further ionization.

15.7.1 VISIBLE EXAMPLES

Corona discharge and Lichtenberg figures show how electrical breakdown happens. Corona discharge appears as a faint glow around sharp points or edges of conductors at high voltages. This occurs because air molecules around the conductor become ionized, causing a localized breakdown. You can see this effect around power lines (figure 15.21) or during thunderstorms.

Lichtenberg figures, on the other hand, are intricate branching patterns formed on insulating surfaces such as acrylic or glass (figure 15.22) when subjected to a high-voltage discharges. These figures are a visual representation of the path taken by the electric current as it propagates

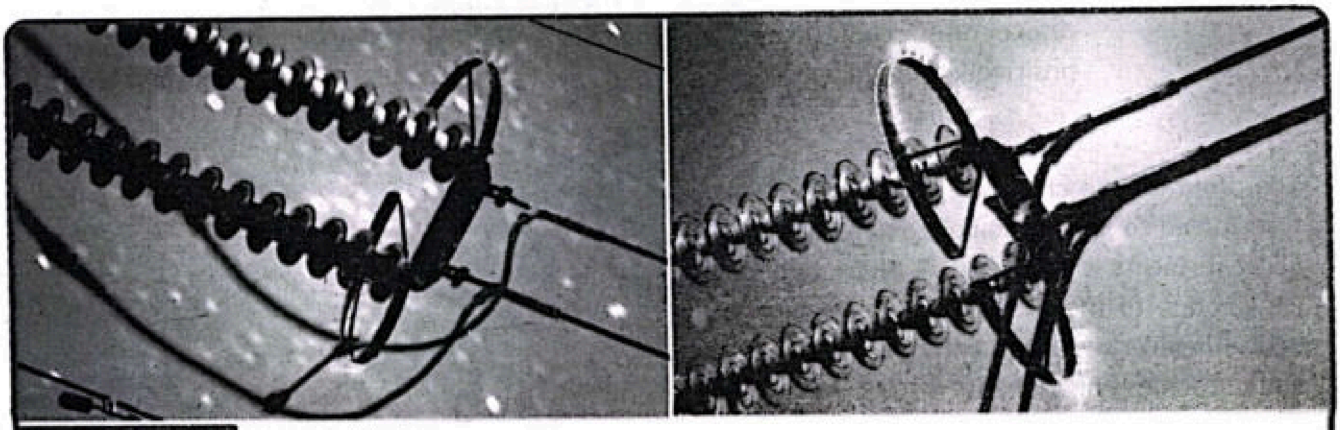


FIGURE 15.21 Corona discharge

through the material, leaving behind permanent, tree-like patterns.

Both phenomena clearly demonstrate electrical breakdown in various situations.

