PERIOD–V

P10CH5

Topic

5

Electrostatics

5.1. ELECTROSTATIC FORCE

Electrostatics is a branch of physics that deals with the phenomena and properties of stationary or slow moving electric charges.

5.1.1. Definition of Electrostatic Force

ACTIVITY 5.1

Demonstrating electrostatic force

Take a plastic straw and cut it into nearly two equal pieces. Suspend one of the pieces from the edge of a table with the help of a piece of thread (Fig. 5.1). Now hold the other piece of straw in your hand and rub its free end with a sheet of paper. Bring the rubbed end of the straw near the suspended straw. Make sure that the two pieces do not touch each other. What do you observe?

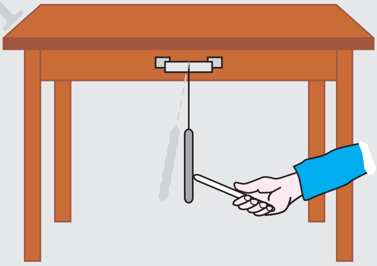


Fig. 5.1. A straw rubbed with paper attracts another straw but repels it if it has also been rubbed with a sheet of paper

Next, rub the free end of the suspended piece of straw with a sheet of paper. Again, bring the piece of straw that was rubbed earlier with paper near the free end of the suspended straw. What do you observe now?

A straw is said to have acquired electrostatic charge after it has been rubbed with a sheet of paper. Such a straw is an example of a charged body.

The force exerted by a charged body on another charged or uncharged body is known as **electrostatic force**.

5.1.1.1. Charging by rubbing

When a plastic refill is rubbed with polythene, it acquires a small electric charge. Similarly, when a plastic comb is rubbed with dry hair, it acquires a small charge. These objects are called **charged objects**. In the process of charging the refill and the plastic comb, polythene and hair also get charged.

5.1.1.2. Types of Charges and their Interaction

ACTIVITY 5.2

Interaction of charges

(a) Inflate two balloons. Hang them in such a way that they do not touch each other (Fig. 5.2). Rub both the balloons with a woollen cloth and release them. What do you observe?

Fig. 5.2. Like charges repel each other

Now let us repeat this activity with the used pen refills. Rub one refill with polythene. Place it carefully in a glass tumbler using the tumbler as a stand (Fig. 5.3).

Fig. 5.3. Interaction between like charges

Rub the other refill also with polythene. Bring it close to the charged refill. Be careful not to touch the charged end with your hand. Is there any effect on the refill in the tumbler? Do the two attract each other, or repel each other?

Fig. 5.4. Unlike charges attract each other

In this activity we have brought close together the charged objects that were made of the same material. What happens if two charged objects made of different materials are brought close to each other? Let's find out.

(b) Rub a refill and place it gently in a glass tumbler as before (Fig. 5.4). Bring an inflated charged balloon near the refill and observe.

Let's summarise the observations:

- A charged balloon repelled a charged balloon.
- A charged refill repelled a charged refill.
- But a charged balloon attracted a charged refill.

Does it indicate that the charge on the balloon is of a different kind from the charge on the refill? Can we say then, that there are two kinds of charges? Can we also say that the charges of the same kind repel each other, while charges of different kind attract each other?

It is a convention to call the charge acquired by a glass rod when it is rubbed with silk as positive. The other kind of charge is said to be negative.

It is observed that when a charged glass rod is brought near a charged plastic straw rubbed with polythene there is attraction between the two.

What do you think would be the kind of charge on the plastic straw? Your guess, that the plastic straw would carry a negative charge is correct.

The electrical charges generated by rubbing are static. They do not move by themselves.

In the International System (SI) of Units, a unit of charge is called a *coulomb* and is denoted by the symbol C. One coulomb is the charge flowing through a wire in 1 s if the current is 1 A (ampere).

In this system, the value of the basic unit of charge is

$$e = 1.602192 \times 10^{-19} \text{ C}$$

Thus there are about 6×10^{18} electrons in a charge of –1 C. In electrostatics, charges of this large magnitude are rarely encountered. Hence we use smaller units 1 μC (micro coulomb) = 10^{-6} C or 1 mC (milli coulomb) = 10^{-3} C.

5.1.2. Quantisation of Electric Charge

Several experiments have shown that in nature electric charges are found to be made up of integral multiples of a smallest amount of charge. This smallest amount is 1.6×10^{-19} coulomb. It is denoted by e and is equal to the charge of an electron. All existing charges are found to be in the magnitude of ... $-3e$, $-2e$, $-e$, 0, $2e$, $3e$, ... etc. or ne, where n is an integer.

Any charge q, no matter what is its origin is given by:

$$q = \pm ne \qquad \text{where } n = 1, 2, 3, \ldots$$

No one has found a charge in fraction of e as $0.7e$ or $2.5e$. It means that electric charge cannot be divided indefinitely. This property of charge is called 'quantisation' of charge. The charge of some natural elementary particles are as follows:

$$\text{Charge of electron} = -e$$
$$\text{Charge of proton} = +e$$

Example 5.1: *How many electrons must be removed from a piece of metal so as to give it a positive charge of 4.8×10^{-7} C?*

Solution: Let n be the number of electrons removed from the given piece of metal. Charge,

$$q = 4.8 \times 10^{-7} \text{ C}$$
$$e = 1.6 \times 10^{-19} \text{ C}$$

Using $q = n\,e$, we have,

$$n = \frac{q}{e} = \frac{4.8 \times 10^{-7}}{1.6 \times 10^{-19}}$$
$$= 3 \times 10^{12}$$

Thus, when 3×10^{12} electrons will be removed from the given piece of metal, 4.8×10^{-7} C of charge will be imparted to it.

Example 5.2: *Which is bigger, a coulomb or charge on an electron? How many electronic charges form one coulomb of charge?*

Solution: Number of electronic charges in one coulomb.

$$n = \frac{q}{e} = \frac{1 \text{ coulomb}}{1.6 \times 10^{-19} \text{ coulomb}}$$
$$= 0.625 \times 10^{19}$$

Clearly, one coulomb of charge is bigger than the charge on an electron.

5.2. PRINCIPLE OF CONSERVATION OF CHARGE

The principle of conservation of charge states that the algebraic sum of all the electric charges in any isolated system is constant. Charge can neither be created nor destroyed. It can only move from one place or object to another.

When we rub two bodies, what one body gains in charge, the other body loses. Within an isolated system, due to interactions among the charged bodies, charges may get redistributed. But it is found that *the total charge of the isolated system is always conserved.*

5.3. LAWS OF ELECTROSTATIC CHARGES

There are two laws of electrostatic charges.

First Law

It states that like charges of electricity repel each other, whereas unlike charges attract each other.

