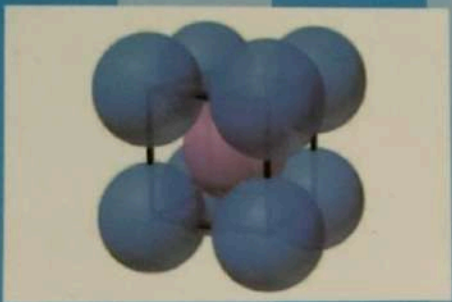
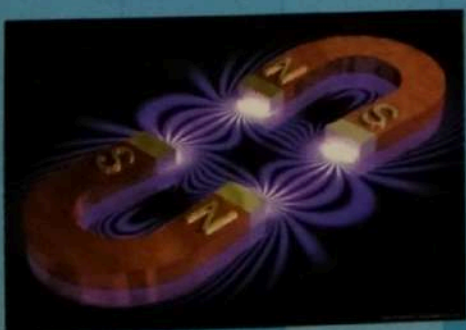
PHYSICS

For Grade XII





Khyber Pakhtunkhwa Textbook Board Peshawar

سچّائی انسان کو ہر آفت سے محفوظ رکھتی ہے
اور جھوٹ اسے ہلاک کر ڈالتا ہے۔

(الحدیث)

"Say no to Corruption."

XII BB

Physics

For

Grade XII

KHYBER PAKHTUNKHWA TEXTBOOK BOARD

Khyber Pakhtunkhwa Textbook Board, Peshawar

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PREFACE

This book is based on national curriculum 2006.

The book include some new approaches of STS (Science Technology and society) connection so that student may aware about the applications of Physics, specially in the field of Medical sciences (MRI, CT Scan, and ECG etc.).

Throughout the book an attempt has been made to present the math symbols in italic for its easy understanding.

In case of any errors we request the readers to point out these errors so that they are eliminated in the next edition. I hope that the teachers students, and experts will keep us informed about the new curriculum and the textbook, so that we may be able to improve the textbook, because there is always room for improvement.

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UNIT 11
ELECTROSTATICS

After studying this chapter the students will be able to

- state Coulomb's law and explain that force between two point charges is reduced in a medium other than free space using Coulomb's law.
- derive the expression $E = 1/4\pi\varepsilon_o\, q/r^2$ for the magnitude of the electric field at a distance 'r' from a point charge 'q'.
- describe the concept of an electric field as an example of a field of force.
- define electric field strength as force per unit positive charge.
- solve problems and analyse information using $E = F/q$.
- solve problems involving the use of the expression $E = 1/4\pi\varepsilon_o\, q/r^2$.
- calculate the magnitude and direction of the electric field at a point due to two charges with the same or opposite signs.
- sketch the electric field lines for two point charges of equal magnitude with same or opposite signs.
- describe the concept of electric dipole.
- define and explain electric flux.
- describe electric flux through a surface enclosing a charge.
- state and explain Gauss's law.
- describe and draw the electric field due to an infinite size conducting plate of positive or negative charge.
- sketch the electric field produced by a hollow spherical charged conductor.
- sketch the electric field between and near the edges of two infinite size oppositely charged parallel plates.
- define electric potential at a point in terms of the work done in bringing unit positive charge from infinity to that point.
- define the unit of potential.
- solve problems by using the expression $V = W/q$.
- describe that the electric field at a point is given by the negative of potential gradient at that point.

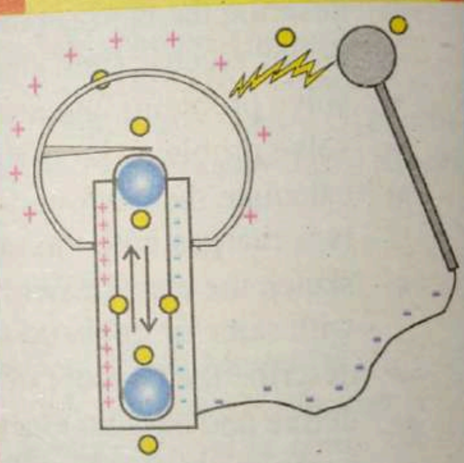
- solve problems by using the expression $E = V/d$.
- derive an expression for electric potential at a point due to a point charge.
- calculate the potential in the field of a point charge using the equation $V = 1/4\pi\varepsilon_o\ q/r$.
- define and become familiar with the use of electron volt.
- define capacitance and the farad and solve problems by using $C=Q/V$.
- describe the functions of capacitors in simple circuits.
- solve problems using formula for capacitors in series and in parallel.
- explain polarization of dielectric of a capacitor.
- demonstrate charging and discharging of a capacitor through a resistance.
- prove that energy stored in a capacitor is $W=1/2\ QV$ and hence $W=1/2\ CV^2$.

Two fundamental processes of electrostatics are introduced: Coulomb's law for force between stationary charges and the principle of superposition for electric field configurations. The electric field at a point in space is defined and used, with Coulomb's law, to derive an expression for the electric field at a distance from a point charge. The concept of work done by an electric field on a charged particle is introduced. For practical purposes, the concept of electric field is translated into concepts of electric potential and electrical potential energy.

The principle of superposition explains the fact that a near-uniform electric field can be produced by two charged parallel conducting plates. The absence of an electric field in hollow conductors is discussed. The presence of strong electric fields in the vicinity of sharp points on charged conductors is identified and applied to corona discharges in relation to photocopiers and laser printers.

Another quantity being discussed that plays an important role in electrical circuits is capacitance and its dependence on the dielectrics.

For your information



A Van de Graaff generator is an electrostatic generator which uses a moving belt to accumulate very high amounts of electrical potential on a hollow metal globe on the top of the stand. A Van de Graaff generator operates by transferring electric charge from a moving belt to a terminal. First invented in 1929, the Van de Graaff generator became a source of high voltage for accelerating subatomic particles to high speeds, making it a useful tool for fundamental physics research.

11.1 PROPERTIES OF CHARGE

In the previous classes we have studied that similar charges repel and opposite charges attract each other with a force, known as force of interaction. There are two different kinds of charges, which are called positive and negative charges.

Electrons have a negative charge and protons have positive charge.

The atom is electrically neutral. In SI units, charge is measured in coulombs (symbol C). The charge carried by an elementary particle is written as e, and its magnitude is

$$1e = 1.6 \times 10^{-19} C$$

The important characteristic of the charge is that charge is quantized. Quantization of charge means that it exists in discrete packets. Charge q is an integral multiple of minimum elementary charge e, i.e.,

For your information

When you charge up your body by touching the Van der Graaf generator your hair stands on end. The hair stands because all hair gains the same electric charge and repel each other. The force of repulsion is so great that it exceeds the weight of each hair strand. Your arms do not lift away from your body though - even they have the same charge as your body. This is because they are too heavy!

$$q = ne \quad \dots (11.1)$$

Here we make quantitative analysis of the nature of these forces. We would like to determine the magnitude and direction of such forces.

11.1 COULOMB'S LAW

The quantitative measurement of the force between two electric charges was first madeby Coulomb (1736-1805).

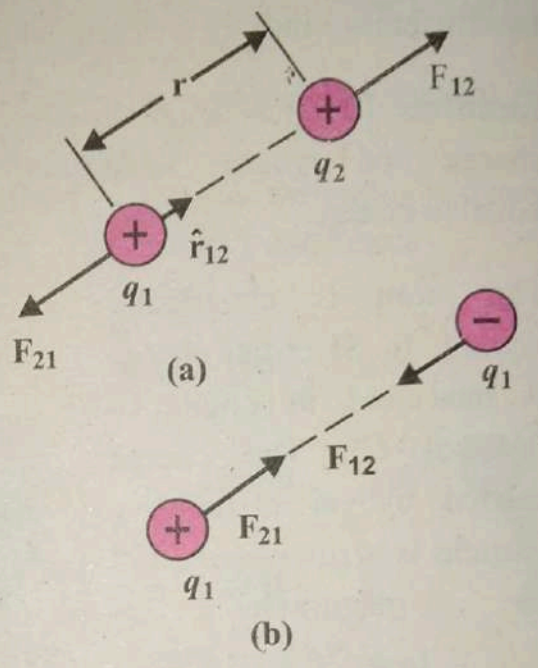


Figure 11.1: Coulomb force between (a) similar charges, and (b) opposite charges.

He carried out series of experiments to measure the force between electric charges using an apparatus known as torsion balance.

Coulomb expresses his experimental data in the form of a statement which is known as Coulomb's law.

It states "*The magnitude of the force between two point charges is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them.*"

The magnitude of the force $\vec{F}$ between two electric charges q_1 and q_2 separated by distance r can be expressed as

$$F \propto q_1 q_2 \qquad ...(A)$$

$$F \propto \frac{1}{r^2} \qquad ...(B)$$

combining Eq(A) & Eq(B)

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

$$F = k\frac{q_1 q_2}{r^2} \qquad ...(11.2)$$

where k is a constant of proportionality and its value depends upon the system of the units used and the medium between the charges. The electric charges q_1 and q_2 are assumed to be point or localized charges, provided the size of the bodies carrying the charges is very small as compared to the distance between them.

In order to show the direction of the force we use unit vector along the line joining the two charges. In fig:11.1(a) $\hat{r}_{12}$ is unit vector, pointing from the charge q_1 towards the charge q_2 which show the force on charge q_2 due to charge q_1 i.e.,

$$\vec{F}_{21} = k\frac{q_1 q_2}{r^2}\hat{r}_{12} \qquad ...(11.3)a$$

For like charges the product q_1q_2 will be positive and a force of repulsion between these two charges will be F_{21}. Similarly for unlike charges the product q_1q_2 will be negetive and a force of attraction between these two charges will be F_{12}. Similarly unit vector $\hat{r}_{21}$, pointing from the charge q_2 towards the charge q_1 which show the force on charge q_1 due to charge q_2 is given by

$$\vec{F}_{12} = k\frac{q_1 q_2}{r^2}\hat{r}_{21} \qquad ...(11.3)b$$

Since $\hat{r}_{12} = -\hat{r}_{21}$

So from Eq: 11.3(a) and 11.3(b) we can write

$$\vec{F}_{21} = -\vec{F}_{12} \qquad ...(11.4)$$

Where $\vec{F}_{21}$ is the force exerted by the charge q_1 on q_2 and $\vec{F}_{12}$ is the force exerted by the charge q_2 on q_1. Eq 11.4 shows that the two forces are same in magnitude but opposite in direction which is illustrated in fig 11.1(b).

The constant k can be generally expressed in terms of permittivity of the free space ε_o i.e., $k = \frac{1}{4\pi\varepsilon_o}$

Experimentally measured value of

$$\varepsilon_o = 8.85\times10^{-12}\, C^2\, N^{-1}\, m^{-2}$$

so $k = \frac{1}{4\pi\varepsilon_o} = 9.0\times10^9\ N\, m^2\, C^{-2}$

Coulomb's law in material media

Eq:(11.2) gives the force between two charges when there is air or vacuum between them. But it is experimentaly observed that when an insulator is placed between the electric charges, it reduces the force. *Permittivity is the property of a medium which affects the magnitude of force between two point charges.* The coulomb's force can now be written as

$$F_{med} = \frac{1}{4\pi\varepsilon}\frac{q_1 q_2}{r^2} \quad \text{... (11.5)}$$

The quantity ε is called the permittivity of the medium. The permittivity of a material medium compared with the permittivity of vacuum is called relative permittivity or dielectric constant ε_r for particular insulator. Its ratio is given by

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_o} \quad \text{... (11.6)}$$

Obviously the ε_r is dimensionless constant and its value is always greater than unity for various dielectrics.

The values of relative permittivity for various dielectrics are given in Table 11.1.

Table 11.1: The relative permittivity of various dielectrics

Material	ε_r	Material	ε_r
Vacuum	1	Glass	4.8-10
Air	1.0006	Mica	3-7.5
Benzene	2.284	Paraffine paper	2
Germinium	16	Rubber	2.94
Water	78.5	Ammonia(liquid)	22-25

The force in a medium of relative permittivity ε_r, is given by

$$F_{med} = \frac{1}{4\pi\varepsilon_o\varepsilon_r}\frac{q_1 q_2}{r^2}\hat{r} \quad \text{... (11.7)}$$

$$F_{med} = \frac{F_{vac}}{\varepsilon_r} \quad \text{... (11.8)}$$

11.2 Electric Field and its intensity

The concept of field theory was introduced by Michael Faraday. He stated that the charge q produces an electric field in the space surrounding it and when a charge q_o is brought in its field then it exerts a force F on it. The electric field around a charge is like a sphere with in which other charges are influenced by it. The existence of electric field can be proved by bringing a test q_o into its field.

An electric field is defined as *any region around a charge in which an electric test charge would experience an electric force.*

The force F experienced by a test charge q_o is given by $F = q_0 E$. Electric field is a vector field so it is characterized by strength and direction at every point in space. The strength and direction of electric field can be determined by placing a unit positive test charge in that field. The strength of the field at a point in space determines the amount of the force that a charge will experience if it is placed at that point. The direction in which this unit positive test charge move or tends to move is the direction of electric field. A single vector quantity containing information about the field strength and its direction at that point is denoted by $\vec{E}$ and is known as electric field intensity. Thus the field strength is the magnitude of the force expressed by the unit positive test charge placed at that point.

