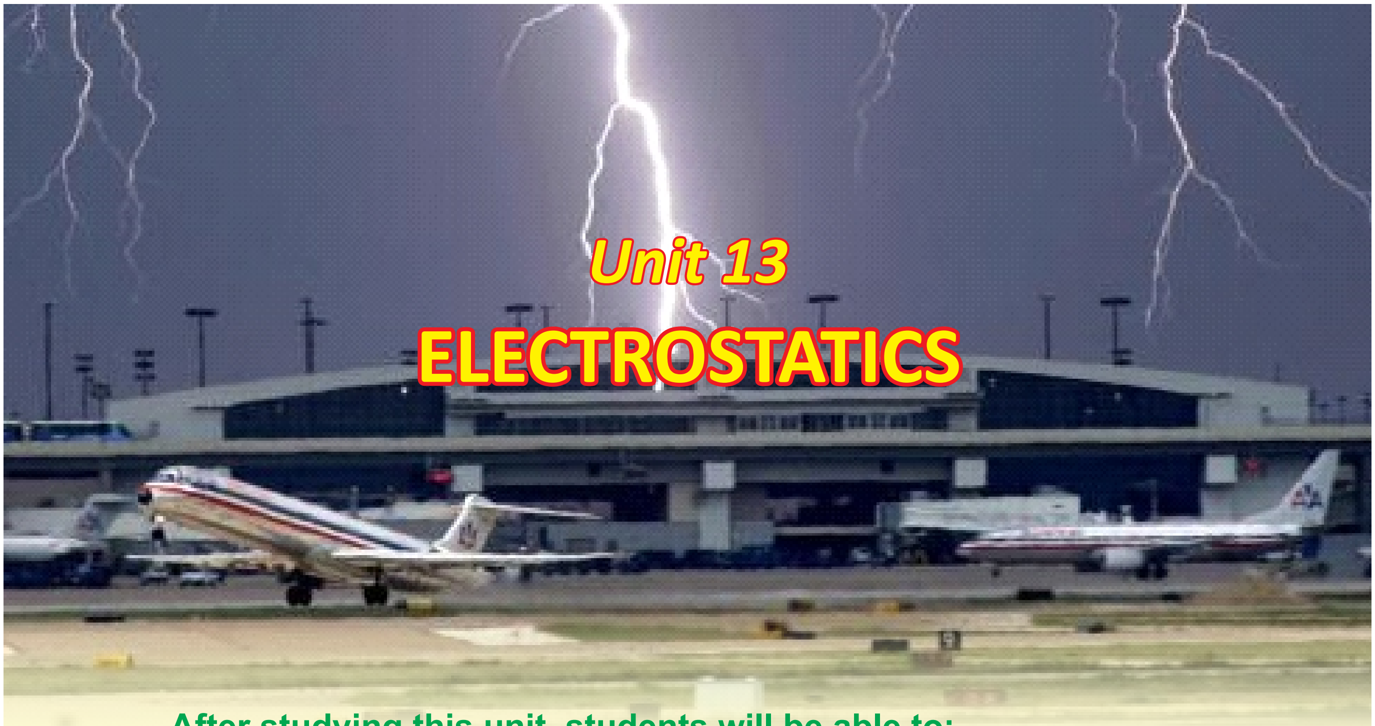


Unit 13

ELECTROSTATICS

After studying this unit, students will be able to:

- describe simple experiments to show the production and detection of electric charge.
- describe experiments to show electrostatic charging by induction.
- state that there are positive and negative charges.
- describe the construction and working principle of electroscope.
- state and explain Coulomb's law.
- solve problems on electrostatic charges by using Coulomb's law.
- define electric field and electric field intensity.
- sketch the electric field lines for an isolated +ve and –ve point charges.
- describe the concept of electrostatic potential.
- define the unit "volt".
- describe potential difference as energy transfer per unit charge.
- describe one situation in which static electricity is dangerous and the precautions taken to ensure that static electricity is discharged safely.
- describe that the capacitor is charge storing device.
- define capacitance and its unit.
- derive the formula for the effective capacitance of a number of capacitors connected in series and in parallel.
- apply the formula for the effective capacitance of a number of capacitors connected in series and in parallel to solve related problems.

Science, Technology and Society Connections

The students will be able to:

- describe the use of electrostatic charging (e.g. spraying of paint and dust extraction).
- list the use of capacitors in various electrical appliances.

In this chapter, we will describe different properties of static charges, such as electric force, electric field and electric potential etc. We will also discuss some uses and safety measures of static electricity. The study of charges at rest is called electrostatics or static electricity.

Fig.13.1: Comb rubbed with hair attracts small pieces of paper

13.1 PRODUCTION OF ELECTRIC CHARGES

If we run a plastic comb through our hair and then bring it near small pieces of paper, the comb attracts them (Fig.13.1). Similarly, amber when rubbed with silk, attracts the small pieces of paper. This property of attraction or repulsion between substances is due to the electric charges they acquire during rubbing.

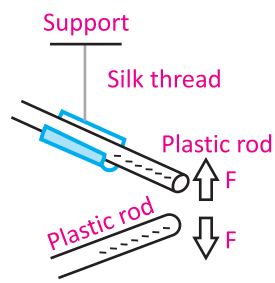


Fig.13.2: Two plastic rods rubbed with fur repel each other

We can produce electric charge by rubbing a neutral body with another neutral body. The following activities show that we can produce two types of electric charges through the process of rubbing.

Activity 13.1. Take a plastic rod. Rub it with fur and suspend it horizontally by a silk thread (Fig. 13.2). Now take another plastic rod and rub it with fur and bring near to the suspended rod. We will observe that both the rods will repel each other. It means during the rubbing both the rods were charged.

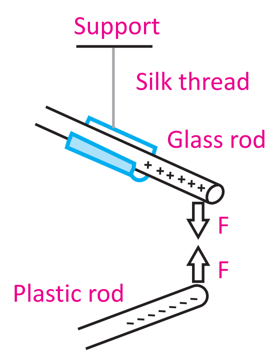


Fig.13.3: Plastic rod rubbed with fur and glass rod rubbed with silk attract each other

Activity 13.2. Now take a glass rod and rub it with silk and suspend it horizontally. When we bring the plastic rod rubbed with fur near to the suspended glass rod, we observe that both the rods attract each other (Fig. 13.3).

In the first activity, both rods are of plastic and both of them have been rubbed with fur. Therefore, we assume that charge on both rods would be of the same kind.

In the second activity, rods are unlike and their attraction implies that charges on two rods are not of the same kind but of opposite nature.

These opposite charges are conventionally called positive charge and negative charge. During the process of rubbing negative charge is transferred from one object to another object.

From these activities, we conclude that:

1. Charge is a basic property of a material body due to which it attracts or repels another object.
2. Friction produces two different types of charge on different materials (such as glass and plastic).
3. Like charges always repel each other.
4. Unlike charges always attract each other.
5. Repulsion is the sure test of charge on a body.