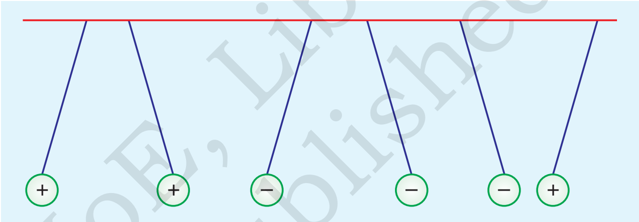


Fig. 5.5. Like charges repel each other and unlike charges attract each other

Second Law

The second law of electrostatic charges is also known as Coulomb's law. It is described below.

Coulomb's Law

Charles Augustin Coulomb, in 1785, studied and experimentally measured the electric forces between small charged spheres using torsion balance. He summarized his results in the form of a law now known as Coulomb's Law.

Charles Augustin Coulomb (1736–1806)

Coulomb's law *states that the electrostatic force of repulsion or attraction between two stationary point charges is directly proportional to the product of the two charges and inversely proportional to the square of distance between them.*

Fig. 5.6. Point charge q_1, q_2 separated by distance r

Let the two point charges be q_1 and q_2 separated by distance r. The force (F) of repulsion (or attraction) between the charges, as per Coulomb's law, is such that:

$$F \propto q_1 q_2$$

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

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

or,
$$F = \frac{k(q_1 q_2)}{r^2}$$

where, k is constant of proportionality and its value depends on the nature of the medium and the system of units used to measure the physical quantities.

In SI units, we write k as $\frac{1}{4\pi\varepsilon_0}$. Its value in these units is

$$k = 1/4\pi\varepsilon_0$$
$$= 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$$

The constant ε_0 is called permittivity of free space.

∴ Coulomb's Law in SI units can be written as

$$F = \frac{1}{4\pi\varepsilon_0}\frac{(q_1 q_2)}{r^2}$$

Example 5.3: *A charge of $\sqrt{2}$ C is placed at the top of your school building and another equal charge at the top of your house. Take the separation between the two charges to be 2 km. How many kilo-newton of force is exerted by the charges on each other?*

Solution:

$$q_1 = q_2 = \sqrt{2} \text{ C},$$
$$r = 2 \times 10^3 \text{ m}, F = ?$$
$$F = 9\times 10^9 \frac{\sqrt{2}\times\sqrt{2}}{(2\times 10^3)^2} \text{ N}$$
$$= 4.5 \times 10^3 \text{ N}$$
$$= 4.5 \text{ kN}$$

Example 5.4: *Two positively charged ions carrying equal charges repel each other by a force 3.7×10^{-9} N when separated by a distance 5 Å from each other. How many electrons are missing from each ion?*

Solution:

$$q_1 = q_2 = q \text{ (say)},$$
$$r = 5 \text{ Å} = 5 \times 10^{-10} \text{ m},$$
$$F = 3.7 \times 10^{-9} \text{ N}, r = ?$$

$$F = \frac{1}{4\pi\varepsilon_0}\frac{(q)(q)}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{(ne)(ne)}{r^2}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{n^2 e^2}{r^2} \quad \boxed{\text{Quantisation of charge : } q = ne.}$$

$$3.7 \times 10^{-9} = 9 \times 10^{9} \frac{n^2 \times (1.6 \times 10^{-19})^2}{(5 \times 10^{-10})^2}$$

$$\text{or } n^2 = \frac{3.7 \times 10^{-9} \times 25 \times 10^{-20}}{9 \times 1.6 \times 1.6 \times 10^{-29}} = 4$$

or $n = 2$

Example 5.5: *Force of attraction between two point charges placed at a distance d is F. What distance apart should they be kept in the same medium so that the force between them is* $\frac{F}{3}$*?*

Solution:

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{d^2} \quad \text{...(1)}$$

$$\text{Again,} \quad \frac{F}{3} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} \quad \text{...(2)}$$

Dividing (1) by (2), $3 = \frac{r^2}{d^2}$

or $r = 1.732\, d$

Example 5.6: *How far must two protons be if the repulsive force acting on either is equal to its weight? Take mass of proton (m) = 1.66 × 10*$^{-27}$ *kg and k = 9 × 10*^{9} *SI units.*

Solution: Let q be the charge on the proton and r be the distance between them.

According to Coulomb's law,

$$F = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{q_1 q_2}{r^2} = \frac{kq^2}{r^2}$$

$$(\because q_1 = q_2 = q)$$

Also, $F = mg$

$$\therefore \frac{kq^2}{r^2} = mg$$

$$\Rightarrow r^2 = \frac{kq^2}{mg} = \frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2}{1.66 \times 10^{-27} \times 9.8}$$

$$\Rightarrow r = \left[\frac{(9 \times 10^9) \times (1.6 \times 10^{-19})^2}{1.66 \times 10^{-27} \times 9.8}\right]^{1/2}$$

Solving we get, $r = 0.199$ m

5.4. INSULATORS AND CONDUCTORS

On the basis of the behaviour in an external electric field, most of the substances can be classified as:

1. **Conductors:** Those substances which allow electric charges to pass through them easily, when subjected to an external electric field, are called conductors.

   e.g., silver, copper, aluminium, and other metals.

2. **Insulators:** Those substances which do not allow electric charges to pass through them when subjected to an external electric field are called insulators.

   e.g., glass, wood, plastic, mica and most of the non-metals.

5.5. ELECTRIC FILED

There is a region or space around a charge or a system of charges within which other charged particles experience electrostatic forces. This region is called an ***electric field***. Thus, a particle is said to be in an electric field if the particle experiences an electrostatic force.

Theoretically speaking, the electric field extends upto infinity but practically the electric field does not show detectable influence beyond a certain limited distance.

5.5.1. Intensity of Electric Field

If $\vec{F}$ is the electrostatic force experienced by a test charge q at a point, then the electric field intensity at that point is given by

$$\vec{E} = \frac{\vec{F}}{q}$$

SI unit of electric field intensity is newton per coulomb (NC^{-1}).

Electric field helps us determine the electrical environment of a system of charges.

5.6. ELECTRIC FIELD LINES

We have already discussed the concept of Electric Field. It is a region of space where any charged particles in it experiences a force.

We can represent an electric field graphically using lines of force known as **electric field lines**.

5.6.1. Electric Field Lines for a Point Charge

ACTIVITY 5.3

Group discussion

In small groups, discuss electric field lines for a point charge.

An isolated positive charge

The electric field lines due to the isolated positive charge would radiate outward uniformly in all directions.