If unit positive test charge q_o experience a force F due to the electric field of charge q. Then *the intensity of an electric field at any point is the force per unit positive test charge placed at that point.*

The electric field intensity $\overline{E}=\dfrac{\overline{F}}{q_o}$

Or

$$\overline{F}=q_o\,\overline{E} \qquad \text{... (11.9)}$$

Electric field strength is also a vector quantity. The test charge is so small that it does not distort the original field due to the primary source. The SI unit of electric field intensity is newton per coulomb (NC^{-1}) or volt per metre (Vm^{-1}).

In order to find out the field intensity due to a point charge q. A unit positive test charge q_o is placed at a distance r from point charge q as shown in fig (11.2). Then by coulomb's law the force experienced by a unit positive test charge q_o due to the field of a point charge q

$$F = \frac{k\,q\,q_o}{r^2}$$

As $\hat{r}$ is the unit vector directed from charge q to q_o so in vector form

$$\vec{F} = \frac{k\,q\,q_o}{r^2}\hat{r}$$

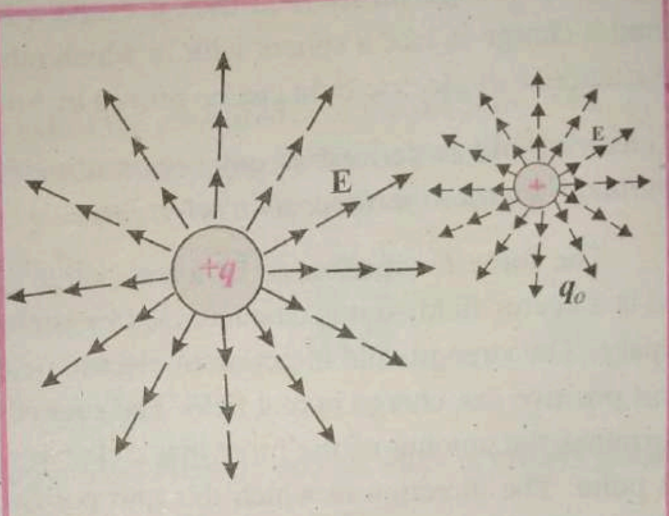


Figure 11.2: electric field intensity due to a point charge.

So the field intensity is given by

$$\vec{E} = \frac{\vec{F}}{q_o} = k\frac{\frac{q\,q_o}{r^2}}{q_o}\hat{r}$$

$$\vec{E} = k\frac{q}{r^2}\hat{r} \qquad ...(11.10)$$

The strength of the field is proportional to the magnitude of the source charge. Its strength decreases as the test charge moves away (unit charge) from source charge q.

Example 11.1

Find electric field at a distance of 30cm from a $3\,\mu C$ point charge?

Solution:

$$r = 30\text{ cm} = 30 \times 10^{-2} = 0.3\text{ m}.$$

$$q = 3\mu C = 3 \times 10^{-6} C$$

Using electric field intensity formulae

$$E = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}$$

$$= (9\times10^9 \, Nm^2 C^{-2}) (\frac{3\times10^{-6} C}{(0.3m)^2}$$

$$= 3\times10^5 \, NC^{-1}$$

Example 11.2

Two small spheres, each having a mass of 0.1g are suspended from a point with the help of threads 20cm long. They are equally charged and they repel each other to a distance of 24cm. What is the charge on each sphere?

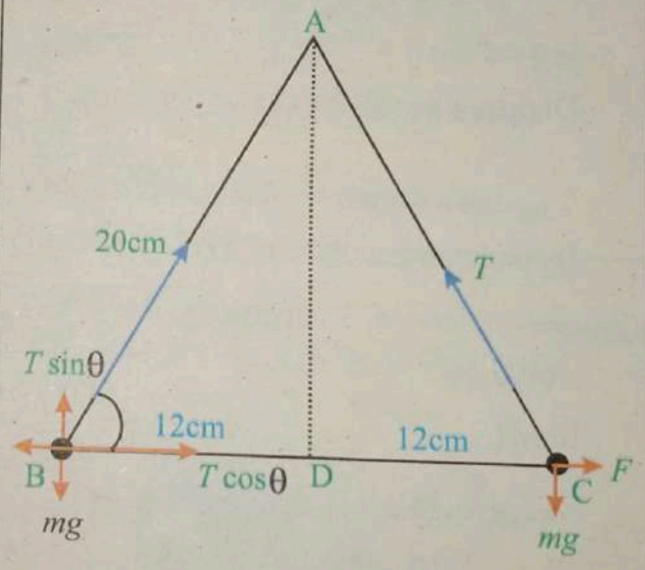


Figure11.3: force between two charge spheres

Solution:

Fig: 11.3: shows that two charged spheres B and C which are separated by distance r due to force of repulsion F i.e., Since two spheres are equally charged so let charge on each sphere = q

Separation between spheres is $r = 0.24$ m

Mass of spheres is $m = 0.1g = 1\times10^{-4}$ kg

Length of threads $= \ell = 20$ cm$= 0.2$ m

$$F = k\frac{q^2}{r^2}$$

putting values $F = 9\times10^9 \dfrac{q^2}{(0.24)^2}$

$$F = 156.25\times10^9 q^2 \qquad \dots (1)$$

Each sphere is under the action of three forces:

(1) weight mg is acting vertically downward, (2) tension T, and (3) electrostatic force F. Considering the sphere B and resolving T into rectangular component, we have,

$mg = T\sin\theta$ ...(2) ; $F = T\cos\theta$ ...(3)

Dividing Eq:(2) by (3) we get

$$\tan\theta = \frac{mg}{F} \qquad \dots(4)$$

By pathagorean theorm $AD^2 = AB^2 - BD^2$

or $AD = \sqrt{AB^2 - BD^2} = \sqrt{(20)^2 - (12)^2} = 16\text{cm}$

from fig $\tan\theta = \dfrac{\text{AD}}{\text{BD}} = \dfrac{16}{12}$ ...(5)

comparing Eq:(4) & (5) we get

$$\frac{16}{12} = \frac{mg}{F}$$

or $F = \dfrac{12}{16}mg = 0.75mg = 0.75\times10^{-4}\times9.8 = 7.4\times10^{-4}$ N

Putting $F = 7.4\times10^{-4}$ N in Eq:(1) we get

$\therefore$ $156.25\times10^9 q^2 = 7.4\times10^{-4}$ or $q^2 = \dfrac{7.4\times10^{-4}}{156.25\times10^9} = 4.8\times10^{-15}$

$$q = 6.9\times10^{-8}\text{C}$$

11.2.1 Representation of Electric Field Lines

The electric field in the vicinity of a charge body can be represented by imaginary lines called electric lines of force. The electric lines of force are the path followed by a unit positive test charge in the field of source charge.

The arrows indicate the electric field at different points. The direction of these arrows is radially outward for positive charge and is radially inward for negative charge as shown in fig:11.4.

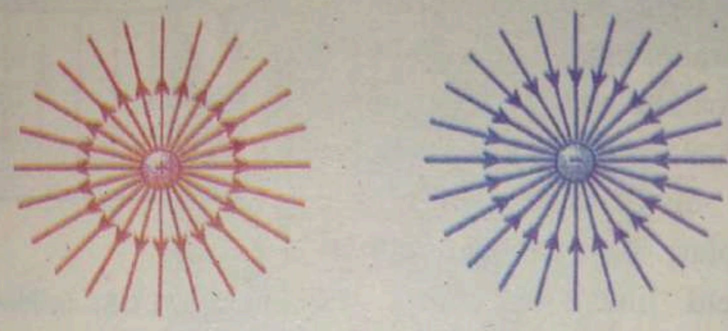


Figure 11.4: Electric lines of force around a charge

These lines are called electric field lines, which increases as we move radially inward and decreases as we move outward in the field. So the drawing lines around a charge helps in visualizing the field.

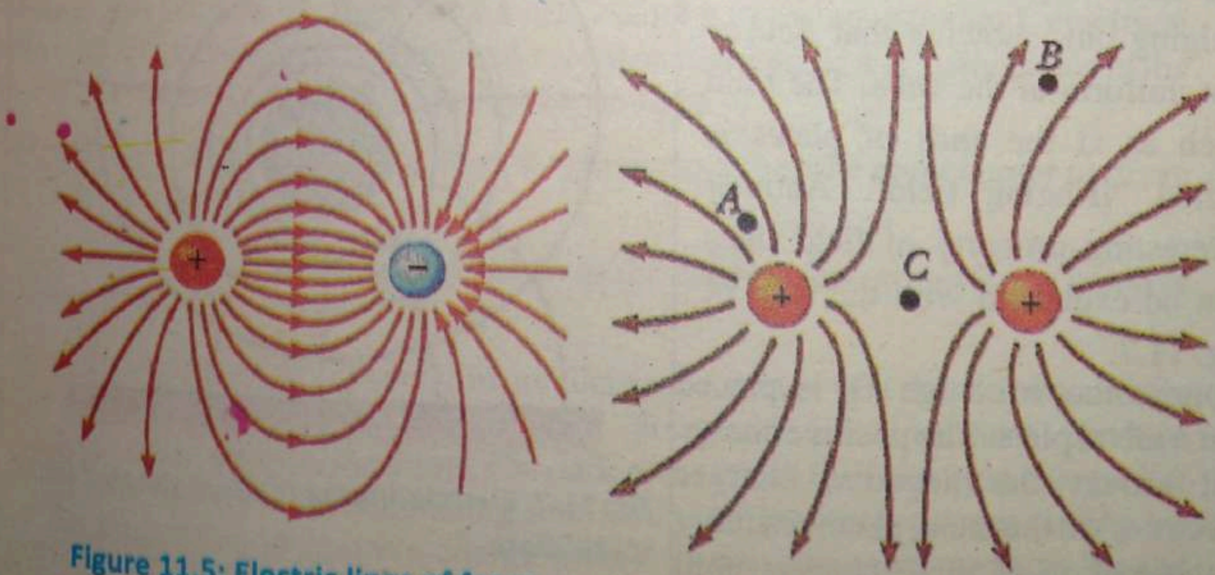


Figure 11.5: Electric lines of force

Fig. (11.5) shows the field lines due to positive and negative charges which are placed at a certain distance from each other. The field lines starts from positive charge and terminate at negative charge. There are some points in the field where the resultant intensity is equal to the sum of intensities due to positive charge and negative charge and its direction is along the tangent to the field. Where at some points the resultant intensity is zero which is called neutral points. Fig:11.6 shows two infinitely large parallel plates separated by a very small distance. The upper plate has a uniform positive charge distribution while the lower plate has a negative one. The field lines start from the positive plate and terminate at negative one.

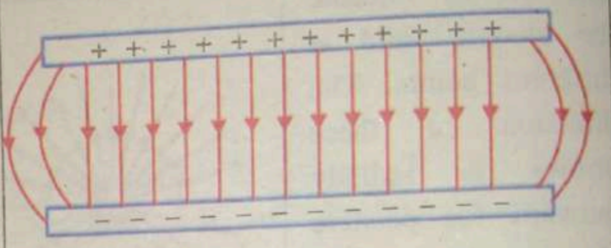


Figure 11.6: uniform electric field between charged plates.

The reason is that the direction of the electric intensity E is the direction in which the force acts on a unit positive charge. If the plates are not of infinite length, the field lines at the ends of plates will be a little bulging out, showing that field is not uniform at the ends. The field such as at the ends of plates is called "fringing field". Another interesting property of field lines can be explained with the help of fig. 11.7.

Suppose that a charge $+q$ is placed near a metal plate. The positive charge will attract the negative charges (electrons) in the metal plate, resulting in the motion of these charges until some of them reach that surface of the

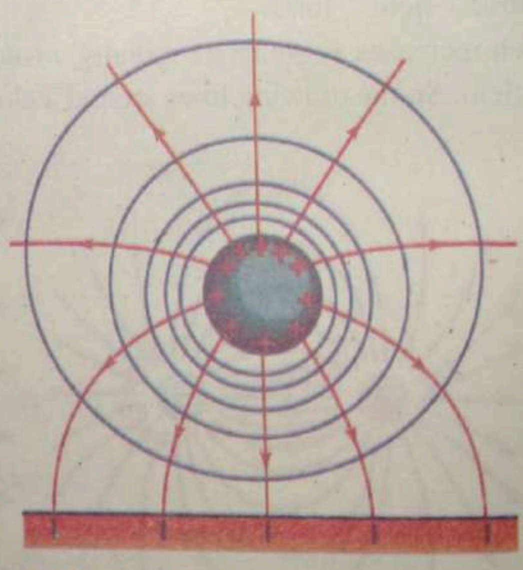


Fig. 11.7: Electric lines of force on the surface of metal plate

metal which is near to $+q$ charge where they will be at rest. Thus, the field lines starting from $+q$ charge will end on the negative charges of the metal plate. Furthermore, these lines are always perpendicular to the metal surface. The electric lines of force cannot pass through a conductor. Therefore electric field is zero inside a conductor. The electric lines of force have the tendency to contract in length. This explains attraction between oppositely charged bodies.

Quiz ?