Self Assessment

1. Do you think amount of positive charge on the glass rod after rubbing it with silk cloth will be equal to the amount of negative charge on the silk? Explain.
2. What would happen if a neutral glass rod is brought near a positively charged glass rod?

For your information

In the list given below, different materials have been arranged in such a way that if any of the two materials are rubbed together, the material occurring first in the list would have positive charge and that occurring next would have negative charge. For example, among cat's skin and lead, skin has positive charge whereas lead has negative charge.

1. Asbestos
2. Glass
3. Mica
4. Woollen cloth
5. Cat's skin
6. Lead
7. Silky cloth
8. Aluminium
9. Cotton cloth
10. Wood
11. Copper
12. Rubber
13. Plastic

13.2 ELECTROSTATIC INDUCTION

Activity 13.3. If we bring charged plastic rod near suspended neutral aluminium rod, both rods attract each other as shown in Fig. 13.4.

This attraction between the charged and uncharged rods shows as if both rods have unlike charges. But this is not true. Charged plastic rod produces displacement of positive and negative charges on the neutral aluminium rod which is the cause of attraction between them. But total charge on aluminium rod is still zero. It implies that attraction is not the sure test of charge on a body.

The above activity shows a phenomenon that is called electrostatic induction as explained below.

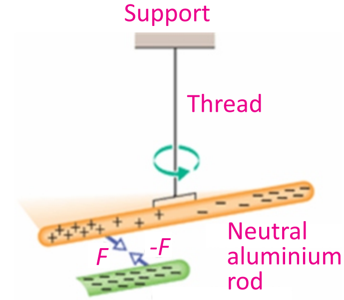
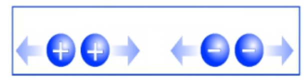


Fig. 13.4: Charged plastic rod attracts neutral aluminium rod.

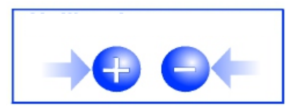
Activity 13.4. Bring two metal spheres A and B and fix them on insulated stands, such that they touch each other as shown in Fig.13.5-a. Now bring a positively charged rod near sphere A as shown in Fig. 13.5-b. Rod will attract negative charge towards it and repel positive charge away from it. Negative charge will appear on the left surface of the sphere A which is close to the rod. While positive charge will appear on the right surface of the sphere B. Now separate the spheres while the rod is still near the sphere A. Now if you test the two spheres, you will find that the two spheres will be oppositely charged (Fig.13.5-c). After removing the rod, the charges are uniformly distributed over the surfaces of the spheres as shown in Fig.13.5-d.

In this process, an equal and opposite charges appear on each

For your information



Like charges repel



Unlike charges attract

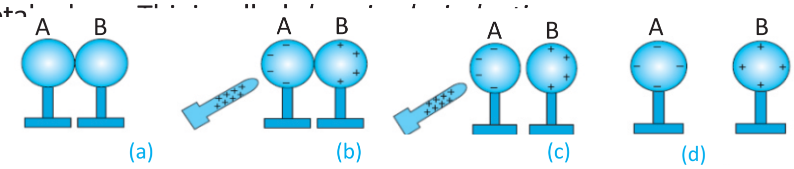


Fig. 13.5: Charging two spheres by electrostatic induction

Hence, we define electrostatic induction as:

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

13.3 ELECTROSCOPE

The gold leaf electroscope is a sensitive instrument for detecting charges. It consists of a brass rod with a brass disk at the top and two thin leaves of gold foil hanging at the bottom (Fig. 13.6). The rod passes through an insulator that keeps the rod in place . Charges can move freely from the disk to the leaves through the rod. A thin aluminium foil is attached on the lower portion of the inside of the jar. Usually, the aluminium foil is grounded by connecting a copper wire. This protects the leaves from the external electrical disturbances.

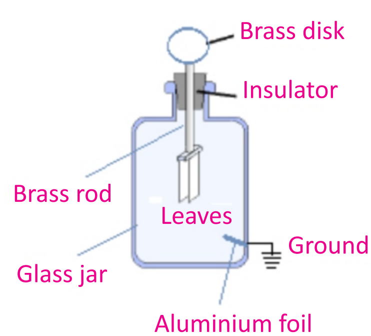


Fig.13.6: Uncharged electroscope

Detecting the Presence of Charge

In order to detect the presence of charge on anybody, bring the body near the disk of an uncharged electroscope. If the body is neutral there will be no deflection of the leaves (Fig.13.7-a). But if the body is positively or negatively charged, the leaves of the electroscope diverge. For example, if the body is negatively charged then due to electrostatic induction, positive charge will appear on the disk while negative charge will appear on the leaves (Fig.13.7-b). The leaves of electroscope repel each other and diverge because each leave gets similar charge. The divergence of leaves will depend on the amount of charge.

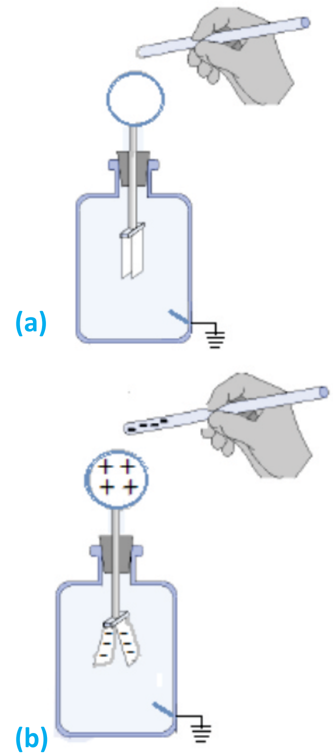


Fig. 13.7

Charging the Electroscope by Electrostatic Induction

Electroscope can be charged by the process of electrostatic induction. In order to produce positive charge on the electroscope, bring a negatively charged body near the disk of the electroscope (Fig.13.8-a). Positive charge will appear on the disk of the electroscope while negative charges will shift to the leaves. Now connect the disk of electroscope to the earthed aluminium foil by a conducting wire (Fig. 13.8-b). Charge of the leaves will flow to the Earth through the wire. Now if we first break the Earth connection and then remove the rod, the electroscope will be left with positive charge(Fig.13.8-c).

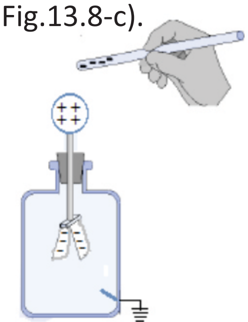


Fig.13.8 (a) Charging the electroscope positively

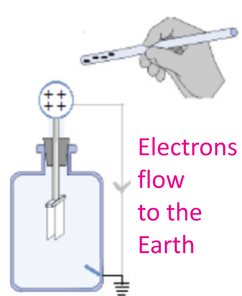


Fig.13.8 (b) Charging the electroscope positively

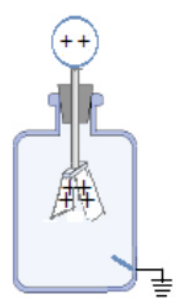


Fig.13.8 (c) Positively charged electroscope

Similarly, electroscope can be charged negatively with the help of a positively charged rod. Can you explain this with the help of a diagram?