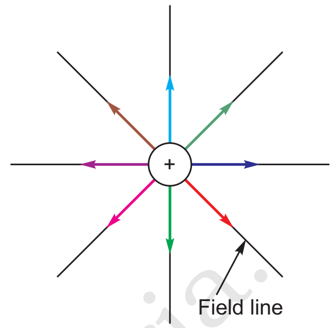


Fig. 5.7. Electric field lines due to isolated positive charge

An isolated negative charge

The electric field lines due to the isolated negative charge would radiate inward uniformly from all directions.

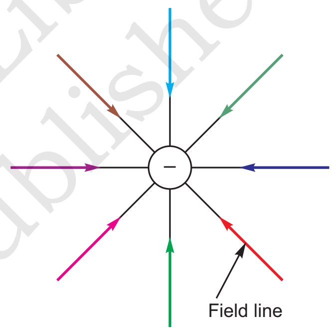


Fig. 5.8. Electric field lines due to an isolated negative charge

5.6.2. Electric Field Lines for Two Like Charges

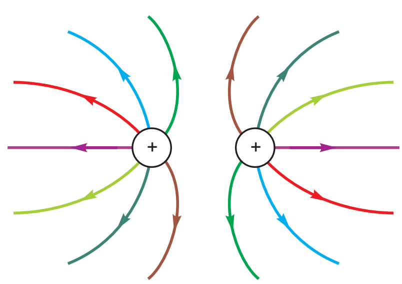
ACTIVITY 5.4

Group discussion

In small groups, discuss electric field lines for two like charges.

Two like charges of equal magnitude

The electric field lines of two like charges of equal magnitude is shown in Fig. 5.9.



For negative charges of equal magnitude, the shape looks the same except for the direction of field lines

Fig. 5.9. Two like charges of equal magnitude

5.6.3. Electric Field Lines for Two Unlike Charges

ACTIVITY 5.5

Group discussion

In small groups, discuss electric field lines for two unlike charges.

Unlike charges of equal magnitude

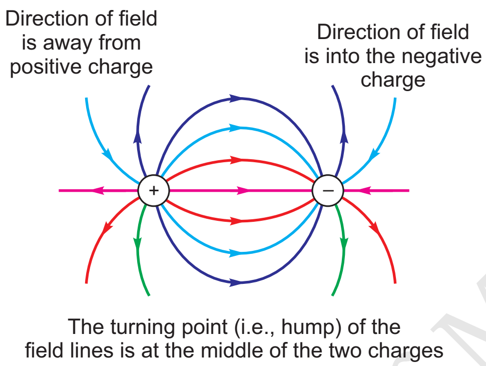


Fig. 5.10. Unlike charges of equal magnitude

Unlike charges (positive charge of larger magnitude)

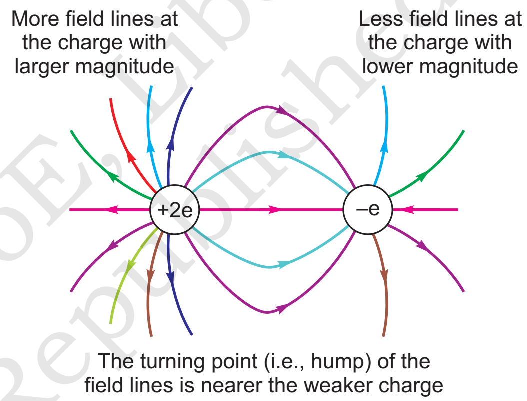


Fig. 5.11. Unlike charges

5.6.4. General Properties of Electric Field Lines

The field lines follow some important general properties:

(i) Field lines start from positive charges and end at negative charges. If there is a single charge, they may start or end at infinity.

(ii) In a charge free region, electric field lines can be taken to be continuous curves without any breaks.

(iii) Two field lines can never cross each other. (If they did, the field at the point of intersection will not have a unique direction, which is absurd).

(iv) Electrostatic field lines do not form any closed loops.

(v) Lines are closer together where the field is stronger.

(vi) Larger charges have more field lines beginning or ending on them.

5.7. ELECTRIC FIELD DUE TO ONE POINT CHARGE

Consider a point charge q called source charge placed at a point 'O' in space. To find its intensity at a point 'P' at a distance 'r' from the point charge we place a test charge q'.

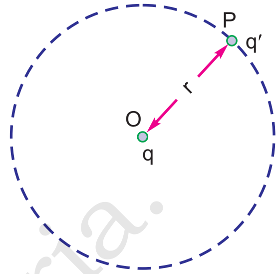


Fig. 5.12.

The force experienced by the test charge q' will be:

$$F = Eq' \qquad ...(1)$$

According to Coulomb's law the electrostatic force between them is given by:

$$F = \frac{kqq'}{r^2}$$

From equation (1)

$$E = \frac{F}{q'}$$

or

$$E = \frac{1}{q'} \times F$$

Putting the value of 'F' we get

$$E = \frac{1}{q'} \times \frac{kqq'}{r^2}$$

$$E = \frac{kq}{r^2}$$

Example 5.7: *What is the strength of the electric field 0.16 m on the left hand side of a 6.7 μC positive charge?*

Solution: Given:

$E = ?$

$k = 9.0 \times 10^9 \text{ N. m}^2/\text{C}^2$

$r = 0.16 \text{ m}$

$q = 6.7\ \mu\text{C}$

The formula used in this problem is:

$$E = \frac{kq}{r^2}$$

$$E = \frac{9.0 \times 10^9 \times 6.7}{(0.16)^2}$$

$$= 2.4 \times 10^6 \text{ N/C}$$

Where:

E is the electric field strength in N/C

k is the constant 9.0×10^9 $N.m^2/C^2$.

q is the size of the charge creating the electric field. (in C)

r is the distance in meters (m) away from the charge.

Example 5.8: *Charge q acts as a point charge to create an electric field. Its strength, measured a distance of 30 cm aways, is 40 N/C. What is the magnitude of the electric field strength that you would expect to be measured at a distance of 60 cm away?*

Solution: We know that, $E = \frac{kq}{r^2}$

(E = electric field intensity and r is the distance)

The electric field strength is inversely related to the square of the distance. So by whatever factor r changes by, the E value is altered in the inverse direction by the square of that factor

As r increases by a factor of 2; divide the original E by 4

Thus, E = 40/4 = 10 N/C

Example 5.9: *Charge q acts as a point charge to create an electric field. Its strength, measured a distance of 30 cm away, is 40 N/C. What would be the electric field strength 30 cm away from a source with charge 2q?*

Solution: We know that, $E = \frac{kq}{r^2}$

The E value is directly related to the source charge and inversely related to the square of the distance. So, twice the source charge will double the E value, *i.e.*, E = 40 × 2 = 80 N/C

5.8. ELECTRIC POTENTIAL

An electric charge has its electric field around it. Strength of this field is different at different points inside the field.