Explain why it is possible for an air passenger to get an electrical shock when he touches the knob of the toilet door in a high altitude flying airplane.

What would you do if you are caught on thunder storm?

11.3 Applications of electrostatics

a) Photocopiers

A photocopier is a machine that makes quickly and easily copies of documents.

The heart of a copier is the drum, an aluminum cylinder coated with a layer of selenium (as shown in Figure 11.8 *a*). Aluminum is an excellent electrical conductor. Selenium, on the other hand, is a photoconductor; it is an insulator in the dark but becomes a conductor when exposed to light.

When the paper to be copied is laid on the glass plate, then the photocopier perform the following function.

- First, an electrode called a *corotron* gives the entire selenium surface a positive charge in the dark.
- Second, a series of lenses and mirrors focuses an image of a document onto the revolving drum. The dark and light areas of the document produce corresponding areas on the drum. The dark areas retain their positive charge, but the light areas become conducting and lose their positive charge, ending up neutralized. Thus, a positive-charge image of the document remains on the selenium surface.

- In the third step, a special dry black powder, called the *toner*, is given a negative charge and then spread onto the drum, where it adheres selectively to the positively charged areas.
- The fourth step involves transferring the toner onto a blank piece of paper. However, the attraction of the positive-charge image holds the toner to the drum. To transfer the toner, the paper is given a *greater positive charge* than that of the image, with the aid of another corotron.
- Last, the paper and adhering toner pass through heated pressure rollers, which melt the toner into the fibers of the paper and produce the finished copy.

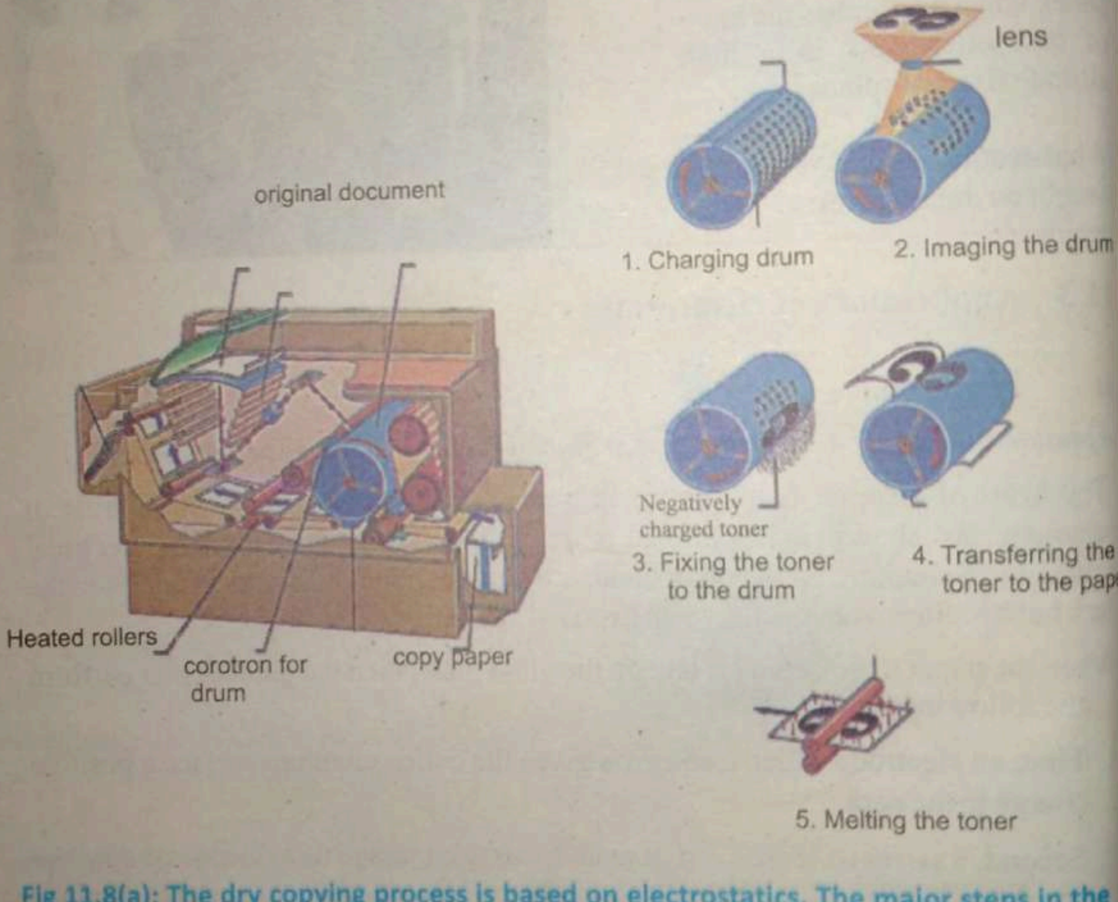


Fig 11.8(a): The dry copying process is based on electrostatics. The major steps in the process are the charging of the photo conducting drum, transfer of an image creating a positive charge duplicate, attraction of toner to the charged parts of the drum, and transfer of toner to the paper.

b)Laser Printer

Laser printer work is largely due to the process called xerography. Initially, the photoreceptor drum is charged positively by corona wire by applying an electrical current on it as shown in fig11.8 (b).

When the light of the laser beam hits the drum, whatever areas that are exposed to the light are rid of these electric charges. The areas that are not exposed to light eventually make up the printed image. These areas, which remain electrostatic, then pick up the particles from the ink toner. The heat generated by the printer melts the dry ink and then gets fused on the paper to create the printed image.

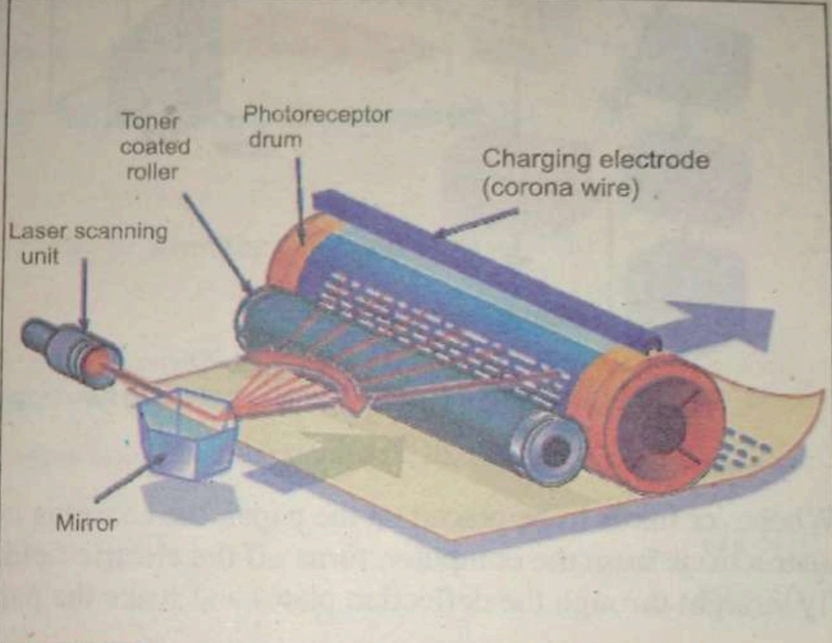


Fig11.8(b): Laser printer with a static laser scanning unit, but movable mirror

c) Inkjet Printers

An inkjet printer is another type of printer that uses electric charges in its operation. While shuttling back and forth across the paper, the inkjet printhead ejects a thin stream of ink. The elements of one type of inject printer is shown in fig:11.9 . During their flight, the droplets pass through two electrical components, an electrode and the deflection plates (a parallel plate capacitor). When the printhead moves over regions of the paper that are not to be inked, the charging control is turned on and an electric field is established between the printhead and the electrode. As the drops pass through the electric field, they acquire a net charge by the process of induction. The deflection plates divert the charged droplets into a gutter and thus prevent them from reaching the paper.

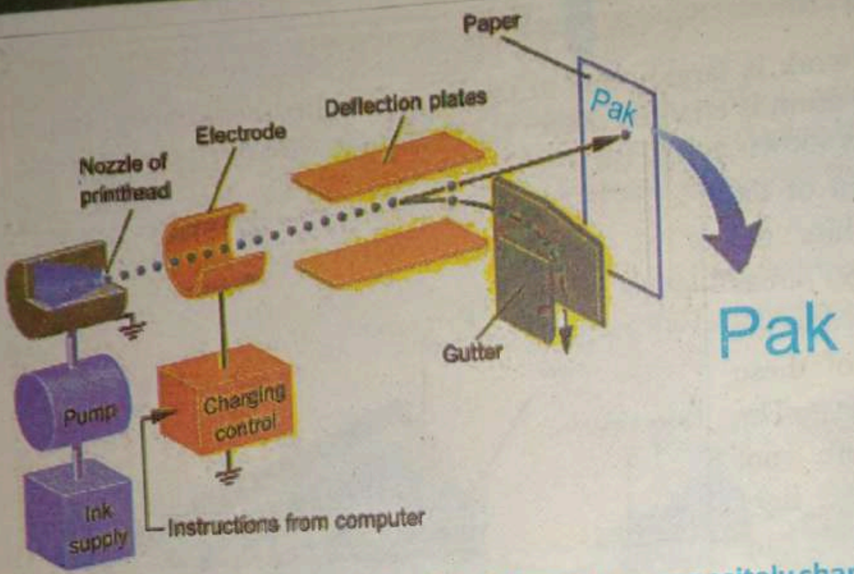


Figure 11.9: charging of ink droplets between two oppositely charged plates.

Whenever ink is to be placed on the paper, the charging control, responding to instructions from the computer, turns off the electric field. The uncharged droplets fly straight through the deflection plates and strike the paper.

Quiz?

What are the basic differences between laser printer and photocopier?
State any two other applications of electrostatic.
State any two hazards of electrostatic.

Example 11.3

A metallic sphere of diameter 30 cm carries a charge of 600 μ C. Find the electric field intensity (a) at a distance of 50cm from the centre of the sphere and (b) at the surface of sphere.

Solution:

The electric field due to a charged sphere has spherical symmetry. Therefore, a charged sphere behaves for external points as if the whole charge is placed at its centre.

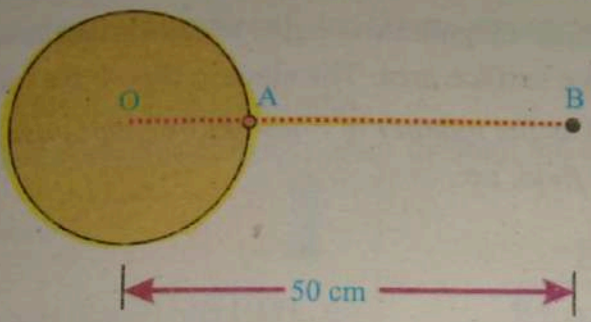


Figure 11.10: field intensity due to a charge sphere

(a) Distance of a charge from the sphere $r = OB = 50\,cm$

$$= 50 \times 10^{-2}\ m;$$

Charge on sphere $q = 600\mu C = 600 \times 10^{-6}\ C$

Electric field intensity from the centre of the sphere *is* $E = k\frac{q}{r^2}$

$$= 9 \times 10^9 \times \frac{600 \times 10^{-6}}{(50 \times 10^{-2})^2}$$

$$= 21.6 \times 10^6\ N/C$$

(b) $r = \frac{d}{2} = \frac{OA}{2} = \frac{30cm}{2} = 0.15m$

Electric field intensity from the surface of a sphere $E = k\frac{q}{r^2}$

$$= 9 \times 10^9 \times \frac{600 \times 10^{-6}}{(0.15)^2}$$

$$= 24 \times 10^7\ N/C$$

11.4 Electric Flux

Before we start to define electric flux we start with area A and we take it as a vector quantity. As you may recall in chap two (class 11[th]) area is geometric representation of a vector product.

In this context A is a vector whose magnitude is equal to the surface area and whose direction is normal to the surface area. The electric flux Φ for uniform field $\vec{E}$ and area $\vec{A}$ is defined as *the number of lines of force that pass through the area placed in the electric field.* i.e.,

$$\Phi = \vec{E}.\vec{A}$$
$$= EA\cos\theta \qquad ...(11.11)$$

Thus flux Φ is the scalar product of the electric field E and plane surface area A. Flux is the flow of field lines through surface area, which is placed in that field. For example Fig 11.11 (a) shows that there are 4 number of lines passing through the surface area of $1m^2$ so flux is $4\ Nm^2C^{-1}$. The electric flux Φ depends upon the orientation of surface area A with respect to the field lines

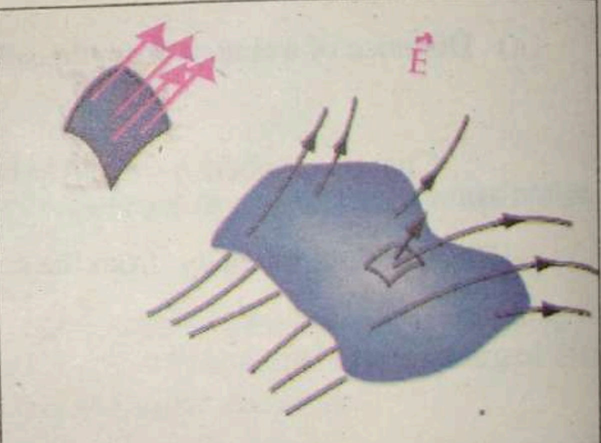


Figure11.11 (a) : electric flux through a unit area and curved surface

Flux at any angle

When the area $\vec{A}$ is tilted such that it is making an angle θ with the electric field lines as shown in Fig 11.11 (b) in this case the electric flux is

$$\Phi = \vec{E}.\vec{A} = EA\ \cos\theta$$

The number of lines passing through the area will be E (A cosθ) depending upon angle θ.