Electroscope can also be charged by the process of conduction. Touch a negatively charged rod with the disk of a neutral electroscope. Negative charge from the rod will transfer to the electroscope and will cause its leaves to diverge.

Detecting the Type of Charge

For the detection of type of charge on a body, electroscope is first charged either positively or negatively. Suppose the electroscope is positively charged as explained before (Fig.13.9-a). Now in order to detect the type of charge on a body, bring the charged body near the disk of the positively charged electroscope. If the divergence of the leaves increases, the body carries positive charge (Fig. 13.9-b). On the other hand if the divergence decreases, the body has negative charge (Fig.13.9-c).

Positively charged electrscope

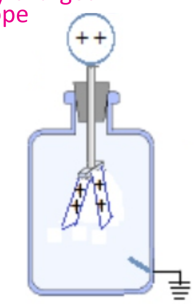


Fig. 13.9 (a)

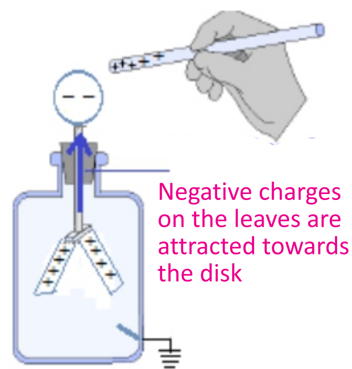


Fig.13.9 (b) Detecting positive charge on body.

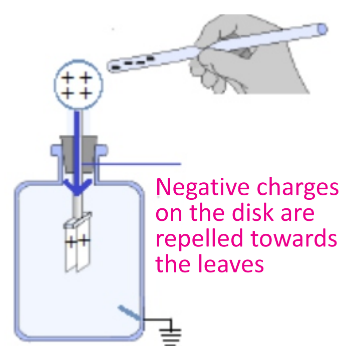


Fig.13.9 (c) Detecting negative charge on body

Identifying Conductors and Insulators

Electroscope can also be used to distinguish between insulators and conductors. Touch the disk of a charged electroscope with material under test. If the leaves collapse from their diverged position, the body would be a good conductor. If there is no change in the divergence of the leaves, it will show that the body under test is an insulator.

13. 4 COULOMB'S LAW

We know that a force of attraction or repulsion acts between two charged bodies. How is this force affected when the magnitude of the charge on the two bodies or the distance between them is changed? In order to find the answers of these questions, a French scientist Charles Coulomb (1736–1806) in 1785 experimentally established the fundamental law of electric force between two stationary charged particles.

Coulomb's Law: *The force of attraction or repulsion between two point charges is directly proportional to the product of the magnitude of charges and inversely proportional to the square of the distance be* $F \propto q_1 q_2$*m. Therefore,*

.... (13.1)

$$F \propto \frac{1}{r^2}$$

.... (13.2)

Combining Eqs. (13.1) and (13.2), we get

$$F = k\,\frac{q_1 q_2}{r^2} \qquad \text{........ (13.3)}$$

Eq. (13.3) is known as Coulomb's law.

where F is the force between the two charges and is called the Coulomb force, q_1 and q_2 are the magnitudes of two charges and 'r' is the distance between the two charges (Fig.13.10). k is the constant of proportionality.

The value of k depends upon the medium between the two charges.

If the medium between the two charges is air, then the value of k in SI units will be $9 \times 10^9\ \mathrm{N\,m^2 C^{-2}}$.

Coulomb's law is true only for point charges whose sizes are very small as compared to the distance between them.

Example 13.1: Two bodies are oppositely charged with 500 µC and 100 µC charge. Find the force between the two charges if the distance between them in air is 0.5m.

Solution: Given that, $r = 0.5$ m, $q_1 = 500\ \mu C = 500 \times 10^{-6}$ C, $q_2 = 100\ \mu C = 100 \times 10^{-6}$ C

Substituting these values in Eq. (13.3), we have

$$F = k\,\frac{q_1 q_2}{r^2} = \frac{9 \times 10^9\ \mathrm{N\,m^2 C^{-2}} \times 500 \times 10^{-6}\ \mathrm{C} \times 100 \times 10^{-6}\ \mathrm{C}}{(0.5\ \mathrm{m})^2}$$

$$F = 1800\ \mathrm{N}$$

13.5 ELECTRIC FIELD AND ELECTRIC FIELD INTENSITY

According to Coulomb's law, if a unit positive charge q_0 (call it

Point to ponder

Why leaves of charged electroscope collapse if we touch its disk with a metal rod but they do not collapse if we touch the disk with a rubber rod?

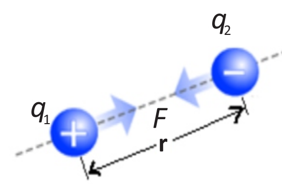


Fig.13.10 (a) Attraction between opposite charges

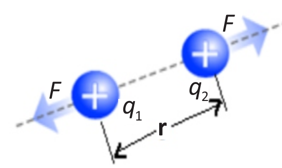


Fig.13.10 (b) Repulsion between similar charges

Point to ponder

On a dry day if we walk in a carpeted room and then touch some conductor we will get a small electric shock! Can we tell why does it happen?

For your information

In SI, the unit of charge is coulomb (C). It is equal to the charge of 6.25×10^{18} electrons. This is very big unit. Usually, charge is measured in micro coulomb. One micro coulomb is equal to 10^{-6}C.

a test charge) is brought near a charge q (call it a field charge) placed in space, the charge q_o will experience a force. The value of this force depends upon the distance between the two charges. If the charge q_0 is moved away from q, this force would decrease till at a certain distance the force would be practically reduced to zero. The charge q_o is then out of the influence of charge q.

The region of space surrounding the charge q in which it exerts a force on the charge q_o is known as electric field of the charge q. Thus, the electric field of a charge is defined as :

The electric field is a region around a charge in which it exerts electrostatic force on another charges.

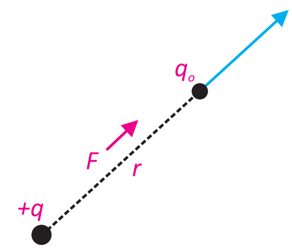


Fig. 13.11: A charge q_o is placed at a distance 'r' from charge $+q$

Electric Field Intensity: *The strength of an electric field at any point in space is known as electric field intensity.*

In order to find the value of electric intensity at a point in the field, of charge $+q$, we place a test charge q_o at that point (Fig. 13.11). If F is the force acting on the test charge q_o, the electric field intensity would be given by

$$E = \frac{F}{q_o} \qquad \text{........ (13.4)}$$

The electric field intensity at any point is defined as the force acting on a unit positive charge placed at that point.