A unit positive charge kept outside the field, experiences no force on itself. When this charge is brought inside the field, it starts experiencing a force when this charge is brought nearer to the field charge, greater force acts on it.

As the charge is moved against the force, some work is done. As the charge is moved further inside the field, more work is done. This work done gives some property to the point and when the test charge is left free at that point, it will start moving itself away from the field charge.

This property, due to which a unit positive charge moves away from the field when free to do so, called ***electric potential****.*

Electric potential at a point inside the field of a given charge is the work done in moving a unit positive charge from infinity (i.e., from outside the field) to that point against the direction of force.

It is represented by the symbol V. Its SI unit is volt (V).

It is a scalar quantity (being the work done),

$$1 \text{ Volt (V)} = \frac{1 \text{ Joule (J)}}{1 \text{ Coulomb (C)}}$$

In general, $$\text{Potential (V)} = \frac{\text{Work done (W)}}{\text{Charge moved } (q)}$$

i.e., $$\text{Work done} = \text{Charge} \times \text{Potential}$$

or $$W = qV$$

5.8.1. Potential Difference

Two points situated inside the electric field of a field charge at different distances from it, have different potentials. Different amount of work is done in bringing a unit positive test charge from infinity to those points. Difference of work done is a measure of difference of potential of the two points.

Potential difference *between two points inside the field of a field charge is defined (or measured) as the work done in moving a unit positive test-charge from one point to other against the force.*

i.e., $$\text{Potential difference} = \frac{\text{Work done}}{\text{Charge moved}}$$

Potential difference is a scalar quantity.

Unit of P.D. If W joule of work has to be done to transfer q coulomb of charge from one point to other, then potential difference (P.D.) between the two points is given by,

$$\text{P.D.} = \frac{W}{q}$$

P.D. is usually denoted by V.

$\therefore$ $$V = \frac{W}{q}$$

SI unit of potential difference is volt.

Potential difference between any two points is said to be one volt if one joule of work is done in moving a charge of one coulomb from one point to other.

i.e.,
$$1 \text{ Volt} = \frac{1 \text{ Joule}}{1 \text{ Coulomb}}.$$

Example 5.10: *How much work is done in moving a charge of 2 C across two points, having a potential difference 12 V?*

Solution: Here,

Charge moved, $q = 2$ C

Potential difference $V = 12$ V

Work done, $W = ?$

From relation,

Work done = charged moved × potential difference

i.e., $W = qV$

Putting values, we get

$W = 2 \text{ C} \times 12 \text{ V} = 24 \text{ CV}$

Work done,

$W = 24$ J.

Example 5.11: *How much energy is given to each coulomb of charge passing through a 6 V battery?*

Solution: Here,

Charge passing, $q = 1$ C

Potential difference of battery,

$V = 6$ V

Energy given, $E = ?$

From relation,

Work done = charge × potential difference

i.e., $W = qV$

Putting values, we get

$W = 1 \text{ C} \times 6 \text{ V} = 6 \text{ CV}$

or Energy given = Work done,

$W = 6$ J.

5.9. CAPACITOR

A capacitor is a two-terminal electrical device that possesses the ability to store energy in the form of an electric charge. It consists of two electrical conductors that are separated by a distance. The space between the conductors may be filled by vacuum or with an insulating material known as a dielectric. The symbol ⊣⊢ is used to represent a capacitor in the circuit.

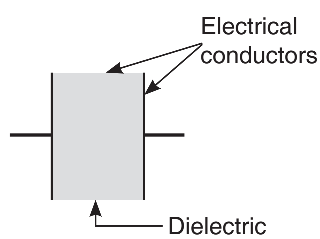


Fig. 5.13. Parallel plate capacitor

Capacitors store energy by holding apart pairs of opposite charges. The simplest design for a capacitor is a parallel plate, which consists of two metal plates with a gap between them. But, different types of capacitors are manufactured in many forms, styles, lengths, girths, and materials.

5.9.1. Capacitance

The ability of the capacitor to store charges is known as capacitance.

The *electric field* in the region between the plates of capacitor depends on the charge given to the conducting plates. We also know that potential difference (V) is directly proportional to the electric field hence we can say,

$$Q \propto V$$
$$Q = CV$$
$$C = Q/V$$

This constant of proportionality is known as the capacitance of the capacitor.

Capacitance is the ratio of the change in the electric charge of a system, to the corresponding change in its electric potential.

The capacitance of any capacitor can be either fixed or variable depending on its usage. From the equation, it may seem that 'C' depends on charge and voltage. Actually, it depends on the shape and size of the capacitor and also on the insulator used between the conducting plates.

5.9.2. Standard Units of Capacitance

The basic unit of capacitance is farad. But, farad is a large unit for practical tasks. Hence, capacitance is usually measured in the sub-units of farad, such as micro-farad (μF) or pico-farad (pF).

Most of the electrical and electronic applications are covered by the following standard unit (SI) prefixes for easy calculations:

- 1 mF (millifarad) = 10^{-3} F
- 1 μF (microfarad) = 10^{-6} F
- 1 nF (nanofarad) = 10^{-9} F
- 1 pF (picofarad) = 10^{-12} F

Example 5.12: *A capacitor of capacitance 20 μF is charged to a potential of 500 volts. Calculate the charge in the capacitor.*

Solution: Given: $C = 20\ \mu F = 20 \times 10^{-6}$ F

$$V = 500 \text{ volts}$$

We know,

$$Q = VC$$
$$= 500 \times 20 \times 10^{-6}\ C = 10^{-2}\ C$$

5.9.3. Charging and Discharging of a Capacitor

Let us consider the most basic structure of a capacitor – the parallel plate capacitor. It consists of two parallel plates separated by a dielectric. When we connect a DC voltage source across the capacitor, one plate is connected to the positive end (plate I) and the other plate to the negative end (plate II). When the potential of the battery is applied across the capacitor, plate I become positive with respect to plate II. The current tries to flow through the capacitor at the steady-state condition from its positive plate to its negative plate. But it is unable to flow due to the separation of these with an insulating material.