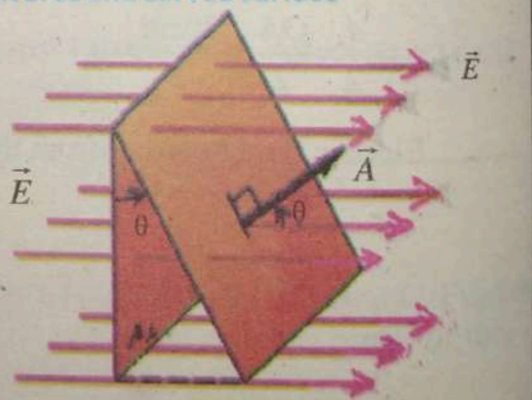


Figure11.11 (b) : electric flux at angle

Maximum Flux:-

If the surface is placed perpendicular to the electric field such that surface area $\vec{A}$ is parallel to electric field $\vec{E}$ (Fig 11.11 b) then maximum electric lines of force will pass through the surface. Consequently maximum electric flux will pass through the surface.

The electric flux is $\Phi = EA\cos 0 = EA$

Therefore large number of lines passes through the area

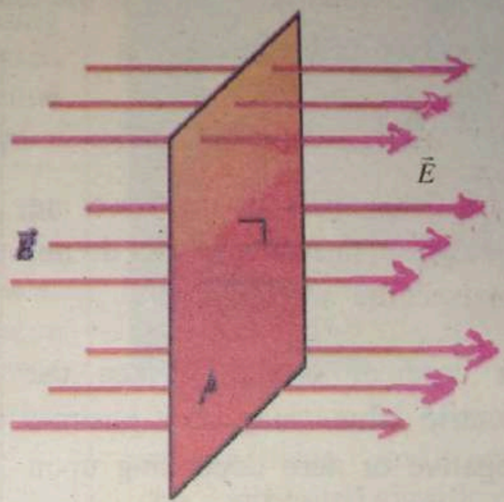


Figure11.11 (c):maximum electric flux

Zero Flux:-

If the surface is placed parallel to the electric field Fig.11.11(d) such that surface area $\vec{A}$ is normal to electric field $\vec{E}$ then no electric lines of force will pass through the surface. Consequently no electric flux will pass through the surface.

Then flux is

$$\Phi = EA\cos 90 = 0$$

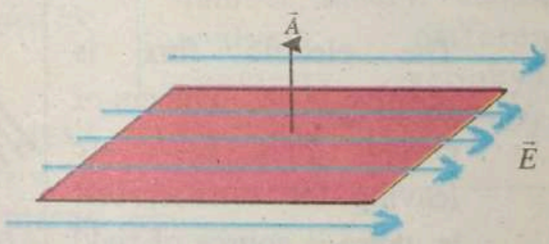


Figure11.11 (d) : electric flux

Electric flux through close surface

If the case is such that either field is non- uniform or the surface is curved, then we divide the surfaces into very small patches of area ΔA called differential area and assume that these are approximately flat and they are so small that electric field E is almost uniform over it. For one of these small patches of area (see Fig.11.12 (a)) electric flux is defined by the relation. (Differential form),

$$\Phi_E = E.\Delta A$$

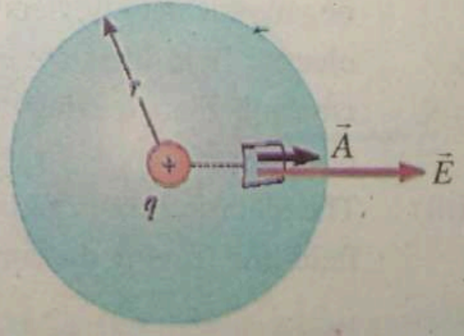


Figure11.12 (a) : electric flux

To calculate total flux through the whole surface we add flux from each patch such that

$$\Phi_E = \Sigma \vec{E}.\Delta\vec{A}$$

Now let us consider a closed surface of arbitrary shape the positive normal is taken to be "outward" from the volume being enclosed. If ΔA is the magnitude of the differential area and $\hat{n}$ is the unit normal to the surface in positive direction, the vector differential $\Delta \vec{A}$ is

$$\Delta \vec{A} = \Delta A \, \hat{n}$$

The fields lines in this case are parallel to surface area and do not intersect the surface.

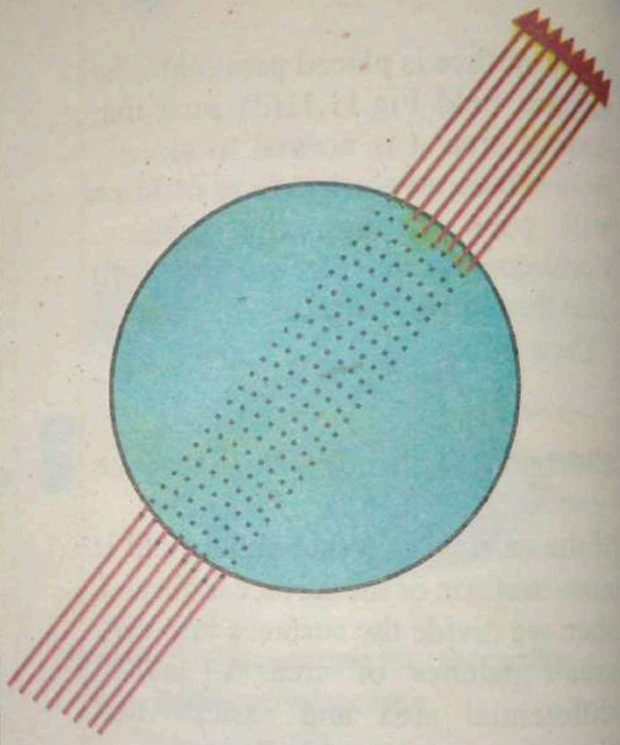


Figure 11.12b: positive, negative and zero flux through a close surface

In case of closed surface the electric flux may be positive negative or zero depending upon the number of lines entering or leaving the surface:

(i) The electric flux is positive if net numbers of electric field lines are leaving the surface, that is, there is source of field lines in the closed surface.

(ii) The electric flux is negative if net numbers of electric field lines are entering the closed surface or more field lines are entering than leaving the surface; there is a sink of field lines in the closed surface.

(iii) The electric flux is zero if numbers of field lines entering are equal to field line leaving the surface or no field line intercepting the surface.

11.5 Gauss's law

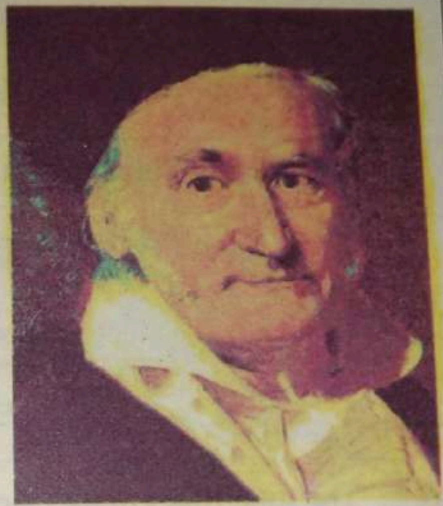
The electric field of a given charge distribution can be calculated using Coulomb's law. The examples discussed before showed however, that the actual calculations can become quite complicated.

An alternative method to calculate the electric field of a given charge distribution relies on a theorem called Gauss' law. Gauss' law provides a relationship between the net electrical flux Φ through a closed surface and the net charge q enclosed by that surface.

Gauss' law states that *the net electric flux through a closed surface is equal to the total charge q enclosed by the surface divided by the permittivity of free space* ε_o.

In order to derive the expression for Gauss's law consider a spherical closed surface of radius r having a point charge q at its center as shown in fig.11.13.

To calculate the electric flux through the whole surface it is divided into n-number of small pieces having area $\Delta A_1, \Delta A_2, \Delta A_3, \Delta A_4........\Delta A_n$. The intensity of electric field is same at every point as they are at equidistant from the charge.



Gauss was a German mathematician and scientist who contributed significantly to many fields, including number theory, statistics, analysis, differential geometry, geophysics, electrostatics, astronomy and optics.

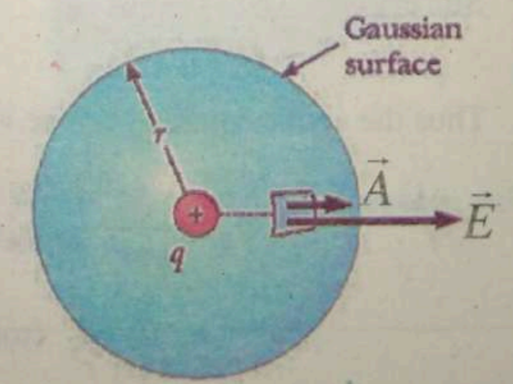


Figure 11.13 : flux through a close surface

The electric flux through the small elements ΔA_1 is

$$\Phi_1 = \vec{E}_1.\Delta\vec{A}_1 = E_1\,\Delta A_1\cos 0 = E_1\Delta A_1$$

The electric flux through the other small element ΔA_2 is

$$\Phi_2 = \vec{E}_2.\Delta\vec{A}_2 = E_2\Delta A_2\cos 0 = E_2\Delta A_2$$

Similarly the electric flux through ΔA_n is

$$\Phi_n = \vec{E}_n.\Delta\vec{A}_n = E_n\Delta A_n\cos 0 = E_n\Delta A_n$$

The total flux through the entire surface is

$$\Phi = \Phi_1 + \Phi_2 + \Phi_3 + \Phi_4 + \dots\dots\dots + \Phi_n$$

$$\Phi = \Sigma_{surface}\, E\Delta A \qquad \text{...(11.12)}$$

But as electric field intensity E is constant over the sphere

Therefore

$$\Phi = E\,\Sigma_{surface}\,\Delta A$$

Since $E = \dfrac{q}{4\pi\varepsilon_o}\dfrac{1}{r^2}$

Thus the above equation can be written as

$$\Phi_E = \frac{q}{4\pi\varepsilon_o}\frac{1}{r^2}\Sigma_{surface}\Delta A$$

$$= \frac{q}{4\pi\varepsilon_o}\frac{1}{r^2}\ \text{(total area enclosed by spherical surface)}$$

$$= \frac{q}{4\pi\varepsilon_o} \frac{1}{r^2} (4\pi r^2)$$

$$= \frac{q}{\varepsilon_o} \qquad \ldots(11.13)$$

The above equation shows that electric flux does not depend upon the shape or geometry of a closed surface. But it depends upon the medium and the charge enclosed by that surface.

Let us consider an irregular closed surface S, enclosing a point charges $q_1, q_2, q_3 \ldots\ldots q_n$ as shown in fig 11.15.

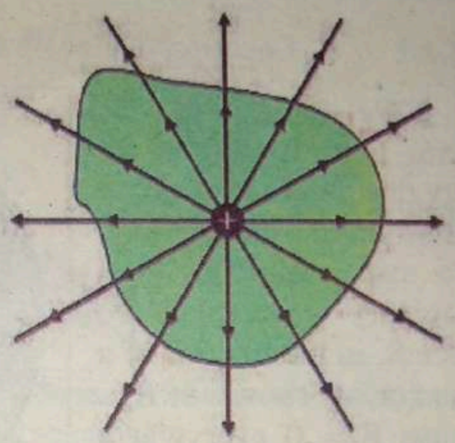


Fig 11.14 : flux through an irregular close surface

Then the total electric flux through that closed surface is

$$\Phi_E = \frac{q_1}{\varepsilon_o} + \frac{q_2}{\varepsilon_o} + \frac{q_3}{\varepsilon_o} \ldots\ldots\ldots \frac{q_n}{\varepsilon_o}$$

$$\Phi_E = \frac{1}{\varepsilon_o}(q_1 + q_2 + q_3 + \ldots\ldots\ldots q_n)$$

$$\Phi_E = \frac{1}{\varepsilon_o} \sum_{i=1}^{n} q_i$$

$$= \frac{1}{\varepsilon_o} \text{(total charge enclosed in surface)}$$

$$= \frac{Q}{\varepsilon_o}$$

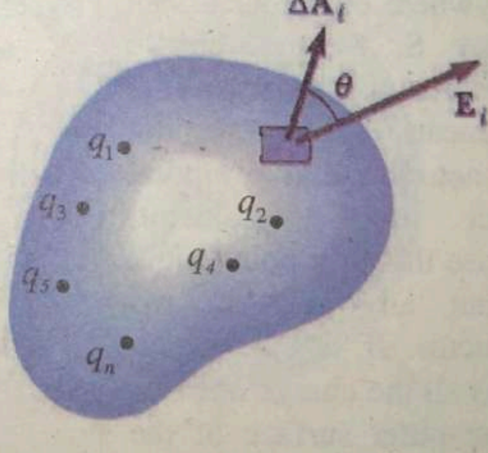


Fig: 11.15: number of charges in a closed surface

Thus Gauss's law shows that *the electric flux through any closed surface is $1/\varepsilon_o$ times the total charge enclosed in it.*

11.5.1 Applications of Gauss's law

Gauss's law provides a convenient method to calculate E in the case of sufficiently symmetrical charge distribution. Some of examples are now presented.