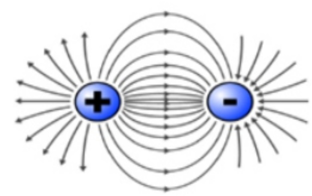
SI unit of electric intensity is N C^{-1}.

If the electric field due to a given arrangement of charges is known at some point, the force on any particle with charge q placed at that point can be calculated by using the formula:

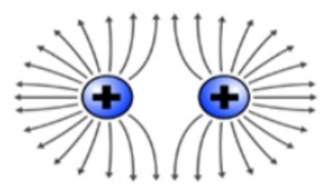
$$F = qE \qquad \text{........ (13.5)}$$

Electric intensity being a force is a vector quantity. Its direction is the same as that of the force acting on the positive test charge. If the test charge is free to move, it will always move in the direction of electric intensity.

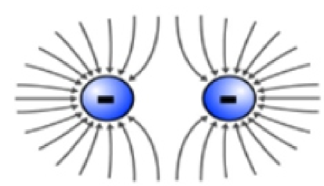
For your information



Electric field lines for two opposite and equal point charges.



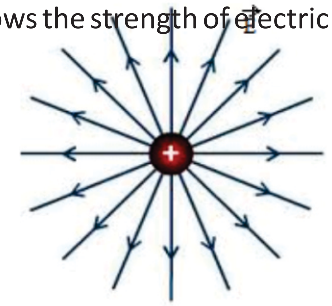
Electric field lines for two positive point charges.



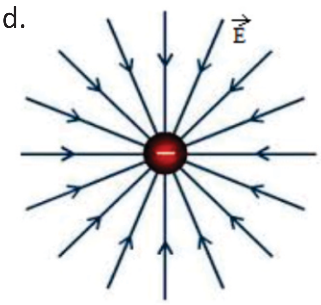
Electric field lines for two negative point charges.

Electric Field Lines

The direction of electric field intensity in an electric field can also be represented by drawing lines. These lines are known as electric lines of force. These lines were introduced by Michael Faraday. The field lines are imaginary lines around a field charge with an arrow head indicating the direction of force. Field lines are always directed from positive charge towards negative charge. The spacing between the field lines shows the strength of electric field.



Electric field lines for an isolated positive point charge.



Electric field lines for an isolated negative point charge.

13.6 ELECTROSTATIC POTENTIAL

The gravitational potential at a point in the gravitational field is the gravitational potential energy of a unit mass placed at that point. Similarly, the electric potential at any point in the electric field is the electric potential energy of a unit positive charge placed at that point.

Electric Potential : *Electric potential at a point in an electric field is equal to the amount of work done in bringing a unit positive charge from infinity to that point.*

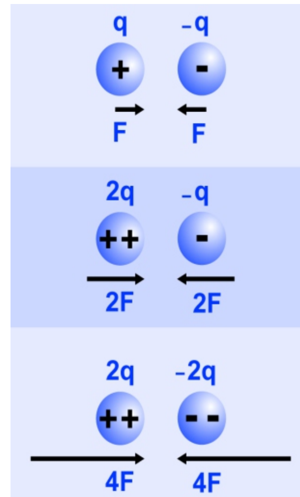
If W is the work done in moving a positive charge q from infinity to a certain point in the field, the electric potential V at this point would be given by $V = \frac{W}{q}$ .... (13.6)

It implies that electric potential is measured relative to some reference point and like potential energy we can measure only the change in potential between two points.

Electric potential is a scalar quantity. Its SI unit is volt which is equal to $J\,C^{-1}$.

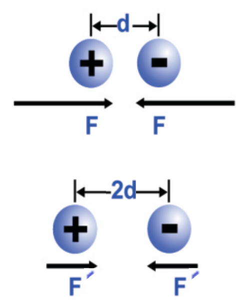
If one joule of work is done against the electric field in bringing one coulomb positive charge from infinity to a point in the

Physics Insight



Variation of magnitude of Coulomb's force between two opposite charges of different magnitudes.

Quick Quiz



If we double the distance between two charges, what will be the change in the force between the charges?

Physics insight

The electrostatic force acting on two charges each of 1 C separated by 1 m is about 9×10^9 N. This force is equal to the gravitational force that the Earth exerts on a billion kilogram object at sea level!

electric field then the potential at that point will be one volt.

A body in gravitational field always tends to move from a point of higher potential energy to a point of lower potential energy. Similarly, when a charge is released in an electric field, it moves from a point of higher potential say A to a point at lower potential say B (Fig.13.12).

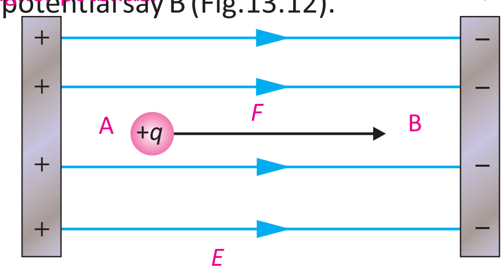


Fig 13.12: Potential difference between two points

If the potential of point A is V_a and that of point B is V_b, the potential energy of the charge at these points will be qV_a and qV_b respectively. The change in potential energy of the charge when it moves from point A to B will be equal to $qV_a - qV_b$. This energy is utilized in doing some useful work. Thus

Energy supplied by the charge = $q(V_a - V_b)$ .... (13.7)

If '*q*' is one coulomb, then the potential difference between two points becomes equal to the energy supplied by the charge. Thus, we define potential difference between two points as:

The energy supplied by a unit charge as it moves from one point to the other in the direction of the field is called potential difference between two points.

If a positive charge is transferred from a point of lower potential to a point of higher potential i.e., against the field direction, energy would have to be supplied to it.

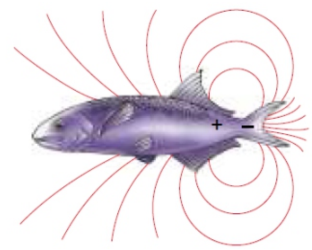
13.7 CAPACITORS AND CAPACITANCE

In order to store the charge, a device which is called capacitor is used. It consists of two thin metal plates, parallel to each other separated by a very small distance (Fig. 13.13). The medium between the two plates is air or a sheet of some

For your information

A tremendous range of field strengths exist in nature. For example, the electric field 30cm away from a light bulb is roughly 5 N C^{-1}, whereas the electron in a hydrogen atom experiences an electric field in the order of 10^{11} N C^{-1} from the atom's nucleus.

Physics of Field Lines

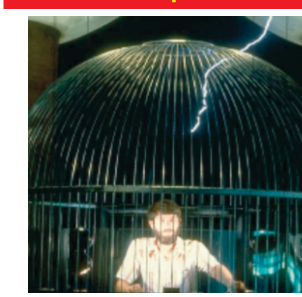


Some animals produce electric fields to detect nearby objects that affect the field.

Do you know?

Electric field lines themselves are not physical entities. They are just used for the pictorial representation of another physical quantity i.e., electric field at various positions.