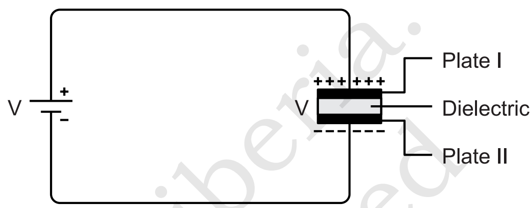


Fig. 5.14. A battery is connected across a parallel plate capacitor

An electric field appears across the capacitor. The positive plate (plate I) accumulates positive charges from the battery, and the negative plate (pate II) will accumulate negative charges from the battery. After a point, the capacitor holds the maximum amount of charge as per its capacitance with respect to this voltage. This time span is called the *charging time of the capacitor.*

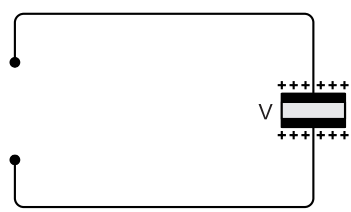


Fig. 5.15. Battery is removed across the parallel plate capacitor

When the battery is removed from the capacitor, the two plates hold a negative and positive charge for a certain time, the capacitor acts as a source of electrical energy.

If these plates are connected to a load, the current flows to the load from Plate I to Plate II unit all the charges are dissipated from both plates. This time span is known as the *discharging time of the capacitor.*

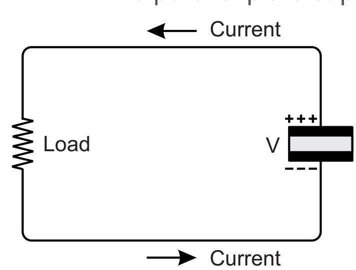


Fig. 5.16. Capacitor acting as a source of electrical energy

5.10. TYPES OF CAPACITORS

There are two types of capacitors: 1. Fixed capacitors and 2. Variable capacitors.

1. **Fixed Capacitors:** Capacitors that have fixed capacitance values are called fixed capacitors.

   Some of fixed capacitors are:

   (a) Electrolytic Capacitor
   (b) Mica Capacitor
   (c) Paper Capacitor
   (d) Film Capacitor
   (e) Non-polarized Capacitor
   (f) Ceramic Capacitor

2. **Variable Capacitors:** Capacitors that have adjustable capacitance values are called variable capacitors.

   The most popularly used variable capacitors are:

   (a) Tuning Capacitors
   (b) Trimmer Capacitors

   The capacitance of these capacitors can be varied with the help of screwdrivers or by any other devices manually.

5.11. USES OF CAPACITORS

(i) In Storing of Charge : The main purpose of a capacitor is to store electric charge. If an instantaneous but strong electric current is to be flown in a circuit, then the best way is to connect the terminals of the circuit to a charged capacitor.

(ii) In Storing of Energy : Capacitors store not only electric charge but electric energy also. The electric field established between the plates of a charged capacitor contains sufficient energy.

(iii) In Electrical Instruments : Many electrical instruments make specific use of capacitors. When an inductive electric circuit is suddenly broken, sparking occurs at the breaking points. But if a capacitor is connected in the circuit in such a way that the induced current produced as a result of breaking of the circuit charges the plates of the capacitor, the sparking will not be produced.

(iv) In Electronic Circuits : Capacitors are used almost in all electronic circuits. For example, they play important role in reducing the fluctuations of voltage in power-supply, in the transmission of pulsed signals, in the production and detection of electro-magnetic oscillations of radio frequency (*i.e.*, in broadcasting/telecasting and receiving the radio and television programmes).

(v) In Scientific Study : Capacitors are also used in scientific study. Using capacitor plates of different shapes and sizes, electric fields of different configurations are established between them and the behaviour of dielectric substances placed in these fields is studied.

5.12. COMBINATIONS OF CAPACITORS

In many situations we need to combine two or more capacitors. We can combine them in series, parallel or in a combination of series-parallel.

(a) In Series : In figure 5.17, three capacitors C_1, C_2 and C_3 are joined in series between points A and B. At point B the second plate of the capacitor C_3 being connected to the earth.

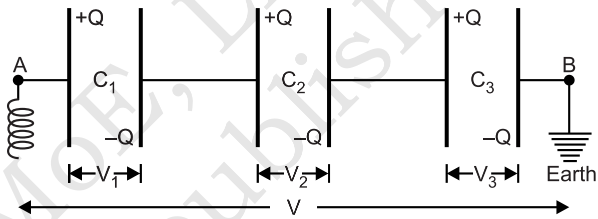


Fig. 5.17.

Suppose, by means of the electric-source + Q charge is given to the first plate of the first capacitor C_1. By induction, – Q charge is produced on the inner surface of the second plate of C_1 and its free charge + Q flows to the first plate of the second capacitor C_2. Thus, the first plate of each capacitor has a charge + Q and the second plate has a charge – Q. Let the potential difference between the plates of the capacitors C_1, C_2 and C_3 be V_1, V_2 and V_3 respectively, Then

$$V_1 = \frac{Q}{C_1},\ V_2 = \frac{Q}{C_2} \text{ and } V_3 = \frac{Q}{C_3}$$

If the total potential difference between points A and B be V, then

$$V = V_1 + V_2 + V_3 = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} \qquad \text{...(1)}$$

If the place of all the three capacitors, only one capacitor be placed between the points A and B, such that on giving it a charge Q, the potential difference between its plates be V, then it will be an 'equivalent capacitor'. If the capacitance of this capacitor be *C*, then

$$V = Q/C. \qquad \text{...(2)}$$

Comparing equations (1) and (2), we have

$$\frac{Q}{C} = \frac{Q}{C_1} = \frac{Q}{C_2} = \frac{Q}{C_3}$$

or
$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}.$$

Thus, *if several capacitors are connected in series, then the reciprocal of the capacitance of the equivalent capacitor is equal to the sum of the reciprocals of the capacitances of the individual capacitors.* In fact, the equivalent capacitance is even less than the lowest capacitance in series.

Example 5.13: *In the combination of four identical capacitors shown, the equivalent capacitance between points P and Q is 1 μF. Find the value of each separate capacitance.*

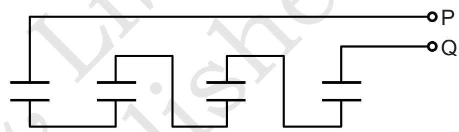


Fig. 5.18.

Solution: Let C be the capacitance of each capacitor. It can be seen that all the four capacitors are joined in series between the points P and Q. Therefore, if C′ be the equivalent capacitance between P and Q, we have

$$\frac{1}{C'} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C} + \frac{1}{C} = \frac{4}{C}$$

or
$$C' = C / 4 = 1 \mu F \qquad \therefore \; C = 4 \; \mu F.$$

(b) In Parallel : Figure 5.19, three capacitors C_1, C_2 and C_3 are connected in parallel between the points A and B. The point B is connected to the earth.