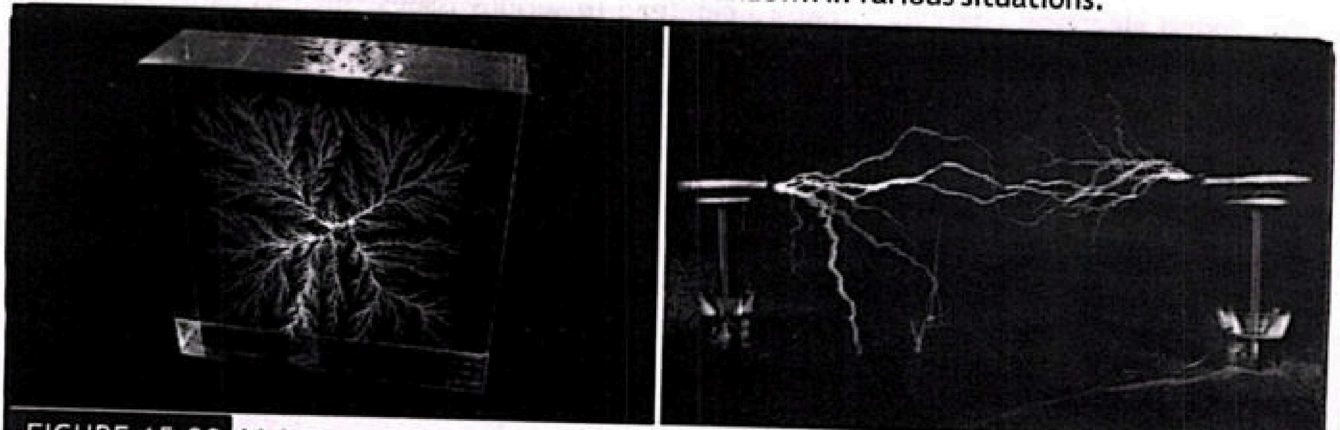


FIGURE 15.22 Lichtenberg figures

15.7.2 LIGHTNING GENERATION

Lightning is a powerful release of electrical energy that occurs in clouds when air, water droplets, or volcanic ash collide, causing electrical charges to separate. Positive charges rise to the top of the cloud, while negative charges sink. This creates a conductive plasma as the cloud becomes more charged. Excess electrons at the cloud's base travel to the ground in a zigzag pattern called a step leader.

The negative charge at the cloud's bottom induces a positive charge on the Earth's surface, creating a polarized effect. Nearby air molecules ionize and rise, forming a positive charge known as a streamer. When the streamer connects with the step leader, a complete path is established, resulting in a lightning strike, with the negative charge moving to the ground at speeds up to 100,000 km/s.

15.7.3 VARIETIES OF ATMOSPHERIC LIGHTNING

Lightning isn't limited to the common cloud-to-ground strike. Most lightning occurs entirely within a cloud (intracloud discharges), where it cannot be seen. However, visible discharges do take place between clouds (cloud-to-cloud discharges) and between a cloud and the Earth (cloud-to-ground discharges). There are many fascinating, less-understood types of lightning that occur high in the atmosphere, such as:

- Sprites - Short-lived, red flashes above thunderstorms.
- Jets - Narrow, upward bursts of blue light.
- Elves - Expanding rings of faint, white light.
- And others with even more whimsical names - Trolls, Pixies, Ghosts, Ball Lightning - These are all being actively researched by scientists.

15.7.4 UNCONTROLLED ELECTRICAL CHARGING

Uncontrolled electrical charging in nature can lead to serious issues, such as lightning. When clouds accumulate positive and negative electricity, the air can no longer insulate, resulting in a lightning strike that can damage property, harm people, and ignite fires.

To stay safe during thunderstorms, seek shelter in a sturdy building. If outside, crouch with your feet together and avoid tall objects and water.

Lightning is destructive because it generates strong currents in poor conductors, creating extreme heat that can endanger buildings. A lightning rod, invented by Benjamin Franklin in the 1750s, helps protect structures. It consists of a pointed metal rod on a building, connected to a buried rod as shown in figure 15.23. This system attracts lightning and provides a safe path for the current to the ground, preventing damage and stopping harmful electrical surges.