11.5.1.1 Location of Excess Charge on a Conductor

We know that the electric field E = 0 at all points due to electrostatic equilibrium in a conductor.

We can make an imaginary Gaussian surface S, in the interior of a conductor, as shown in fig:. Because E = 0 everywhere in this surface, the net charge inside the surface has to be zero. Since E = 0 everywhere on the Gaussian surface S, the net charge inside that point is zero. That also means that there cannot be a net charge at any point within the conductor, because that tiny point could be put anywhere in the conductor. If that's so, that means all the charge must be on the outer surface of the conductor, as shown in fig 11.16.

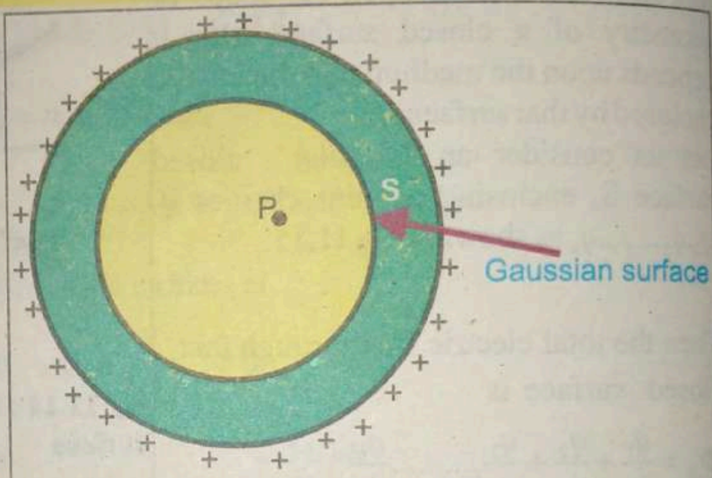


Fig: 11.16: Gaussian surface inside a conductor

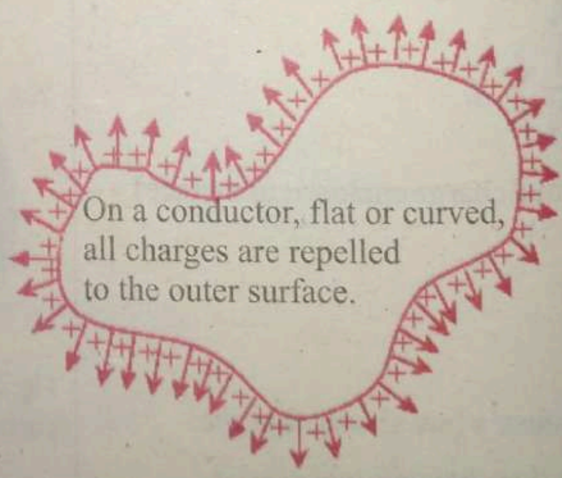


Fig: 11.17: Excess of charge on the surface of a conductor

Now let's consider a hollow conductor as shown in the illustration 11.18.

Since the conductor is hollow so there is no net charge at any point within the conductor. The cavity is surrounded by a Gaussian surface S which encloses no net charge and so there is no charge on the internal cavity. Again all the charge is deposited on the outer surface of the conductor.

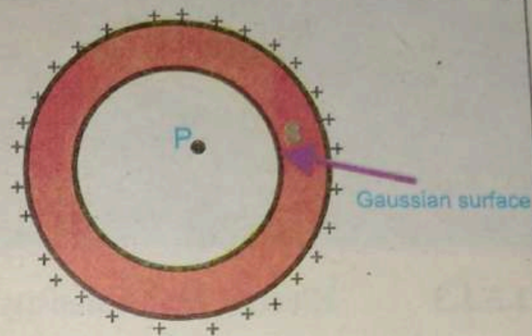


Figure 11.18 : an excess of charge on the outer surface of a hollow conductor

In the third case as shown in the fig: 11.19. Let's put a charge q inside the hollow conductor. We insulate it so no charges can jump from one surface to another. Now if we use Gauss's Law with Gaussian surface S again, the net charge of what it encloses has to be zero because there was no charge transfer between the charge and the conductor. Initially the conductor was uncharged but when charge q is inserted, then there will be negative charge on the inside cavity in order to maintain its neutral status.

So the other surface must have a charge equal but opposite the charge of the internal cavity, or the outer surface's charge is equal to that of charge q.

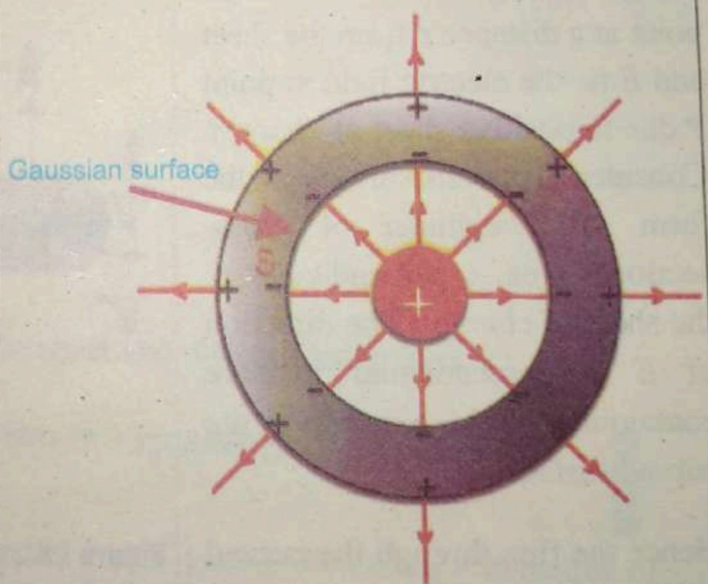


Figure 11.19 : charge q inside the hollow conductor having a Gaussian surface S

For your information

Figure 11.20 : Airlines Airbus A380 flew through a storm when 500 peoples were on the board but none of them were injured. As there is no electric field, no potential difference inside a metal shell, so one of the safest way to be inside a metal shell during thunderstorm.

11.5.1.3 Electric field Intensity Due To an Infinite Sheet of Charge

Consider an infinite plane sheet of charge with surface charge density σ. Let P be the point at a distance *r* from the sheet and *E* be the electric field at point P due to positive sheet of charges. Consider Gaussian surface in the form of a cylinder of cross-sectional area *A* perpendicular to the sheet of charge. The direction of *E* is perpendicular to face containing P and parallel to the curved surface.

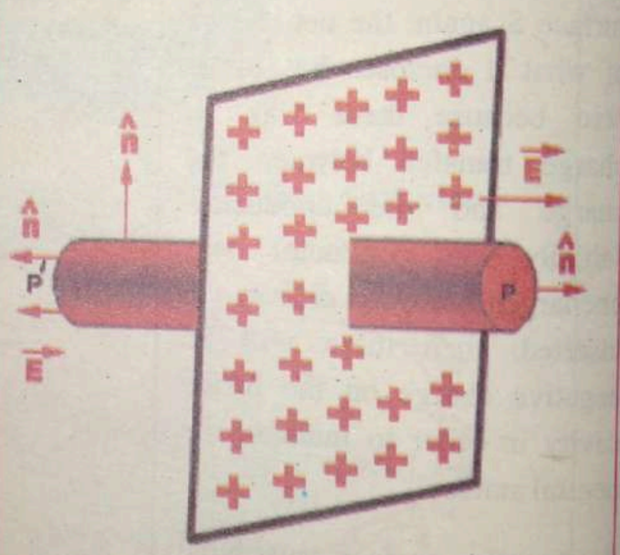


Figure 11.21 : Gaussian surface in the form of a cylinder perpendicular to the sheet of charge

Hence the flux through the curved surface is zero while it is 2 *EA* through the two end faces of the closed surface, where *A* is the area of cross section, as shown in Fig11.21. The charge enclosed by the surface will be σ *A*. Since we know by Gauss's law

$$\text{Total electric flux} = \frac{1}{\varepsilon_0} \times (\text{Charge enclosed by the closed surface})$$

$$\Phi = \frac{1}{\varepsilon_0} \times (Q)$$

As surface charge density $\sigma = Q/A$ or,

$$\sigma A = Q \qquad \ldots(11.14)$$

$$\Phi_E = \frac{\sigma A}{\varepsilon_0}$$

The electric flux through the end faces is

$$\vec{E}.\Delta\vec{A} + \vec{E}.\Delta\vec{A} = \frac{\sigma A}{\varepsilon_o}$$

Hence, $$2EA = \frac{\sigma A}{\varepsilon_0}$$

or $$E = \frac{\sigma}{2\varepsilon_0} \qquad \ldots(11.15)$$

and $$\vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{r} \qquad \ldots(11.16)$$

Where $\hat{r}$ is the unit vector normal to the sheet and directed away from it.

11.5.1.3 Electric field intensity between two oppositely charged parallel plates.

Consider two oppositely charged parallel metal plates. The charge densities of these metal plates are $+\sigma$ and $-\sigma$. These plates are assumed to be of infinite length in order to avoid fringing field at end. Under these conditions, the field intensity will be uniform and normal to the plates. In order to find the electric field intensity E, at point P between the plates consider a Gaussian surface in the form of a box as shown in fig (11.22). Let A be the cross sectional area of the box but as the box sides are parallel to electric field E so the flux through sides will be zero, the electric field intensity E is normal to the lower surface of Gaussian box. Therefore by Gauss's Law electric flux is

$$\Sigma \vec{E}.\Delta\vec{A} = \frac{Q}{\varepsilon_o}$$

$$\vec{E}.\Delta\vec{A} + \vec{E}.\Delta\vec{A} + \vec{E}.\Delta\vec{A} = \frac{Q}{\varepsilon_o}$$

$$\vec{E}\,\vec{A} + 0 + 0 = \frac{Q}{\varepsilon_o}$$

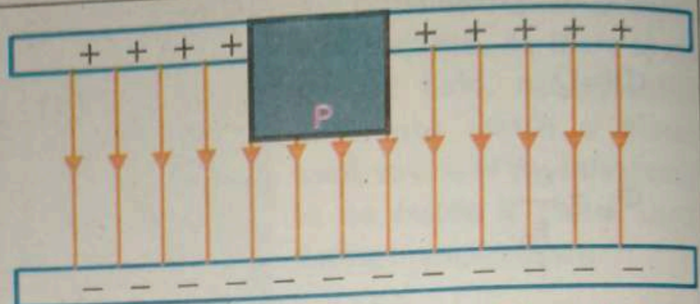


Figure 11.22: Gaussian surface in the form of a box between the plates

As the charge per unit area is σ and the charge enclosed in the box is σA. So

$$EA = \frac{\sigma A}{\varepsilon_o} \qquad \therefore Q = \sigma A$$

$$E = \frac{\sigma}{\varepsilon_o} \qquad ...(11.17)$$

and $\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{r}$

This gives the electric field between oppositely charged parallel plates. The magnitude of the field is independent of the position between plates.

11.6 ELECTRIC POTENTIAL

Let us consider a positive charge $+q$ placed in oppositely charged parallel plates. A charge experienced a force in an electric field. If the charge is allowed to move freely in an electric field it will move from plate A to plate B and acquire kinetic energy as shown in Fig:11.23(a). On the other hand external force is required to move the charge against electric field. In order to move the charge q_o, with uniform velocity from B to A an external force F must be applied which is equal and opposite to $q_o E$ as shown in Fig 11.23(b) .This force will maintain the equilibrium by preventing the charge q_o from acceleration while, moving from A to B.

Let W_{BA} be the work done by the force in carrying a positive charge q_o from point B to point A without disturbing the equilibrium state of the charge. The change in potential energy ΔU of charge q_o is defined to be equal to the work done by the force in carrying the charge q_o from one point to the other against the electrical field, i.e.,

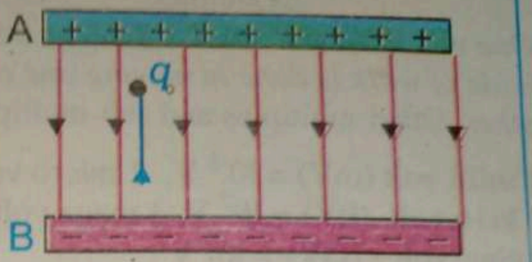


Figure 11.23 (a) : potential difference between point A & B in electric field.

$$\Delta U = W_{BA}$$

$$U_A - U_B = W_{BA} \qquad \text{... (11.18)}$$

where U_A and U_B represent the potential energies at point A and B respectively.