Suppose + Q charge is given to the point A by means of an electric source. This charge is distributed on all the three capacitors according to their capacitances. By induction, equal amounts of negative charges are induced on the inner surfaces of the second plates of the capacitors, while the free positive charges induced on their outer surfaces flow into the earth. Since all the three

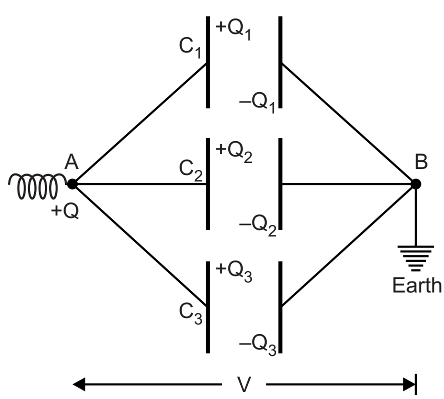


Fig. 5.19.

capacitors are connected between the points A and B the potential difference between the plates of each capacitor will be the same. Let it be V. If the charges on the capacitors C_1, C_2 and C_3 be Q_1, Q_2 and Q_3 respectively, then

$$Q_1 = C_1 V, \quad Q_2 = C_2 V \text{ and } Q_3 = C_3 V.$$

Total charge on all the three capacitors is

$$Q = Q_1 + Q_2 + Q_3$$
$$= C_1 V + C_2 V + C_3 V = V (C_1 + C_2 + C_3). \qquad ...(3)$$

If, in place of all the three capacitors, only one capacitor be placed between A and B such that on giving it a charge Q the potential difference between its plates be V, then it will be an 'equivalent capacitor'. If the capacitance of this capacitor be C, then

$$Q = V C \qquad ...(4)$$

Comparing equations (3) and (4), we have

$$V C = V (C_1 + C_2 + C_3)$$

or $$C = C_1 + C_2 + C_3.$$

Thus, *the equivalent capacitance of the capacitors joined in parallel is equal to the sum of their individual capacitances.*

Example 5.14: *Three capacitors 10 μF, 20 μF and 25 μF are connected in parallel with a 250 V supply. Calculate the equivalent capacitance of the circuit.*

Solution:

$$C_1 = 10\ \mu F$$
$$C_2 = 20\ \mu F$$
$$C_3 = 25\ \mu F$$

Equivalent capacitance of a parallel combination is

$$C = C_1 + C_2 + C_3$$
$$= 10\ \mu F + 20\ \mu F + 25\ \mu F$$
$$= 55\ \mu F$$

Example 5.15: *A circuit shown below consists of four capacitors connected in parallel and a DC voltage source.*

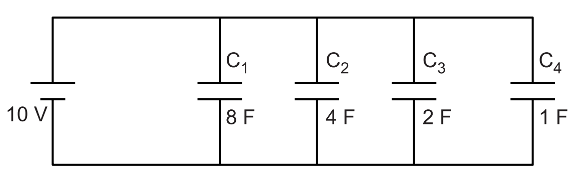


Fig. 5.20.

Find the total capacitance of the circuit.

Solution: $C_1 = 8$ F, $C_2 = 4$ F, $C_3 = 2$ F, $C_4 = 1$ F

All four capacitors are connected in parallel in the given circuit, so total capacitance

$$C = C_1 + C_2 + C_3 + C_4$$
$$= 8\ F + 4\ F + 2\ F + 1\ F$$
$$= 15\ F$$

Example 5.16: *Three capacitors each of capacitance C are connected in series. Their equivalent capacitance is C_s. The same three capacitors are now connected in parallel. Their equivalent capacitance becomes C_p, find the ratio $\left(\frac{C_p}{C_s}\right)$.*

Solution: When connected in series,

$$\frac{1}{C_s} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C} = \frac{3}{C}$$
$$C_s = \frac{C}{3}$$

When connected in parallel,

$$C_p = C + C + C = 3\ C$$

Therefore,

$$\frac{C_p}{C_s} = \frac{3C}{\frac{C}{3}} = \frac{9}{1}$$

or $\quad C_p : C_s = 9 : 1.$

(c) In Series–Parallel : In this type of combination capacitors are connected in a combination of both series and parallel in a circuit.

Example 5.17: *Four capacitors are connected, as shown in the figure below. Calculate the equivalent capacitance between the points P and Q.*

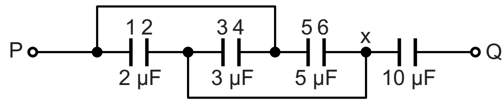


Fig. 5.21.

Solution: The capacitors 2 μF, 3 μF and 5 μF form a parallel combination (As plates 1, 4 and 5 is connected with point P and plates 2, 3 and 6 are connected with X) of equivalent to following circuit:

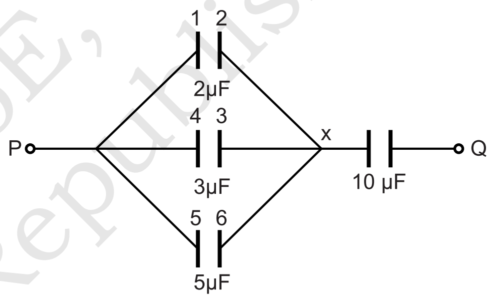


Fig. 5.22

Capacitance 2 μF + 3 μF + 5 μF = 10 μF (see the figure). This combination is in series with the capacitor 10 μF. Thus, if C be the equivalent capacitance between points P and Q we have

$$\frac{1}{C} = \frac{1}{10\ \mu F} + \frac{1}{10\ \mu F} = \frac{2}{10\ \mu F}$$

$\therefore \quad C = 5\ \mu F.$

Example 5.18: *Determine the equivalent capacitance between A and B in the network shown in figure 5.23.*

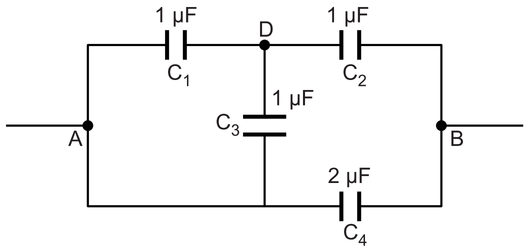


Fig. 5.23.

Solution: C_1 and C_3 are in parallel between points A and D. Therefore, the equivalent capacitance between points A and D is

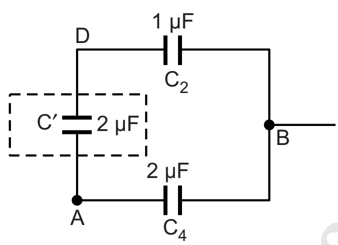


Fig. 5.24.

$C' = C_1 + C_3 = 1\ \mu F + 1\ \mu F = 2\ \mu F.$

The above network can be replaced by the network as shown in the above figure. Now, between points A and B, the capacitors C′ and C_2 are in series and C_4 in parallel. Hence, the equivalent capacitance between A and B is

$$\frac{C'C_2}{C'+C_2}+C_4$$

$$=\frac{2\mu F\times 1\mu F}{2\mu F+1\mu F}+2\ \mu F=\frac{8}{3}\ \mu F.$$

GLOSSARY

Atoms: The basic building blocks of matter that make up everyday objects.