Point to ponder!



A strong electric field exists in the vicinity of this "Faraday cage". Yet the person inside the cage is not affected. Can you tell why?

insulator. This medium is known as dielectric.

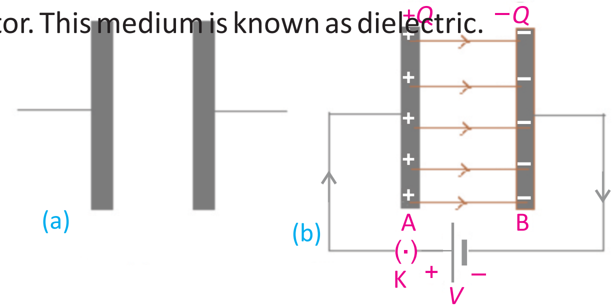


Fig. 13.13 (a) Parallel plate capacitor (b) Plates of capacitor connected with battery

If a capacitor is connected to a battery of V volts, then the battery transfers a charge $+Q$ from plate B to plate A, so that $-Q$ charge appears on plate A and $+Q$ charge appears on plate B.

The charges on each plate attract each other and thus remained bound within the plates. In this way, charge is stored in a capacitor for a long time.

Also, the charge Q stored on plates is directly proportional to the potential difference V across the plates i.e.,

$$Q \propto V$$

$$Q = CV \qquad ....(13.8)$$

where C is the constant of proportionality, called the capacitance of the capacitor and is defined as the ability of the capacitor to store charge. It is given by the ratio of charge and the electric potential as:

$$C = \frac{Q}{V}$$

SI unit of capacitance is farad (F), defined as:

If one coulomb of charge given to the plates of a capacitor produces a potential difference of one volt between the plates of the capacitor then its capacitance would be one farad.

farad is a large unit, usually, we use a smaller unit such as micro farad (μF), nano farad (nF) and pico farad (pF) etc.

Example 13.2: The capacitance of a parallel plate capacitor is 100 μF. If the potential difference between its plates is

Potential and Potential Energy

Electric potential is a characteristic of the field of source charge and is independent of a test charge that may be placed in the field. But, potential energy is a characteristic of both the field and test charge. It is produced due to the interaction of the field and the test charge placed in the field.

50 volts, find the quantity of charge stored on each plate.

Solution: Given that; $V = 50\text{ V}$, $C = 100\ \mu\text{F} = 100 \times 10^{-6}\text{F}$

Using the formula

$$Q = C\,V$$

Putting the values

$$Q = 100 \times 10^{-6}\text{ F} \times 50\text{ V}$$
$$= 5 \times 10^{-3}\text{ C} = 5\text{ mC}$$

Charge on each plate will be 5 mC, because each plate has equal amount of charge.

Combinations of Capacitors

Capacitors are manufactured with different standard capacitances, and by combining them in series or in parallel, we can get any desired value of the capacitance.

(i) Capacitors in Parallel

In this combination, the left plate of each capacitor is connected to the positive terminal of the battery by a conducting wire. In the same way, the right plate of each capacitor is connected to the negative terminal of the battery (Fig. 13.14).

This type of combination has the following characteristics:

1. Each capacitor connected to a battery of voltage V has the same potential difference V across it. i.e.,
   $V_1 = V_2 = V_3 = V$
2. The charge developed across the plates of each capacitor will be different due to different value of capacitances.
3. The total charge Q supplied by the battery is divided among the various capacitors. Hence,

$$Q = Q_1 + Q_2 + Q_3$$

$$Q = C_1V + C_2V + C_3V$$

or $$\frac{Q}{V} = C_1 + C_2 + C_3$$

or

4. Thus, we can replace the parallel combination of capacitors with one equivalent capacitor having capacitance C_{eq}, such that

$$C_{eq} = C_1 + C_2 + C_3$$

Physics insight

A voltage across a device, such as capacitor, has the same meaning as the potential difference across the device. For instance, if we suppose that the voltage across a capacitor is 12 V, it also means that the potential difference between its plates is 12 V.

For your information

Farad is a bigger unit of capacitance. We generally use the following submultiples:

1 micro farad = 1 μF = 1×10^{-6} F

1 nano farad = 1 nF = 1×10^{-9} F

1 pico farad = 1 pF = 1×10^{-12} F

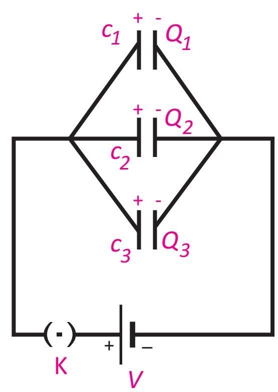


Fig.13.14: Capacitors in parallel combination

For your information

Three factors affect the ability of a capacitor to store charge.

1. Area of the plates
2. Distance between the plates
3. Type of insulator used between the plates.

In the case of 'n' capacitors connected in parallel, the equivalent capacitance is given by

$$C_{eq} = C_1 + C_2 + C_3 + ... + C_n \quad ....(13.9)$$

5. The equivalent capacitance of a parallel combination of capacitors is greater than any of the individual capacitances.

Example 13.3: Three capacitors with capacitances of 3.0 μF, 4.0 μF, and 5.0 μF are arranged in parallel combination with a battery of 6 V, where 1 μF = 10^{-6}F. Find

(a) the total capacitance
(b) the voltage across each capacitor
(c) the quantity of charge on each plate of the capacitor

Solution: Diagram is shown on right.

(a) Total capacitance is given by

$C_{eq} = C_1 + C_2 + C_3$

$C_{eq} = 3.0 \times 10^{-6}\text{F} + 4.0 \times 10^{-6}\text{F} + 5.0 \times 10^{-6}\text{F}$

$C_{eq} = (3+4+5) \times 10^{-6}\text{F} = 12 \times 10^{-6}\text{F}$

$C_{eq} = 12\ \mu\text{F}$

(b) As three capacitors are connected in parallel, the voltage across each capacitor will be same and is equal to the voltage of the battery i.e., 6 V.

(c) Charge on a capacitor with capacitance C_1

$Q_1 = C_1V$

$Q_1 = 3.0 \times 10^{-6}\text{F} \times 6\text{ V} = (3 \times 6) \times 10^{-6}\text{F V}$

$Q_1 = 18\ \mu\text{C}$

Similarly, charge on capacitors with capacitances C_2 and C_3 is 24 μC and 30 μC respectively.

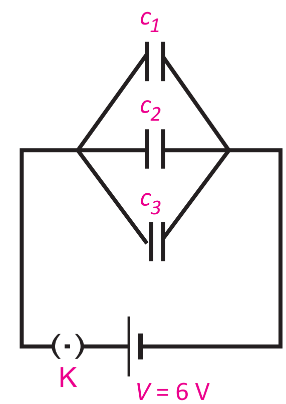
(ii) Capacitors in Series

In this combination, the capacitors are connected side by side i.e., the right plate of one capacitor is connected to the left plate of the next capacitor (Fig. 13.15). This type of combination has the following characteristics:

1. Each capacitor has the same charge across it. If the battery supplies +Q charge to the left plate of the capacitor C_1, due to induction –Q charge is induced on its right plate and +Q charge on the left plate of the capacitor C_2 i.e.,

Quick Quiz

Is the equivalent capacitance of parallel capacitors larger or smaller than the capacitance of any individual capacitor in the combination?