If this charge is released from point A, it will move from A to B and will gain an equivalent amount of K.E. Potential difference between two points is the work done in moving a unit positive charge from one point to another keeping the charge in electrostatic equilibrium. It implies that

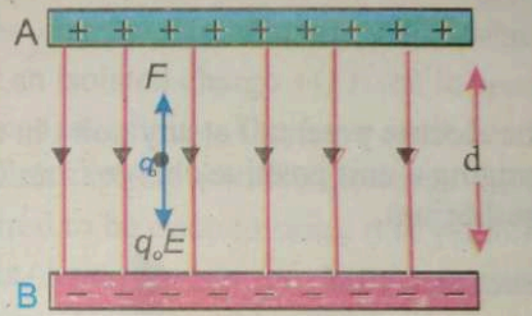


Figure 11.23 (b) : potential difference between point A & B in electric field.

$$\frac{\Delta U}{q_o} = \frac{W_{BA}}{q_o} \qquad \text{... (11.19)}$$

$$\frac{\Delta U}{q_o} = \frac{U_A}{q_o} - \frac{U_B}{q_o} = V_A - V_B = \Delta V \qquad \text{...(1)}$$

where V_A and V_B are the electric potentials at point A and B, respectively. The defining equations give.

$$U_A = q_o V_A, \; U_B = q_o V_B$$

Thus

$$\Delta U = q_o \Delta V = W_{BA} \qquad \text{...(11.20)}$$

Where ΔV is potential difference between A and B. Potential difference is the joule per coulomb which is termed as volt.

$$1\ \text{volt} = \frac{1\ \text{Joule}}{1\ \text{Coulomb}}$$

One volt is the potential difference between two points in an electric field if one joule of work is done in moving one coulomb of charge from the one point to the other. Other multiples and sub-multiples of volt are

1 milli volt (mV) = 10^{-3} V, 1 micro volt (μV) = 10^{-6} V
1 kilo volt (kV) = 10^{3} V, 1 mega volt (MV) = 10^{6} V
1 giga volt (GV) = 10^{9} V

If an amount of work W is required to move a charge Q from one point to another, then the potential difference between the two points is given by,

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

The electric potential at any point in an electric field is equal to work done in bringing a unit positive charge from infinity to that point keeping it in equilibrium.

Example 11.4

What is the electric potential energy of a 7 n C charge that is 2 cm from a 20 n C charge?

Solution:

We will use the equation: $U = k\frac{q_1 q_2}{r}$

Putting values:

$$U = 9.0 \times 10^{9}\ \frac{(7\times10^{-9})(20\times10^{-9})}{0.02\text{m}}$$

$$U = 6.3\times10^{-5}\text{J}$$

Example 11.5

What is the potential difference between two points in an electric field if it takes 600 J of energy to move a charge of 2 C between these two points?

Solution

We will use the equation: $V = \frac{W}{Q}$

$$= \frac{600}{2}$$

$$= 300\text{ V}$$

Electric Potential Energy and Potential due to a point charge

Like earth gravitational field every charge has electric field which theoretically expands up to infinity. Consider an isolated charge +Q fixed in space as shown in fig11.24. If a test charge q is placed at infinity. The force on it due to charge +Q is zero. As the test charge is at infinity which is moved towards +Q as force of repulsion acts on it. So work is required to be done to bring it to point A. Hence when the test charge is at point A it has some amount of electric potential energy. The closer the test charge to the charge +Q the higher will be the electric potential energy. Electric field does not remain constant but varies as the square of the distance from the charge. The equation for electric field intensity is

$$\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{Q}{r^2}\hat{r} \qquad (1)$$

In order to keep E constant the test charge is moved through infinitesimally small displacements Δr.

The work done is

$$\Delta W = -q\,\vec{E}.\Delta\vec{r} = -\,q\,E\Delta r\cos 180^o$$

$$= q\,E\Delta r \qquad \text{... (11.21)}$$

The negative sign in the above equation shows that E and Δr, are in opposite direction. Now putting the value of E from Eq (1) in Eq (11.21) we have

$$\Delta W = \frac{1}{4\pi\varepsilon_o}\frac{Qq}{r^2}\Delta r$$

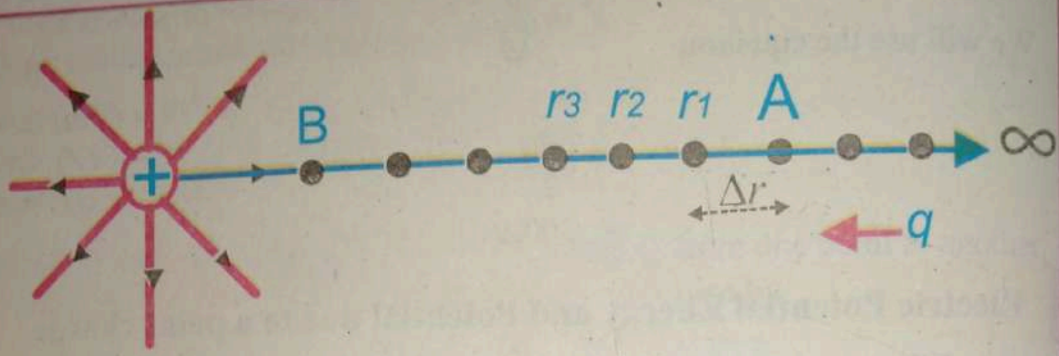


Figure 11.24 : work done on a test charge *q* in moving it towards source charge +*Q*

Now let the test charge is at a large distance r_A from charge Q. We divide the distance between r_A and r_B into infinitesimally small displacement so that the field intensity over each displacement remains constant. At the beginning of the first displacement E varies as $1/r_A^2$ and at the end E varies as $1/r_1^2$ since the average $1/r^2$ over each small displacement is

$$\frac{1}{<r^2>} = \frac{1}{<rr>}$$

Therefore one r is replaced by r_A and another by r_1.

$$\frac{1}{<r^2>} = \frac{1}{r_A r_1}$$

To calculate work done in this small displacement we put $1/r^2 = 1/r_A r_1$ and $\Delta r = r_A - r_1$

We get

$$\Delta W_{r_1 \to r_A} = \frac{Qq}{4\pi\varepsilon_o}\left(\frac{r_A - r_1}{r_A r_1}\right)$$

By division

$$\therefore \left(\frac{r_A}{r_A r_1} - \frac{r_1}{r_A r_1}\right) = \left(\frac{1}{r_1} - \frac{1}{r_A}\right)$$

$$\Delta W_{r_A \to r_1} = \frac{Qq}{4\pi\varepsilon_o}\left(\frac{1}{r_1} - \frac{1}{r_A}\right) \qquad \text{... (11.22)}$$

Similarly for second small displacement $\Delta r = r_1 - r_2$. Work done is

$$\Delta W_{r_1 \to r_2} = \frac{Qq}{4\pi\varepsilon_o}\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$$

And

$$\Delta W_{r_n \to r_B} = \frac{Qq}{4\pi\varepsilon_o}\left(\frac{1}{r_B} - \frac{1}{r_n}\right) \qquad \text{... (11.23)}$$

The total work done in moving a charge q from r_A to r_B can be calculated by taking its sum.

$$\Delta W_{r_A \to r_B} = \frac{Qq}{4\pi\varepsilon_o}\left(-\frac{1}{r_A} + \frac{1}{r_1} - \frac{1}{r_1} + \frac{1}{r_2} - \frac{1}{r_2} + ... + \frac{1}{r_B}\right)$$

$$\Delta W_{r_A \to r_B} = \frac{Qq}{4\pi\varepsilon_o}\left(\frac{1}{r_B} - \frac{1}{r_A}\right) \qquad \text{... (11.24)}$$

The work done to move a test charge q from infnity to a distance r from Q is

$$W_{r_A \to r_B} = \frac{Qq}{4\pi\varepsilon_o}\left(\frac{1}{r_B} - \frac{1}{\infty}\right)$$

$$= \frac{Qq}{4\pi\varepsilon_o}\left(\frac{1}{r_B}\right) \qquad \text{... (11.25)}$$

The electric potential energy at distance r from Q is

$$U = \frac{Qq}{4\pi\varepsilon_o}\left(\frac{1}{r}\right) \quad \text{... (11.26)}$$

The electric potential at distance r from Q is

$$V = \frac{W}{q} = \frac{1}{4\pi\varepsilon_o}\frac{Q}{r} \quad \text{... (11.27)}$$

Example 11.6

A point charge of 3μC is placed at point O between M and N, 3cm apart. Point M is 2cm from the charge and N is 1cm from the charge. What is the potential difference $V_M - V_N$?

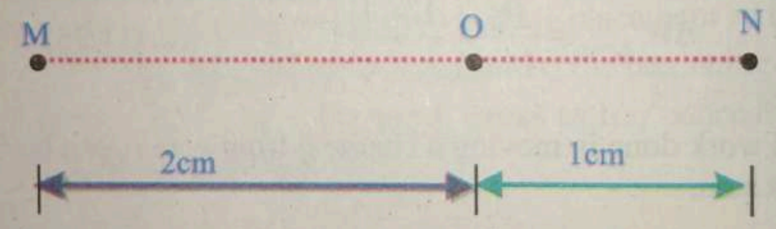


Figure 11.25: potential due to a point charge

Solution

Potential at M due to the charge is $V_M = k\frac{q}{r}$

$$V_M = 9\times10^9 \times \frac{3\times10^{-6}}{2\times10^{-2}} = 13.5\times10^5\ \text{V}$$

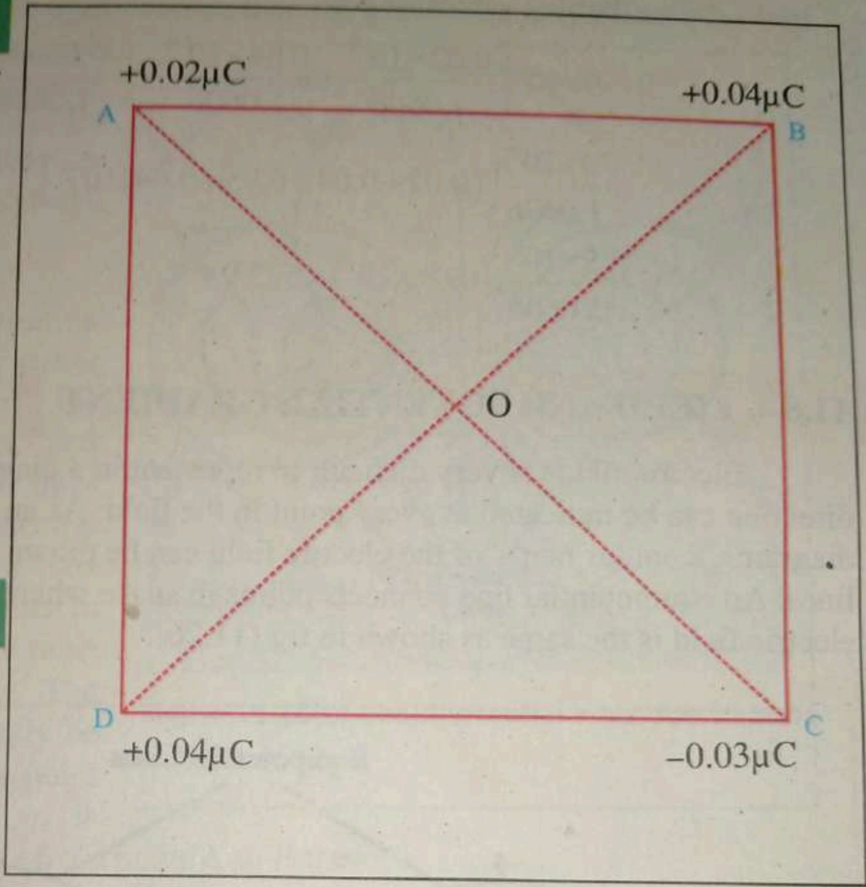
Potential at N due to the charge is

$$V_N = 9\times10^9 \times \frac{3\times10^{-6}}{1\times10^{-2}} = 27\times10^5\ \text{V}$$

$$\therefore \quad V_M - V_N = 13.5\times10^5 - 27\times10^5 = -13.5\times10^5\ \text{V}$$

Example 11.7

Four point charges of +0.02μC, +0.04μC, -0.03μC and +0.04μC are placed at the corner A, B, C and D of a square ABCD respectively. Find the potential at the centre of the square if each side of the square is 1.5m apart.



Solution:

Fig: shows the square ABCD with charges placed at its corners. The diagonals of the square intersect at point O. Clearly, point O is the centre of the square. The distance of each charge from point O is

$$=\frac{1}{2}\sqrt{(1.5)^2+(1.5)^2}=1.0606\text{m}$$

The potential at point O due to all charges is equal to the algebraic sum of potentials due to each charge.