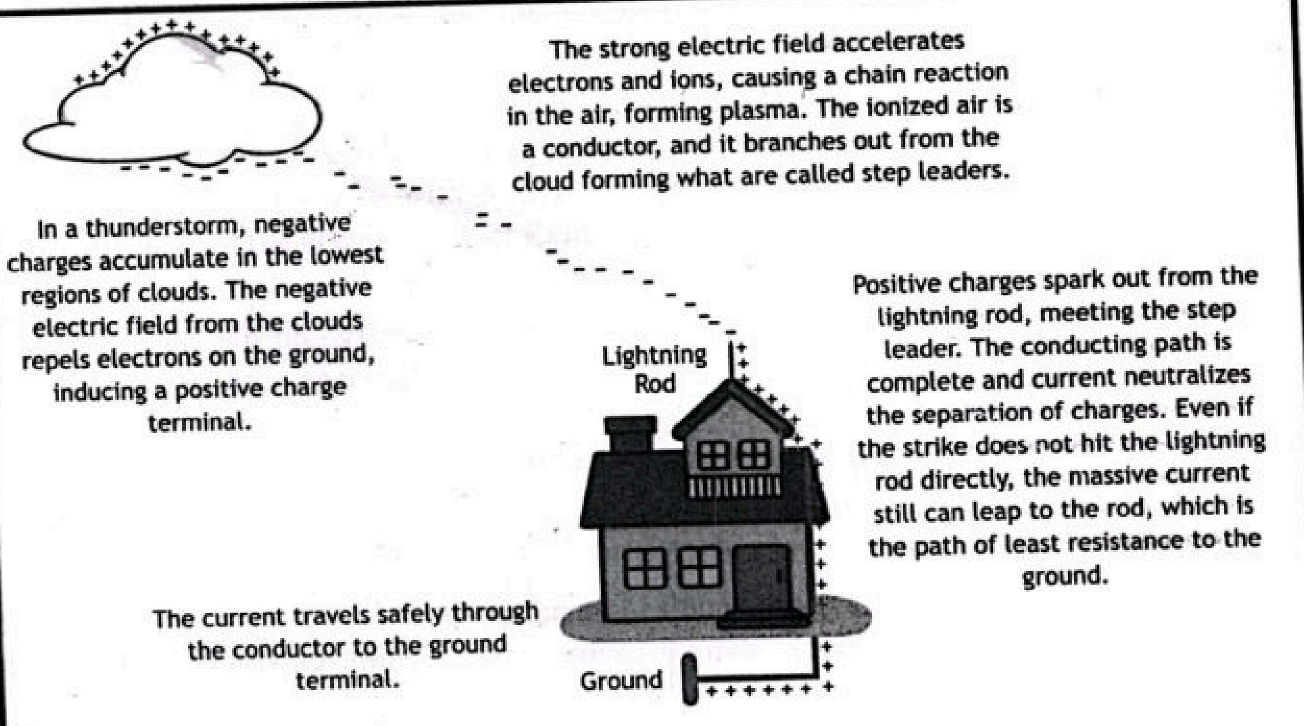


FIGURE 15.23 Lightning and lightning rod

SUMMARY

- **Electrification** is the process by which an object acquires an electric charge. This can happen through various methods like friction, contact, or induction.
- **Conservation of charge** is a fundamental law stating that the total electric charge in an isolated system remains constant. In simpler terms, charge can't be created or destroyed, only transferred between objects.
- **Quantization of charge** is the principle that electric charge exists in discrete units called electrons and protons. These fundamental particles have specific charges (negative for electrons, positive for protons), and charge cannot be further subdivided.
- **Conductors** are materials that allow electric charge to flow freely through them. They have loosely bound electrons that can easily move under the influence of an electric field. Examples include metals like copper and aluminum.
- **Insulators** are materials that resist the flow of electric charge. They have tightly bound electrons that are difficult to move. Examples include rubber, plastic, and wood.
- **Charging by friction** involves rubbing two dissimilar materials together transfers electrons from one material to the other.
- **Charging by contact** is the process when a charged object comes into contact with a neutral object, some electrons transfer between them, causing the neutral object to acquire the same charge type (positive or negative) as the charged object, but to a lesser degree.
- **Charging by induction** is a method where a charged object influences the distribution of charge in a nearby neutral object without physically touching it. This creates a temporary separation of charges in the neutral object.
- **Discharging** is the process by which an object loses its electric charge. It can happen through conduction (touching a grounded object), convection (charged particles carried by air), or a spark (sudden movement of charge).
- **Induced polarization** occurs when a charged object is brought near an insulator, the electric field from the charged object redistributes the charges within the insulator, creating a slight separation of positive and negative charges.
- **Electroscope** is a simple instrument used to detect the presence and sign (positive or negative) of electric charge. It typically consists of two thin metal leaves that diverge when charged.
- **Electric field** is a region of space where a charged object experiences a force. The strength and direction of the electric field depend on the amount and type of charge present.