Conductors: Substances which readily allow passage of electricity through them.

Electric field: It is defined as the electric force per unit charge.

Electric potential: The amount of work needed to move a unit charge from a reference point to a specific point against an electric field.

Electrons: These are negatively charged particles that surround the atom's nucleus.

Electrostatic charge: The electric charge that is confined to an object and is not moving, it is called an electrostatic charge.

Electric charge: The physical property of matter that causes it to experience a force when placed in an electromagnetic field. There are two types of electric charges: positive and negative.

Electrostatics: The study of stationary electric charges or fields.

Insulators: Substances which offer high resistance to the passage of electricity through them.

Intensity: The measurable amount of a property, such as force, brightness, or a magnetic field.

Magnitude: The great size or extent of something.

Negative charge: Having a surplus of electrons.

Neutrons: These are uncharged particles found within atomic nuclei.

Protons: These are positively charged particles found within atomic nuclei.

Positive charge: Having a deficiency of electrons.

REVIEW EXERCISES

Do the review exercises in your notebook.

A. Choose the correct option.

1. What charge does an object have if it gains electrons?

(a) negative (b) positive
(c) neutral (d) none of these

2. What charge does an object have if it loses electrons?

(a) neutral (b) positive
(c) negative (d) none of these

3. What is the name given to an area where an electric charge experiences a force?

(a) Static field (b) Magnetic field
(c) Electric field (d) none of these

4. What transfers from a nylon carpet to you to give you a static electric shock?

(a) Electrons (b) Protons
(c) Neutrons (d) none of these

5. Which of these is a good insulator?

(a) Plastic (b) Metal
(c) Graphite (d) none of these

6. Work done in moving a unit positive test charge from one point to other inside an electric field is called

(a) potential (b) field
(c) field intensity (d) potential difference

7. Quantisation of charge implies that

(a) charge does not exist
(b) charge exists on particles
(c) there is minimum permissible magnitude of charge
(d) charge can't be created

8. Farad is the SI unit of

(a) potential (b) capacitance
(c) charge (d) energy

9. In which of the following forms is the energy stored in a capacitor?

(a) charge (b) potential
(c) capacitance (d) electric field

10. What is the equivalent capacitance of the combination show in figure given below.

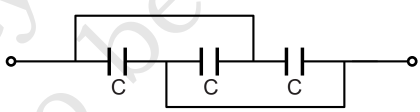


Fig. 5.25

(a) 3C (b) C/2
(c) C (d) infinity

B. Fill in the blanks.

1. To induce the charge on object just by bringing another charged object close, is called charging by ________.

2. The process that produces electric charges on an object is called ________.

3. ________ deals with the study of forces, fields and potentials arising from static charges.

4. The total charge of an isolated system is always ________.

5. Theoretically speaking, the electric field extends upto ________ .
6. Electric field lines are ________ together where the field is stronger.
7. Larger charges have more field lines ________ or ________ on them.
8. In a charge-free region, electric field lines can be taken to be ________ curves without any breaks.
9. The formula for calculating electric field intensity due to one point charge is E = ________ .
10. Electric potential at a point in an electric field is measured as the ________ done in bringing a unit positive test charge from infinity to that point.
11. 1 pF (picofarad) = ________ F.
12. The space between the conductors may be filled by vacuum or with insulating material known as a ________ .

C. State whether the following statements are true or false.

1. Cars are a safe place to be in a lightning storm because of the rubber tyres.
2. It is not safe to talk on a phone that is connected to a wall via a cord during a lightning storm.
3. To minimize being struck by lightning in an open ground, you should make yourself the lowest thing around by laying down on the ground.
4. Charging a metal by bringing it in physical contact with another charges metal is called charging by rubbing.
5. Electrostatics deals with the phenomenon and properties of moving electric charges.
6. Object that acquire a small charge due to rubbing are called charged objects.
7. Coulomb's law deals with the force between two point charges.
8. SI unit of electric field intensity is NC.
9. No work is done in moving a test charge between two points at different potentials.
10. A field intensity is measured by the field charge.
11. A capacitor is a two-terminal electrical device that possesses the ability to store energy in the form of an electric charge.
12. The equivalent capacitance of the capacitors joined in series is equal to the sum of their individual capacitances.

D. Answer the following questions.

1. Explain the types of electrostatic charges.
2. Describe the methods of charging bodies.
3. State the law of electrostatic charge.
4. Explain the principle of charge conservation.
5. Define:
   (i) Coulomb's law
   (ii) Electric field
   (iii) Electric potential
   (iv) Insulators
   (v) Conductors
6. Describe field patterns for two point charges.
7. Explain the intensity of electrical field to the position of charge.
8. Explain electric field intensity at different point due to a charge.
9. What is meant by electrical potential?
10. What is you mean by capacitor?
11. Discuss the charging and discharging of a capacitor.
12. Discuss different uses of capacitor briefly.

E. Numericals.

1. Charge q acts as a point charge to create an electric field. Its strength, measured at a distance of 30 cm away, is 40 N/C. What is the magnitude of the electric field strength that you would expect to be measured at a distance of ...
   (a) 15 cm away? (b) 90 cm away?
   (c) 3 cm away? (d) 45 cm away?
2. Charge q acts as a point charge to create an electric field. Its strength, measured at a distance of 30 cm away, is 40 N/C. What would be the electric field strength.
   (a) 30 cm away from a source with charge 3q?
   (b) 60 cm away from a source with charge 2q?
   (c) 15 cm away from a source with charge 2q?
   (d) 150 cm away from a source with charge 0.5q?

3. Use your understanding of electric field strength to complete the following table.

Charge creating the E field (C)	Charge used to test the E field (C)	Force experienced by test charge (N)	Electric field intensity (N/C)	Distance (fictional units)
(a) 4×10^{-4} C	1×10^{-6} C	0.20 N		r
(b) 4×10^{-4} C	2×10^{-6} C		$2 \times 10^{+5}$ N/C	r
(c) 8×10^{-4} C	1×10^{-6} C	0.40 N		r
(d) 8×10^{-4} C	2×10^{-6} C		$4 \times 10^{+5}$ N/C	r
(e) 8×10^{-4} C		0.60 N		r
(f) 8×10^{-4} C	1×10^{-6} C		$1 \times 10^{+5}$ N/C	$2r$
(g) 8×10^{-4} C	2×10^{-6} C			$2r$
(h) 8×10^{-4} C		0.10 N		$2r$
(i) 4×10^{-4} C			$8 \times 10^{+5}$ N/C	$0.5\ r$
(j) 4×10^{-4} C				$0.5\ r$

4. Calculate the force (F) between two small charged spheres having charges of 0.2 μC and 0.3 μC placed 30 cm apart in air.