Energy Stored in a Capacitor

Capacitor stores energy in an electric field between two plates in the form of electrostatic potential energy.

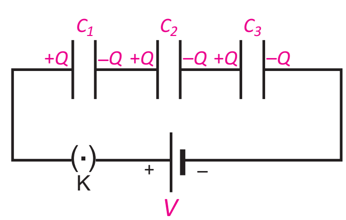


Fig.13.15: capacitors in series combination.

$$Q_1 = Q_2 = Q_3 = Q$$

2. The potential difference across each capacitor is different due to different values of capacitances.

3. The voltage of the battery has been divided among the various capacitors. Hence

$$V = V_1 + V_2 + V_3$$
$$= \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$
$$= Q\left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right]$$
$$\frac{V}{Q} = \left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right]$$

Quick Quiz

Is the equivalent capacitance of series capacitors larger or smaller than the capacitance of any individual capacitor in the combination?

4. Thus, we can replace series combination of capacitors with one equivalent capacitor having capacitance C_{eq} i.e.,

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

In the case of 'n' capacitors connected in series, we have

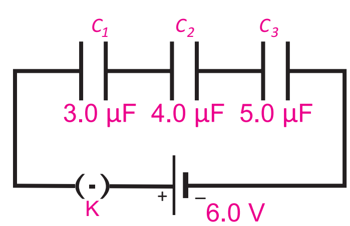
$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots\cdots + \frac{1}{C_n} \quad ....(13.10)$$

Example 13.4: Three capacitors with capacitances of 3.0 μF, 4.0 μF, and 5.0 μF are arranged in series combination to a battery of 6V, where 1 μF = 10^{-6}F. Find

(a) the total capacitance of the series combination.
(b) the quantity of charge across each capacitor.
(c) the voltage across each capacitor.

Solution: (a) Diagram is shown on right. For total capacitance,

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$
$$\frac{1}{C_{eq}} = \frac{1}{3.0 \times 10^{-6}\,F} + \frac{1}{4.0 \times 10^{-6}\,F} + \frac{1}{5.0 \times 10^{-6}\,F}$$
$$\frac{1}{C_{eq}} = \left[\frac{1}{3} + \frac{1}{4} + \frac{1}{5}\right] \times \frac{1}{10^{-6}\,F}$$
$$\frac{1}{C_{eq}} = \frac{47}{60} \times \frac{1}{10^{-6}\,F}$$
$$C_{eq} = 1.3\ \mu F$$



(b) In series combination, charge across each capacitor is same and can be found as:

$Q = CV = (6.0\,V)(1.3 \times 10^{-6} F) = 7.8\,\mu C$

(c) Voltage across capacitor $C_1 = V_1 = \frac{Q}{C_1} = \frac{7.8 \times 10^{-6} C}{3.0 \times 10^{-6} F} = 2.6\,V$

Voltage across capacitor $C_1 = V_2 = \frac{Q}{C_2} = \frac{7.8 \times 10^{-6} C}{4.0 \times 10^{-6} F} = 1.95\,V$

Voltage across capacitor $C_1 = V_3 = \frac{Q}{C_3} = \frac{7.8 \times 10^{-6} C}{5.0 \times 10^{-6} F} = 1.56\,V$

13.8 DIFFERENT TYPES OF CAPACITORS

Parallel plate capacitors are not commonly used in most devices because in order to store enough charge their size must be large which is not desirable. A parallel plate capacitor has a dielectric between its plates and is made of a flexible material that can be rolled into the shape of a cylinder. In this way, we can increase the area of each plate while the capacitor can fit into a small space. Some other types of capacitors use chemical reactions to store charge. These are called electrolytic capacitors.

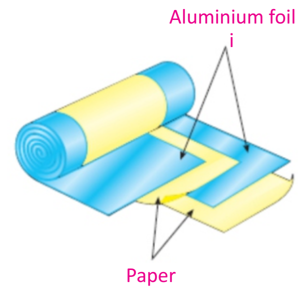


Fig. 13.16: Paper capacitor

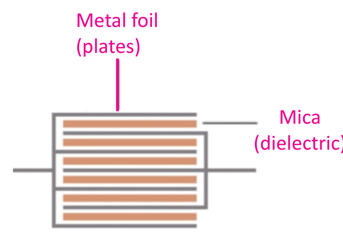


Fig. 13.17: Mica capacitor

Capacitors have different types depending upon their construction and the nature of dielectric used in them.

Paper capacitor is an example of fixed capacitors (Fig. 13.16). The paper capacitor has a cylindrical shape. Usually, an oiled or greased paper or a thin plastic sheet is used as a dielectric between two aluminium foils. The paper or plastic sheet is firmly rolled in the form of a cylinder and is then enclosed into a plastic case.

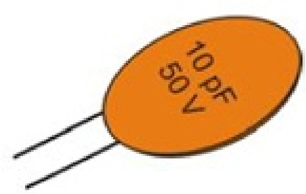


Fig. 13.18: Mica capacitor

Mica capacitor is another example of fixed capacitors. In these capacitors, mica is used as dielectric between the two metal plates (Fig.13.17). Since mica is very fragile, it is enclosed in a plastic case or in a case of some insulator. Wires attached to plates project out of the case for making connections (Fig. 13.18). If the capacitance is to be increased, large number of plates is piled up, one over the other with layers of dielectric in between and alternative plates are connected with each other.

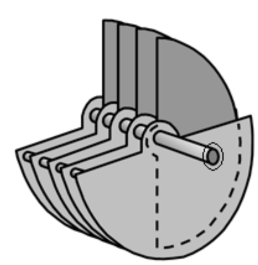


Fig. 13.19: Variable capacitor

In variable type of capacitors, some arrangement is made to change the area of the plates facing each other (Fig. 13.19). It is generally a combination of many capacitors with air as dielectric. It consists of two sets of plates. One set remains fixed while the other set can rotate so the distance between the plates does not change and they do not touch each other. The common area of the plates of the two sets which faces each other, determines the value of capacitance. Thus, the capacitance of the capacitor can be increased or decreased by turning the rotatable plates in or out of the space between the static plates. Such capacitors are usually utilized for tuning in radio sets.

An electrolytic capacitor is often used to store large amount of charge at relatively low voltages (Fig.13.20). It consists of a metal foil in contact with an electrolyte—a solution that conducts charge by virtue of the motion of the ions contained in it. When a voltage is applied between the foil and the electrolyte, a thin layer of metal oxide (an insulator) is formed on the foil, and this layer serves as the dielectric. Very large capacitances can be attained because the dielectric layer is very thin.