∴ Potential at O due to all charges

$$V=k\left[\frac{q_A}{r_A}+\frac{q_B}{r_B}+\frac{q_C}{r_C}+\frac{q_D}{r_D}\right]$$

Putting values we get

$$=9\times10^{9}\left[\frac{0.02\times10^{-6}}{1.0606}+\frac{0.04\times10^{-6}}{1.0606}+\frac{-0.03\times10^{-6}}{1.0606}+\frac{0.04\times10^{-6}}{1.0606}\right]$$

$$=\frac{9\times10^{9}}{1.0606}\left[(0.02+0.04-0.03+0.04)10^{-6}\right]$$

$$=\frac{9\times10^{9}}{1.0606}\times0.07\times10^{-6}=593.9\text{V}$$

11.8 FIELD AND POTENTIAL GRADIENT

Electric fields is very difficult to represent in a diagram. Both strength and direction can be indicated at every point in the field. As an alternative to field-line diagrams, 'contour maps' of the electric field can be drawn using equipotential lines. An equipotential line connects points in space where the potential of an electric field is the same as shown in fig (11.26).

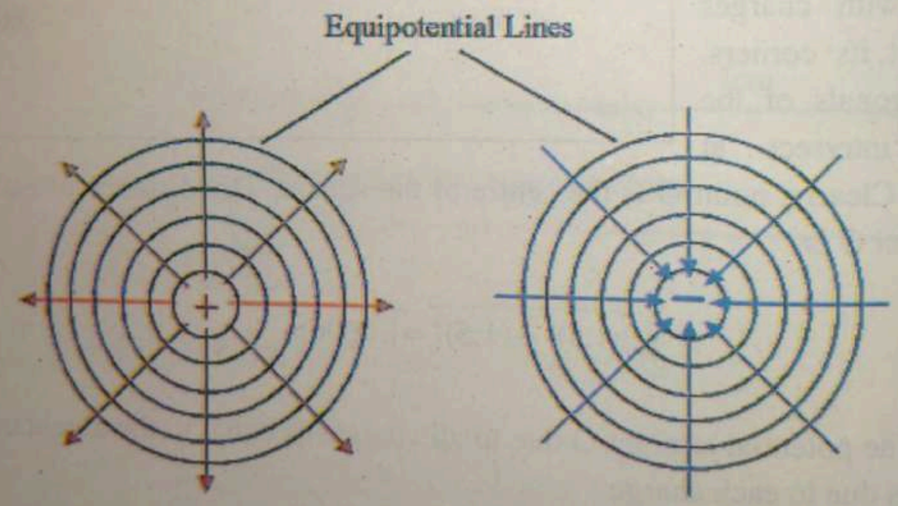


Figure 11.26(a) : equipotential lines around positive and negetive charges

For a point charge $V=\frac{q_o}{4\pi\varepsilon_o r}$

so all points at the same distance r from the charge will have the same potential — the equipotential lines form circles centred on the charge.

If there are two or more charges present, then the potential at any point is the sum of the potentials due to each charge. Potential is a scalar quantitiy. However; potential can be either positive or negative, depending upon the sign of the charge.

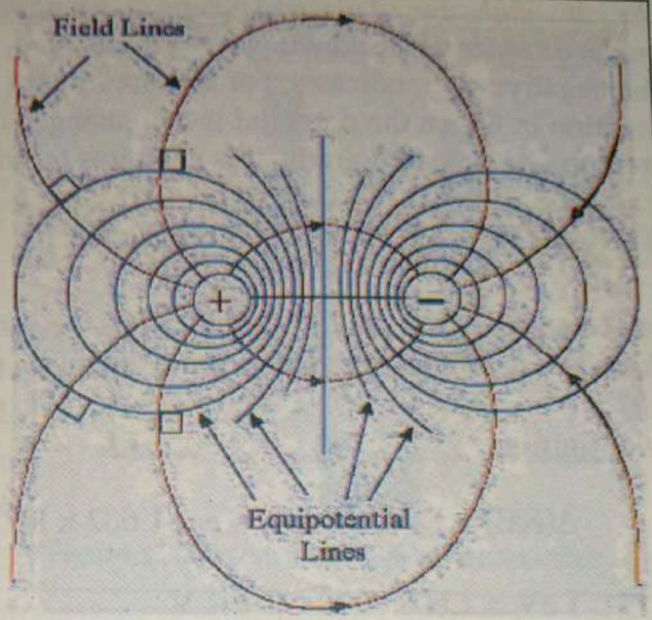


Figure 11.26(b) : equipotential lines due to two charges

The same basic idea is true on an equipotential map the closer the lines are together; the stronger the field is at that point if the equipotential lines are close together, the electric potential energy must be changing by large amounts in small distances, and there must be a large force acting. The exact relationship can easily be derived for the field of a point charge if a test charge q_o is moved a small distance Δr from point A to B then

work done on test charge = force acting × distance moved

$$W = F\,\Delta r$$

In an electric field, the force acting is equal to the charge times the field strength

$$F = q_o E$$

work done = $W = E\,q_o\,\Delta r$

Now the work done on the charge is equal to the decrease in electric Potential energy (remember that the potential energy is the charge times potential)

$$\therefore W = -\,q_o\,\Delta V$$

The negetive sign is applied because the work done on q_o is against field force $q_o E$

, so

$$q_o\,\Delta V = -E\,q_o\,\Delta r$$

$$E = -\frac{\Delta V}{\Delta r} \qquad \text{... (11.28)}$$

The strength of the field is equal to the potential gradient.

The rate of change of electric potential ΔV with respect to displacement Δr is known as potential gradient.

The negative sign indicates that the direction of the field is opposite to the direction in which the potential is increasing. This relationship between field strength and potential gradient is analogus to gravitational fields.

11.9 THE ELECTRON VOLT (eV)

One elecrton volt is the the amount of energy acquired or lost by an electron when it is displaced across two points between which potential difference is one volt.

By definition

$$\Delta(KE) = 1\text{ eV, when } q = e = 1.602 \times 10^{-19}\text{ C and } \Delta V = 1\text{V}.$$

thus

$$I\text{ eV} = 1.602 \times 10^{-19}\text{ C} \times 1\text{ V}$$
$$= 1.602 \times 10^{-19}\text{ J}$$

The electron volt (eV) is just another unit of energy like the joule.

This is the smaller unit of energy. Its bigger units are multiples of 1 eV that are in frequent use are given below.

I Million electron volt = I Mev = 10^6 eV

I Giga electron volt = I GeV = 10^9 eV

Example.11.8

A particle carrying a charge ($3e$) falls through a potential difference of 5V. Calculate in joules the energy acquired by the particle.

Solution:

The energy acquired by the charged particle is

$\Delta(KE) = q\,\Delta V$=(3e) (5 V) =15eV

= $15 \times 1.602 \times 10^{-19}$ J= 2.4×10^{-18} J

11.10 Capacitor

A device which is used for storing electric charges is called capacitor. It consists of two parallel metal plates, separated by small distance. The medium between the two plates is air or a sheet of some insulator. This medium is known as dielectric.

When a charge is transferred to one of the plate say (A) due to electrostatic induction it would induce charge Q on the inner surface of the other plate B. The capacitor is commonly charged by connecting its plates for a while to the opposite terminals of a battery. In this way some electrons are transferred through the battery from the positive plate to the negative plate. Charge $+Q$ and $-Q$ appear on the plates. Mutual attraction between the charges keeps them bound on the inner surface of two plates and thus the charge remains stored in the capacitor even after removal of the battery.

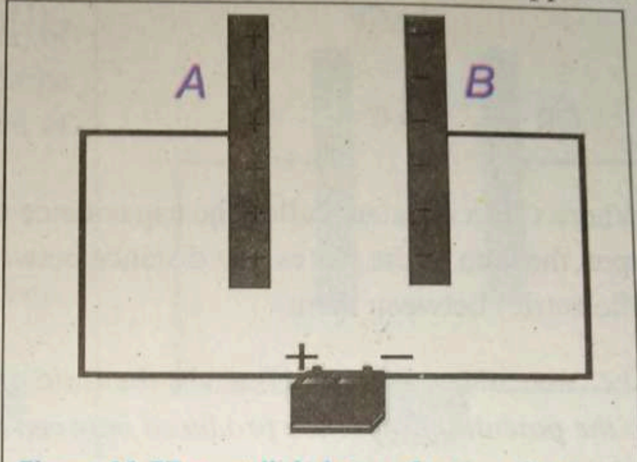


Figure 11.27 : parallel plates of a capacitor


Fig:11.28 Capacitors use in different electronic devices.

11.10.1 Capacitance of a capacitor and its unit

The capability of a capacitor to store charges is called it capacitance. When a charge Q is transferred on one of the plates of a capacitor, the potential difference V between the plates also increases. In other words, the charge 'Q' on the plate of a capacitor is directly proportional to the electric potential difference V between them i.e.

$$Q = CV \qquad ...(11.29)$$

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

Where C is a constant called the capacitance of capacitor. The value of C depends upon the area of the plates, the distance between the plates and the medium (dielectric) between them.

The capacitance is thus defined as *the ratio of magnitude of charge on either plate to the potential difference produced between the plates.*

Substituting V with 1 volt in Eq. (11.29) it reduce to Q = C. This implies that if the potential difference between the plates of capacitor is 1 volt then the amount of charge stored on its plates is equal to its capacity. The SI unit of capacitance is called farad. Farad (F) is defined as "*the capacity of that capacitor which stores a charge of 1 coulomb having the potential difference of 1 volt between the plates*".

Convenient sub-multiples of farad are:

$$1\mu F(\text{micro Farad}) = 10^{-6} F \ \& \ 1\mu\mu F(\text{Pico Farad}) = 10^{-12} F$$

11.10.2 CAPACITANCE OF A PARALLEL PLATE CAPACITOR

Let us consider a parallel plate capacitor connected to a voltage source V. The source, charges the capacitor plates till the potential difference across the plates builds to V. Let the charges on the plates are $+Q$ and $-Q$ when the potential difference is V. If the positive plate is at potential V_1 and negative plate is at potential V_2, then the electric field strength between the plates is

$$E = \frac{-\Delta V}{\Delta r} = \frac{-(V_2 - V_1)}{d} = \frac{V_1 - V_2}{d} = \frac{V}{d} \qquad (1)$$

Where $V_1 - V_2 = V$, the P.D. between the plates, and d is the separation between the plates. The strength of the electric field also depends on the number of charges on the plates. The charge density is the total charge per area of the plate. $\sigma = \frac{Q}{A}$

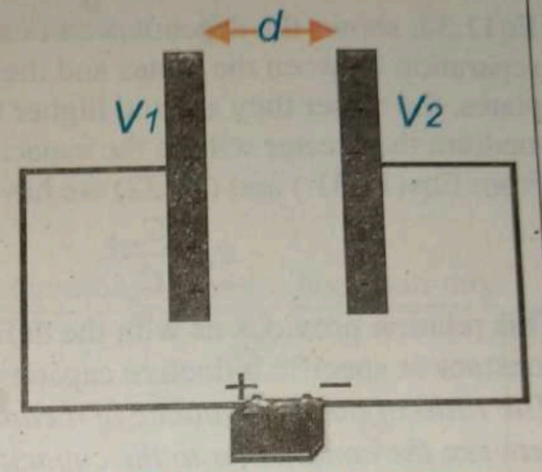


Figure 11.29 : plates of a capacitor separated by a distance *d*

By using Gauss's law the electric field intensity E between the plates is

$$E = \frac{\sigma}{\varepsilon_o} = \frac{Q}{\varepsilon_o A} \qquad (2)$$

From Eq (1) & (2) we have

$$E = \frac{V}{d} = \frac{Q}{\varepsilon_o A}$$

Or

$$Q = \frac{\varepsilon_o A V}{d} \qquad \text{... (11.30)}$$

By using $C_{vac} = \frac{Q}{V}$ Eq (11.30) becomes

$$C_{vac} = \frac{Q}{V} = \frac{\varepsilon_o A}{d} \qquad \text{... (11.31)}$$

When a dielectric is inserted between the plates of a capacitor, then it is seen that the charge storing capacity of a capacitor is enhanced by the dielectric which permits it to store ε_r times more charge for the same potential difference. ε_r is a dimensionless quantity which is always greater than unity for dielectric and is independent of the size and shape of the dielectrics. It is called dielectric constant or relative permittivity.

In case of a parallel plate capacitor completely filled with a dielectric the capacitance is

$$C_{med} = \frac{\varepsilon_o \varepsilon_r A}{d} \quad \text{... (11.32)}$$

Eq11.32: shows the dependence of capacitance upon the area of the plates, the separation between the plates and the medium between them. The larger the plates, the closer they are and higher the dielectric constant of the separating medium the greater will be the capacitance of the capacitor.

From Eqs(11.31) and (11.32) we have

$$\varepsilon_r = \frac{C_{med}}{C_{vac}} \quad \text{... (11.33)}$$

This relation provides us with the definition of relative permittivity or dielectric constant or specific inductive capacity:

The ratio of the capacitance of a capacitor with a given material filling the space between the conductors to the capacitance of the same capacitor when the space is evacuated is the relative permittivity ε_r of the material.

11.10.3 Combinations of Capacitors

We know that the capacitors can be connected either in series or in parallel. We want to find out an equivalent capacitor that has the same capacitance as that of the combination of capacitors.