- **Electric field lines** are imaginary lines that depict the direction and strength of an electric field. They point away from positive charges and towards negative charges, with the density of lines indicating the field's strength.
- **Electrostatic precipitator** is a device that uses an electric field to remove dust particles and other pollutants from air. Charged particles are attracted to collection plates, removing them from the air stream.
- **Corona discharge** is a faint glow or ionization of air caused by a strong electric field around a conductor. It can be seen around high-voltage power lines.
- **Lichtenberg figures** are branching, fern-like patterns left on an insulator's surface when a high-voltage discharge passes through it.
- **Lightning Generation** is the rapid discharge of electricity that occurs within a cloud or between a cloud and the ground. This is caused by the buildup of electric charge within the cloud due to various atmospheric processes.
- **Lightning control rod** are a well-established and effective method for protecting structures from lightning strikes.

EXERCISE

MULTIPLE CHOICE QUESTIONS

QI. Choose the best possible option in the following questions.

1. A rubber rod is rubbed with fur. The fur is then quickly brought near the bulb of an uncharged electroscope. The sign of the charge on the leaves of the electroscope is
   A. positive B. negative C. neutral D. zero
2. A negatively charged object is brought close to the surface of a conductor, whose opposite side is then grounded. What kind of charge is left on the conductor's surface?
   A. positive B. negative C. neutral D. zero
3. A small metal ball hangs from the ceiling by an insulating thread. The ball is attracted to a positively charged rod held near the ball. The ball must be:
   A. positive. B. negative. C. positive or neutral. D. negative or neutral.
4. A positive ion is formed when:
   A. a neutral atom loses electron B. a neutral atom gains electron
   C. negatively charged atom loses electron D. can be true for all these cases

5. A charged rod is brought near a suspended object, which is repelled by the rod. We can conclude that the suspended object is:
   A. uncharged
   B. Charged with different sign
   C. Charged with same sign
   D. can be true for all these cases
6. You have two lightweight metal spheres, each hanging from an insulating nylon thread. One of the spheres has a net negative charge, while the other sphere has no net charge. You now allow the two spheres to touch. Once they have touched, will the two spheres:
   A. attract each other
   B. repel each other
   C. exert no force on each other
   D. neutralize each other
7. A negative point charge moves along a straight-line path directly toward a stationary positive point charge. Which aspect(s) of the electric force on the negative point charge will remain constant as it moves?
   A. Magnitude
   B. direction
   C. both magnitude and direction
   D. neither magnitude nor direction
8. To be safe during a lightning storm, it is best to be
   A. in the middle of a grassy meadow.
   B. inside a metal car.
   C. next to a tall tree in a forest.
   D. on a metal observation tower.
9. What causes the leaves of an electroscope to move apart when charged?
   A. Attraction of unlike charges
   B. Repulsion of like charges
   C. Neutral nature of leaves
   D. Air Pressure
10. Corona discharge is most likely to occur at which of the following locations on a conductor?
    A. Flat surfaces
    B. Sharp points
    C. Smooth spheres
    D. Insulated areas
11. What do Lichtenberg figures typically look like?
    A. Straight lines
    B. Circular rings
    C. Branching tree-like patterns
    D. Rectangular shapes

CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. (a) In your notebook, draw two parallel lines representing metal plates, one positive and one negative.

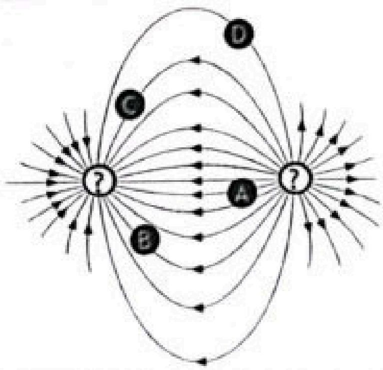
(b) Eight negative point charges of equal magnitude are distributed evenly around a circle. Sketch the electric field in the region around and within this charge distribution. Explain how this charge distribution can be used to model the electric field inside a coaxial cable.