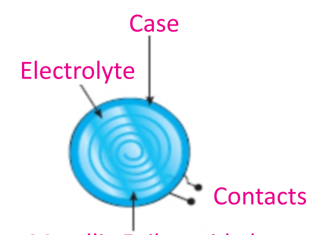


Fig.13.20: Electrolytic capacitor

Uses of Capacitors

Capacitors have wide range of applications in different electrical and electronic circuits. For example, they are used for tuning transmitters, receivers and transistor radios. They are also used for table fans, ceiling fans, exhaust fans, fan motors in air conditioners, coolers, motors washing machines, air conditioners and many other appliances for their smooth working.

Capacitors are also used in electronic circuits of computers etc.

Capacitors can be used to differentiate between high frequency and low frequency signals which make them useful in electronic circuits. For example, capacitors are used in the resonant circuits that tune radios to particular frequencies. Such circuits are called filter circuits. One type of capacitor may not be suitable for all applications. Ceramic capacitors are generally superior to other types and therefore can be used in vast ranges of application.

For your information

All of these devices are capacitors, which store electric charge and energy.

13.9 APPLICATIONS OF ELECTROSTATICS

Static electricity has an important place in our everyday lives which include photocopying, car painting, extracting dust from dirty carpets and from chimneys of industrial machinery etc.

Electrostatic Air Cleaner

An *electrostatic air cleaner* is used in homes to relieve the discomfort of allergy sufferers. Air mixed with dust and pollen enters the device across a positively charged mesh (Fig.13.21). 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 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.

Through this process we can remove a very high percentage of contaminants from the air stream.

Electrostatic Powder Painting

Automobile manufacturers use static electricity 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 (Fig.13.22). Due to mutual repulsion, charge particles coming out of the nozzle form a fine mist and are evenly distributed on the surface of the object. The charged paint particles are attracted to the car and stick to the body, just like a charged balloon sticks to a wall. Once the paint dries, it sticks much better to the car and is smoother, because it is uniformly distributed. This is a very effective, efficient and economical wa

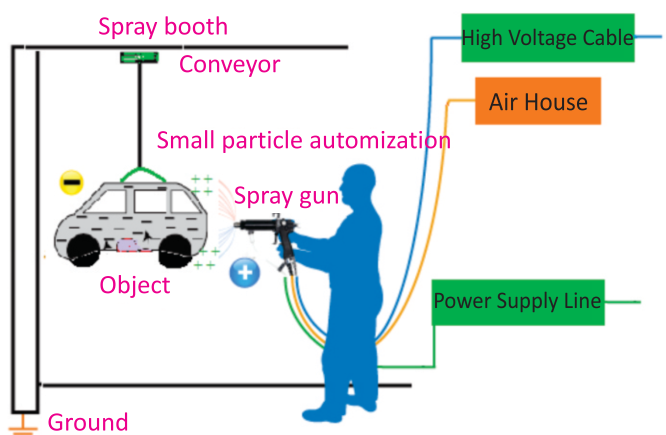


Fig. 13.22: Schematic diagram of electrostatic spray painting system. Car is negatively charged and spray gun is positively charged. As drops have

Point to Ponder!
Capacitor blocks dc but allows ac to pass through a circuit. How does this happen?

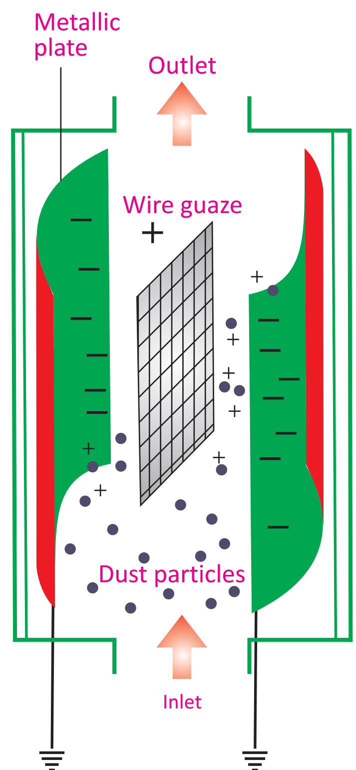


Fig. 13.21

Point to Ponder!
How would you suspend 500,000 pounds of water in the air with no visible means of support? (Hint: build a cloud!)

same charge they repel and give a fine mist of spray

13.10 SOME HAZARDS OF STATIC ELECTRICITY

Lightning

The phenomenon of lightning occurs due to a large quantity of electric charge which builds up in the heavy thunderclouds. The thunderclouds are charged by friction between the water molecules in the thunderclouds and the air molecules. When the charge on the thunderclouds is sufficiently high, It induces opposite charge on the objects present on the ground giving rise to a strong electric field between the cloud and the ground. Suddenly, the charge in cloud jumps to the ground with a violent spark and explosion. This is called lightning.

To prevent lightning from damaging tall buildings, lightning conductors are used. The purpose of the lightning conductor is to provide a steady discharge path for the large amount of negative charge in the air to flow from the top of the building to the Earth. In this way, the chances of lightning damage due to sudden discharge can be minimized.

Fires or Explosions

Static electricity is a major cause of fires and explosions at many places. A fire or an explosion may occur due to excessive build-up of electric charges produced by friction.

Static electricity can be generated by the friction of the gasoline being pumped into a vehicle or container. It can also be produced when we get out of the car or remove an article of clothing. Static charges are dangerous. If static charges are allowed to discharge through the areas where there is petrol vapour a fire can occur.

Dangers of Static Electricity

Static electricity can spark a fire or explosions. Care must be taken to avoid sparks when putting fuel in cars or aircraft. Spark may be produced due to friction between the fuel and the pipe. This can cause a serious explosion. The spark can be avoided if the pipe nozzle is made to conduct by connecting an earthing strap to it. The earthing strap connects the pipe to the ground.

For your information

The energy in lightning is enough to crack bricks and stone in unprotected buildings, and destroy electrical equipments inside. Each bolt of lightning contains about 1000 million joules of energy! This energy is enough to boil a kettle continuously for about two weeks. A flash of lightning is brighter than 10^7 light bulbs each of 100 watt.

For your information

During flight, body of an aeroplane gets charged. As the aeroplane lands, this charge is transferred to ground though the specially designed tyres.