5. Two insulated charged copper spheres have their centres separated by a distance of 50 cm. If each sphere is having a charge of 6.5×10^{-7} C, then calculate force of repulsion between them. The radii of two spheres are negligible.

Also calculate force between two spheres if the spheres are placed in water of dielectric constant 80.

6. The electrostatic force on a small sphere of charge 0.4 μC due to another small sphere of charge –0.8 μC in air is 0.2 N.

(a) What is the distance between the two spheres?

(b) What is the force on the second sphere due to first?

7. Two positive ions carrying equal charges are separated by a distance of 5 Å. Calculate the number of electrons missing from each ion, if the electrostatic force of repulsion between them is 3.7×10^{-9} N.

8. Two charged particles having charge 2.0×10^{-8} C each are joined by an insulating string of length 1 m and the system is kept on a smooth horizontal table. Find the tension in the string.

9. What is the force between the two small charged spheres having charges 2×10^{-7} C and 3×10^{-7} C and placed 30 cm apart in air?

10. Which of the figures in Fig. 5.26 cannot represent electrostatic field lines? Given reason.

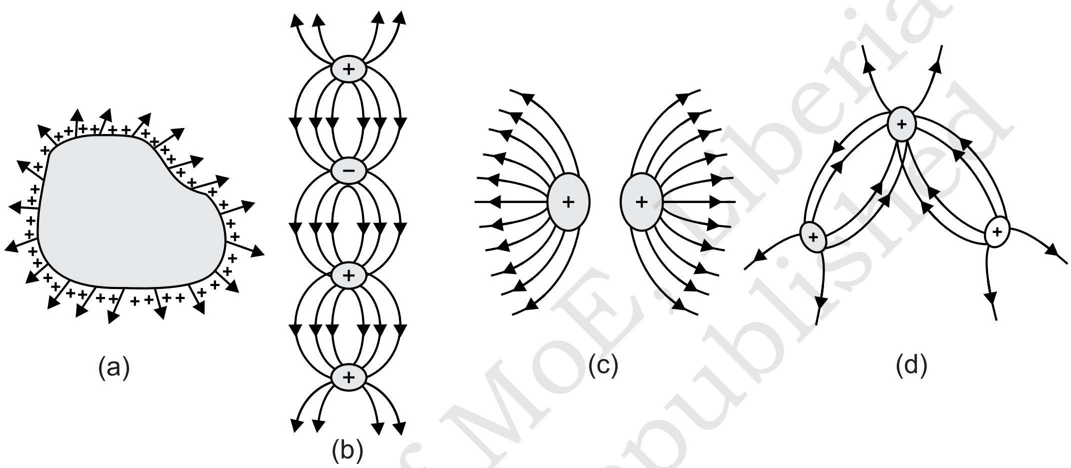


Fig. 5.26.

11. Calculate the work done to carry 8 C of charge from a point at 110 V to 130 V.

12. 30 coulombs of charge is brought from infinity to a given point in an electric field when 90 joules of work is done. What is the potential at a point?

13. A charge of 5 coulombs is moved into an electric field from infinity, when the work done at point A is 20 J and at point B is 30 J. Calculate the potential difference between points A and B.

14. A potential difference of 450 volts is applied across the plates of a capacitor of capacity 20 pF. What is the vaule of charge on the plates of the capacitor?

15. Three capacitors, each of 9 pF are connected in series.

(a) What is the total capacitance of the combination?

(b) What is the p.d. across each capacitor if the combination is connected to a 120 V supply?

16. Three capacitors of capacitances 2 pF, 3 pF and 4 pF are connected in parallel.

(a) What is the total capacitance of the combination?

(b) Determine the charge on each capacitor, if the combination is connected to 120 volts supply.

17. Calculate the capacitance in the given arrangement. The equivalent capacitance of the combination between P and Q is 30 μF.

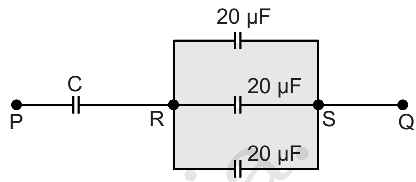


Fig. 5.27.

18. What is the equivalent capacitance of the combination between P and Q, as shown in Fig. 5.28?

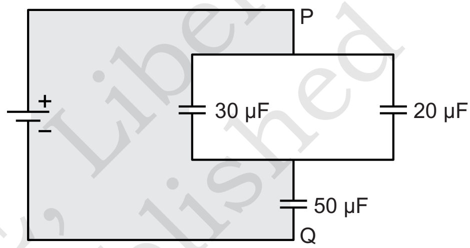


Fig. 5.28.

19. A combination of four identical capacitors is shown in the given arrangement. If resultant capacitance of the combination between the points P and Q is 2 μF, calculate the capacitance of each capacitor.

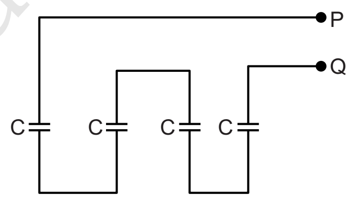


Fig. 5.29.

20. What is the equivalent capacitance between the points P and Q in the combination shown in Fig. 5.30?

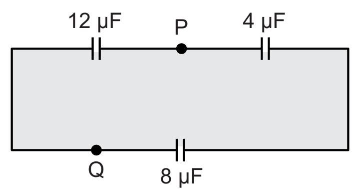


Fig. 5.30.

21. What is the equivalent capacitance between P and Q in the arrangement in Fig. 5.31?

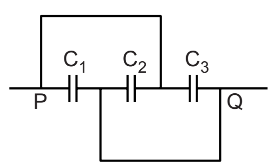


Fig. 5.31.

22. Three capacitors, each of capacitance 9 pF, are connected in series.

(a) What is the total capacitance of the combination?

(b) What is the potential difference across each capacitor if the combination is connected to a 120 V supply?

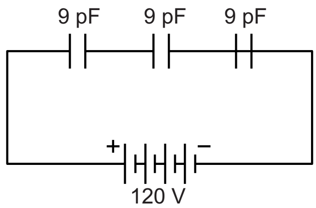


Fig. 5.32.

23. Three capacitors of capacitances 2 pF, 3 pF and 4 pF are connected in parallel.

(a) What is the total capacitance of the combination?

(b) Determine the charge on each capacitor if the combination is connected to a 100 V supply.