2. Figure shows a source that consists of two charged particles.

(a) What is the sign of the charge on each particle?

(b) In which region (A, B, C or D) is the electric field the weakest?

(c) In which region (A, B, C or D) is the electric field the strongest?



SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. What is the relationship between charge and mass when a metal becomes charged, and assess whether the mass change is significant?
2. How do grounding systems prevent static buildup in fuel trucks, what are the dangers without grounding?
3. Why do electrons transfer charge instead of protons or neutrons, and how does this affect circuit and device design?
4. Why does a charged balloon stick to a neutral wall due to polarization? Compare the interaction with a conductor vs. an insulator.
5. How do positive and negative charges behave differently in an electric field?
6. What are the effects of changing electric field direction or strength in applications like capacitors?
7. Compare electric and gravitational fields in terms of strength, range, and forces, and evaluate situations where both fields affect objects.
8. Can insulators be charged by induction, under what conditions does this happen, and what are alternative methods for charging insulators?
9. What is corona discharge around conductors, especially sharp points?
10. How does electric field concentration cause ionization, and what are its practical uses or problems?
11. What causes Lichtenberg figures to form after lightning strikes, why don't they always appear?
12. How do lightning rods protect buildings, what is the role of pointed rods in attracting discharge?
13. How can lightning rod design and placement be optimized for better protection?

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. Explain electrification and how charge conservation and quantization govern particle behavior, with real-world examples like electronics.
2. Describe how objects gain charge through triboelectric effects and how they behave when in contact with conductors.
3. Compare conductors and insulators at the atomic level, focusing on electron configurations and their practical uses.
4. Evaluate charging methods (friction, conduction, induction) and their efficiency in different materials, with real-world applications.
5. Design a procedure to charge two metal spheres via electrostatic induction and discuss realworld uses of induction.
6. Analyze electric fields and how field lines help visualize field intensity, with applications like capacitors and shielding.
7. Explain how an electroscope works to detect charge and suggest improvements for detecting weaker charges.
8. Analyze electrostatic precipitators and photocopiers, and propose ways to improve their energy efficiency and performance.
9. Investigate electric breakdown, how it occurs, and suggest safety measures for high-voltage environments.
10. Explain lightning production and how lightning rods work, proposing additional safety measures for lightning-prone areas.

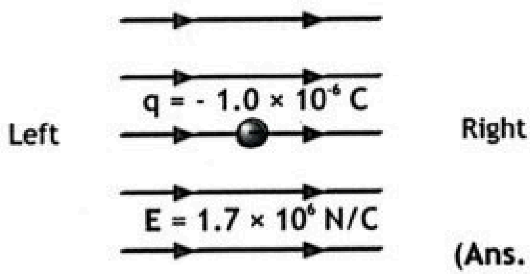
NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. A positive test charge of 30 μC is placed in an electric field. The force on it is 0.600 N. What is the magnitude of the electric field at the location of the test charge?

(Ans. 2.00×10^4 N/C)

2. How much force is exerted on a charge of -1.0×10^{-6} C in a field of strength 1.7×10^{6} N/C (right)? Now when the field strength is doubled, how much force is exerted on a charge of $+1.0 \times 10^{-6}$ C?



(Ans. 1.7 N [left], 3.4 N [right])

3. Find magnitude of the positive test charge that experiences a force of 0.5 N when placed in an electric field of 2.0 N/C. (Ans. 0.25 C)
4. A small Charge of 3.0 μC is placed in a uniform electric field of 1.5 N/C. Calculate force on the charge. (Ans. 4.5 μN)
5. Calculate the electric field strength when an electron enters it and experiences a force of 0.01 N. The charge of an electron is 1.6×10^{-19} C. (Ans. 6.25×10^{16} N/C)
6. What is magnitude of force on an electron released from rest in a uniform electric field of magnitude 20 N/C? (Ans. 3.2×10^{-18} N)