SUMMARY

- Electric charges are of two types, positive charge and negative charge. Like charges repel each other and unlike charges attract each other.
- Electrostatic induction is the process of charging a conductor without any contact with the charging body.
- Coulomb's law states that the force of attraction or repulsion between two charged bodies is directly proportional to the product of the charges and inversely proportional to the square of the distance between them. Mathematically, it is given by

$$F = k\frac{q_1 q_2}{r^2}$$

- Electric field is a region of space surrounding a charged body in which a unit positive point charge can experience a force.
- Electric potential at any point in the field is defined as the work done in moving a unit positive charge from infinity to that point. Unit of potential is volt which is equal to one joule of work done in moving one coulomb of positive charge from infinity to that point.
- Capacitor is a device which is used to store electric charge. Capacitance is the ability of a capacitor to store electric charge. Its SI unit is farad (F). If one coulomb of positive charge given to one of the plates of the capacitor develops a potential difference of one volt, then its capacitance will be one farad.
- The equivalent capacitance C_{eq} of a parallel combination of 'n' capacitors is given by

$$C_{eq} = C_1 + C_2 + C_3 + \ldots\ldots + C_n$$

- The equivalent capacitance C_{eq} of a series combination of 'n' capacitors is given by

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots\cdots + \frac{1}{C_n}$$

MULTIPLE CHOICE QUESTIONS

Choose the correct answer from the following choices:

i. A positive electric charge
(a) attracts other positive charge (b) repels other positive charge
(c) attracts a neutral charge (d) repels a neutral charge

ii. An object gains excess negative charge after being rubbed against another object, which is:
(a) neutral (b) negatively charged
(c) positively charged (d) either a, b or c

iii. Two uncharged objects A and B are rubbed against each other. When object B is placed near a negatively charged object C, the two objects repel each other. Which of the following statements is true about object A?

(a) remains uncharged b) becomes positively charged
(c) becomes negatively charged (d) unpredictable

iv. When you rub a plastic rod against your hair several times and put it near some bits of paper, the pieces of papers are attracted towards it. What does this observation indicate?

(a) the rod and the paper are oppositely charged
(b) the rod acquires a positive charge
(c) the rod and the paper have the same charges
(d) the rod acquires a negative charge

v. According to Coulomb's law, what happens to the attraction of two oppositely charged objects as their distance of separation increases?

(a) increases (b) decreases
(c) remains unchanged (d) cannot be determined

vi. The Coulomb's law is valid for the charges which are

(a) moving and point charges (b) moving and non-point charges
(c) stationary and point charges (d) stationary and large size charges

vii. A positive and a negative charge are initially 4 cm apart. When they are moved closer together so that they are now only 1 cm apart, the force between them is

(a) 4 times smaller than before (b) 4 times larger than before
(c) 8 times larger than before (d) 16 times larger than before

viii. Five joules of work is needed to shift 10 C of charge from one place to another. The potential difference between the places is

(a) 0.5 V (b) 2 V
(c) 5 V (d) 10 V

ix. Two small charged spheres are separated by 2 mm. Which of the following would produce the greatest attractive force?

(a) +1q and +4q (b) –1q and –4q
(c) +2q and +2q (d) +2q and –2q

x. Electric field lines

(a) always cross each other
(b) never cross each other
(c) cross each other in the region of strong field
(d) cross each other in the region of weak field

xi. Capacitance is defined as

(a) VC (b) Q/V
(c) QV (d) V/Q

REVIEW QUESTIONS

13.1. How can you show by simple experiments that there are two types of electric charges?
13.2. Describe the method of charging bodies by electrostatic induction.
13.3. How does electrostatic induction differ from charging by friction?
13.4. What is gold leaf electroscope? Discuss its working principle with a labelled diagram.
13.5. Suppose you have a glass rod which becomes positively charged when you rub it with wool. Describe how would you charge the electroscope (i) negatively (ii) positively.
13.6. With the help of electroscope how you can find presence of charge on a body.
13.7. Describe how you would determine the nature of the charge on a body by using electroscope.
13.8. Explain Coulomb's law of electrostatics and write its mathematical form.
13.9. What is meant by electric field and electric intensity?
13.10. Is electric intensity a vector quantity? What will be its direction?
13.11. How would you define potential difference between two points? Define its unit.
13.12. Show that potential difference can be described as energy transfer per unit charge between the two points.
13.13. What do you mean by the capacitance of a capacitor? Define units of capacitance.
13.14. Derive the formula for the equivalent capacitance for a series combination of a number of capacitors.
13.15. Discuss different types of capacitors.
13.16. What is difference between variable and fixed type capacitor?
13.17. Enlist some uses of capacitors.
13.18. Discuss one application of static electricity.
13.19. What are hazards of static electricity?

CONCEPTUAL QUESTIONS

13.1. An electrified rod attracts pieces of paper. After a while these pieces fly away! Why?
13.2. How much negative charge has been removed from a positively charged electroscope, if it has a charge of 7.5×10^{-11} C?
13.3. In what direction will a positively charged particle move in an electric field?
13.4. Does each capacitor carry equal charge in series combination? Explain.
13.5. Each capacitor in parallel combination has equal potential difference between its

two plates. Justify the statement.

13.6. Perhaps you have seen a gasoline truck trailing a metal chain beneath it. What purpose does the chain serve?

13.7. If a high-voltage power line fell across your car while you were in the car, why should you not come out of the car?

13.8. Explain why, a glass rod can be charged by rubbing when held by hand but an iron rod cannot be charged by rubbing, if held by hand?

NUMERICAL PROBLEMS

13.1. The charge of how many negatively charged particles would be equal to 100 µC. Assume charge on one negative particle is 1.6×10^{-19} C ? **Ans. (6.25×10^{14})**

13.2. Two point charges q_1 = 10 µC and q_2 = 5 µC are placed at a distance of 150 cm. What will be the Coulomb's force between them? Also find the direction of the force.

Ans. (0.2 N, the direction of repulsion)

13.3. The force of repulsion between two identical positive charges is 0.8 N, when the charges are 0.1 m apart. Find the value of each charge. **Ans. (9.4×10^{-7} C)**

13.4. Two charges repel each other with a force of 0.1 N when they are 5 cm apart. Find the forces between the same charges when they are 2 cm apart. **Ans. (0.62 N)**

13.5. The electric potential at a point in an electric field is 10^4 V. If a charge of +100 µC is brought from infinity to this point. What would be the amount of work done on it?

Ans.(1 J)

13.6. A point charge of +2 C is transferred from a point at potential 100 V to a point at potential 50 V. What would be the energy supplied by the charge? **Ans. (100 J)**

13.7. A capacitor holds 0.06 coulombs of charge when fully charged by a 9 volt battery. Calculate capacitance of the capacitor. **Ans. (6.67×10^{-3} F)**

13.8. A capacitor holds 0.03 coulombs of charge when fully charged by a 6 volt battery. How much voltage would be required for it to hold 2 coulombs of charge? **Ans.(400 V)**

13.9. Two capacitors of capacitances 6 µF and 12 µF are connected in series with 12 V battery. Find the equivalent capacitance of the combination. Find the charge and the potential difference across each capacitor. **Ans. (4 µF, 48 µC, 8 V, 4 V)**

13.10. Two capacitors of capacitances 6 µF and 12 µF are connected in parallel with a 12 V battery. Find the equivalent capacitance of the combination. Find the charge and the potential difference across each capacitor. **Ans. (18 µF, 72 µC, 144**