Series Combination of capacitors

When the capacitors are connected plate to plate i.e. the right plate of one capacitor is connected to the left plate of the next capacitor so on as shown in fig:11.30 (a) then it is called series combination. A battery of voltage V is connected between points A and B. Then it supplies $+Q$ charge to the left plates of the capacitor C and $-Q$ charge is induced on its right plates. As a result of this charging each capacitor gets an equal amount of charge Q on each of its plates. The potential difference V must be equal to the sum of potential difference, V_1, V_2 & V_3 across the capacitors i.e. $V = V_1 + V_2 + V_3$ (i)

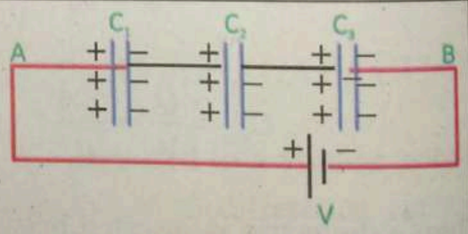


Figure 11.30(a) : series combination of capacitors

We know that: $V_1 = \frac{Q}{C_1}, V_2 = \frac{Q}{C_2}, \& V_3 = \frac{Q}{C_3}$ Substituting these expressions into the above Equation(i), we have $V=\frac{Q}{C_1}+\frac{Q}{C_2}+\frac{Q}{C_3}$ or $V=Q(\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3})$

Let C_e be the capacitance of an equivalent capacitor, which would hold the same charge when the potential difference V is applied. That is $V=\frac{Q}{C_e}$

Therefore $\frac{Q}{C_e}=Q(\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3})$

or $\frac{1}{C_e}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}$ ... (11.34)

Thus the equivalent capacitance of a series combination is always less than any individual capacitance in the combination.

Parallel Combination of capacitors

When two or more capacitors are connected between the same two points in a circuit, as shown in fig:11.30(b), then it is called parallel combination of capacitors. Three capacitors C_1, C_2, & C_3 are connected in parallel between two points A and B. The potential difference between the plates of each capacitor is the same and is equal to the applied potential difference V i.e $V=V_1=V_2=V_3$.

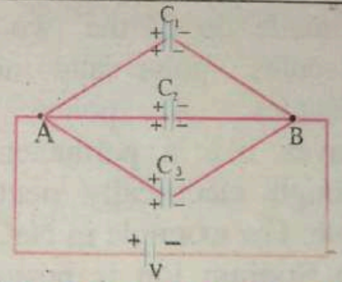


Figure 11.30 (b): parallel combination of capacitors

When Q charge is supplied to the capacitors C_1, C_2, and C_3, they acquire different amount of charges Q_1, Q_2, and Q_3 respectively depending upon their capacitances. Let C_e be the capacitance of an equivalent capacitor, which would hold the same amount of charge as all the three capacitors C_1, C_2, and C_3 hold under the same potential difference.

$\therefore Q=Q_1+Q_2+Q_3$ But $Q_1=C_1V$, $Q_2=C_2V$, $Q_3=C_3V$ & $Q=C_eV$

so $C_eV=C_1V+C_2V+C_3V=(C_1+C_2+C_3)V$

$C_e=C_1+C_2+C_3$ (11.35)

Thus the equivalent capacitance of a parallel combination is always larger than any individual capacitance in the combination.

11.11 ELECTRIC POLARIZATION

When insulating material with relative permittivity (or dielectric constant) ε_r is inserted into an initially charged parrallel plates of a capacitor. Then negative charges appear on the left face and positive charges on the right face of the dielectric as shown in fig11.31. The phenomenon is known as electric polarization and dielectric is said to be polarized under such condition. The charges on the dielectric faces are called induced charges; they are induced by the external field and appear on the dielectric faces only. The electric field from the free charges is left to right whereas the electric field due to induced charges is right to left.

Molecules in the dielectric material have their positive and negative charges separated slightly, causing the molecules to be oriented slightly in the electric field of the charged capacitor. As electric field due to induced charges is opposite to the external electric field so it reduces the intensity of external field due to oppositely charged plates of the capacitor.

We know that dielectric materials are made up of the two types of molecules ;polar and non polar molecules. A polar molecule behaves like a permanent dipole; although electrically neutral as a whole. For example in NaCl the end with Sodium ion is positive while the end with Chlorine ion is negative.

On the other hand, a non-polar molecule like oil has no electric dipole moment in the absence of an external field. The centre of positive and negative charges coincide in the absence of an extenal electric field. When a non polar dielectric material is placed in an external field, it gets polarized, that is, it displaces the electrons to the opposite of electric field E as shown in fig. Under the action of external field the centres of negative and positive charges shift and form dipoles (Two opposite point charge separated by a finite distance d constitutes a dipole).

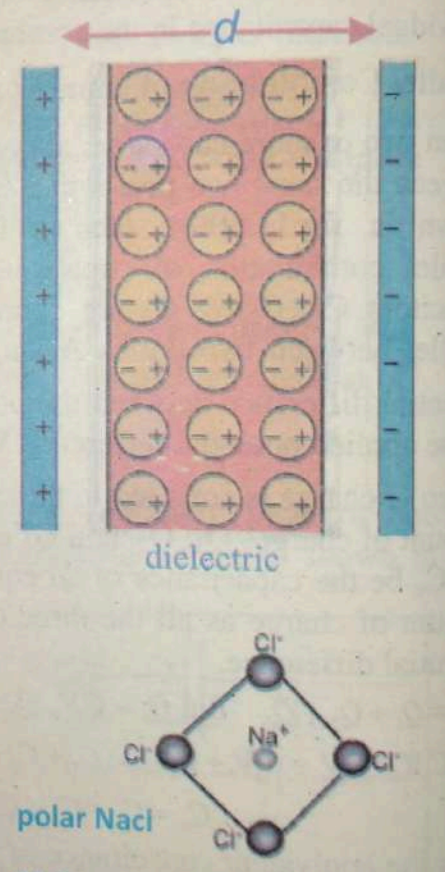


Figure 11.31: Polarization of a dielectric in an electric field gives rise to thin layers of bound charges on the surfaces, creating positive and negative surface charge densities.

The system in which two charges of equal magnitude but of opposite sign separated by the distance d, are present is termed as a dipole.

Electric dipole moment is represented by P, which is equal to the product of the charge q present in the dipole and the distance d between the two charges of the dipole.

$$P = |qd| \quad \ldots(11.36)$$

Where P is a vector quantity.

Example 11.9

Fig:(11.32). shows a different combination of capacitors, if the total charge is 600μC. Then determine the values of V_1, and C_2.

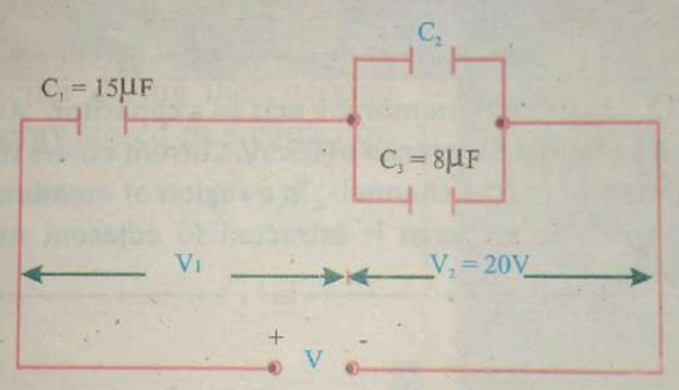


Figure 11.32: capacitors C_1, C_2, & C_3 connected to potential V

Solution:

$$\text{P.D. across capacitor } C_1: V_1 = \frac{Q}{C_1} = \frac{600\times10^{-6}}{15\times10^{-6}} = 40\text{V}$$

$$\text{Total p.d.: } V = V_1 + V_2 = 40 + 20 = 60\text{V}$$

$$\text{Charge on capacitor } C_3 \text{ is}: Q_3 = C_3 \times V_2$$

$$= (8\times10^{-6})\times20$$

$$= 160\times10^{-6}\,C = 160\mu\text{C}$$

$$\therefore \text{Charge on capacitor } C_2 \text{ is}: Q_2 = 600 - 160 = 440\mu\text{C}$$

$$\therefore \text{Capacitacnce of capacitor } C_2 = \frac{440\times10^{-6}}{20}$$

$$= 22\times10^{-6}\,\text{F} = 22\mu\text{F}$$

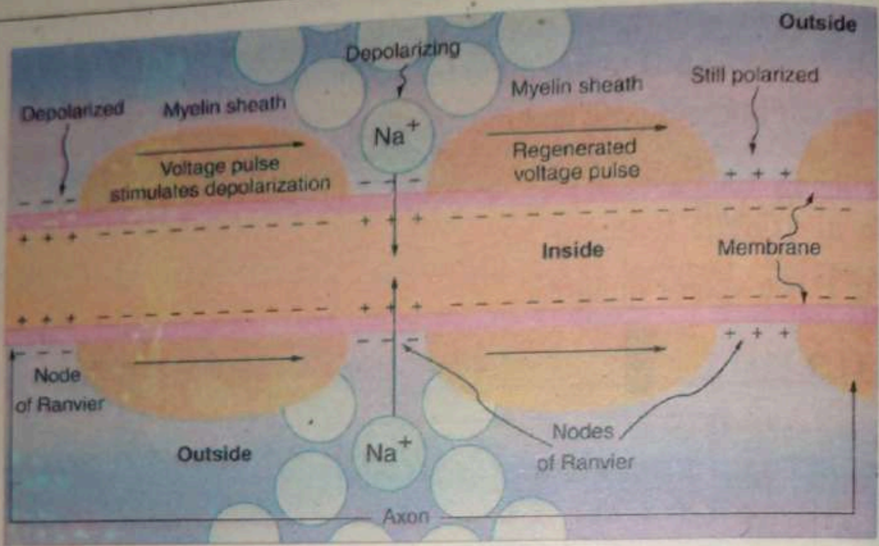


Figure 11.33: an axon membrane acts as a capacitor. Axon of a resting human nerve cell has a potential difference of 65mV. Current enters the axon (or dendrite) through ion channels (e.g. Na+ channels) in a region of membrane, depolarizing that region. The intracellular + charge is attracted to adjacent negatively charged regions of membrane.

Example 11.10

A 6μF capacitor is charged to a P.D. of 200V and then connected in parallel with an un-charged 3μF capacitor. Calculate the P.D. across the parallel plate capacitors.

Solution:

Capacitance of charged capacitor = $C_1 = 6\mu F$

Capacitance of un-charged capacitor = $C_2 = 3\mu F$

Charge on capacitor, C_1 is: $Q = C_1 V = (6\times10^{-6}) \times 200 = 0.0012C$

The equivalent capacitance of parallel combination of capacitors is

$C_{eq} = C_1 + C_2 = 6 + 3 = 9\mu F.$

The charge 0.0012 C is distributed between the two capacitors to have a common P.D.

$$\therefore \text{P.D. across Parallel plate capacitors}: V = \frac{Q}{C_{eq}} = \frac{0.0012}{9\times10^{-6}} = 133.3\text{V}$$

11.12 ENERGY STORED IN A CAPACITOR

Let us suppose that initially the capacitor is uncharged when voltage is zero. When it is connected to source of potential difference V it is charged. Initially, when the capacitor is uncharged, the potential difference between the plates is zero. Finally when charge $+Q$ and $(-Q)$ are deposited on the plates, the potential difference between the plates becomes V. The average voltage on the capacitor during the charging process is $V/2$. Thus the energy stored in a capacitor, is

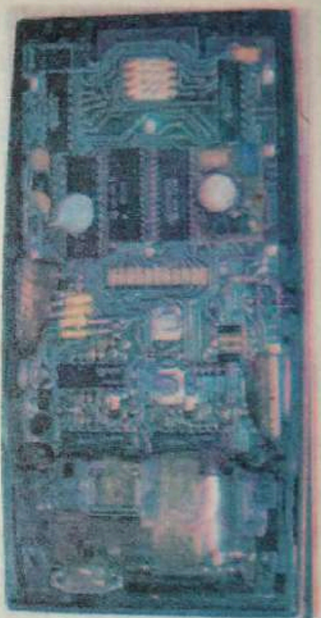


Figure 11.34: Energy stored in the large capacitor is used to preserve the memory of an electronic calculator when its batteries are charged.

$$\text{Energy} = U = \frac{QV}{2} \qquad \text{... (11.37)}$$

Where Q is the charge on a capacitor with a voltage V applied. Charge and voltage are related to the capacitance C of a capacitor by $Q = CV$ and so the expression for U can be written in three equivalent expressions as:

$$U = \frac{QV}{2} = \frac{CV^2}{2} = \frac{Q^2}{2C} \qquad \text{... (11.38)}$$

It is also possible to regard the energy as being stored in the electric field between the plates rather than the potential energy of the charges on the plates. Such a view point is useful when the Electric field between the plates is considered rather than the charges on the plates causing the field is to be considered.

We know that

$$V = E\,d$$

and

$$C = \frac{A\varepsilon_r\varepsilon_o}{d}$$

Substituting these values in Eq.(11.38). We get

$$U = \frac{1}{2} \times \frac{A\varepsilon_r\varepsilon_o}{d} \times (Ed)^2$$

$$U = \frac{1}{2}\varepsilon_r\,\varepsilon_o\,E^2 \times (Ad) \qquad \text{...(11.39)}$$

The product (Ad) is volume between the plates. Let u denote the energy density that is, the energy contained in a unit volume of the field. Then

$$u = \frac{\text{Energy}}{\text{Volume}} = \frac{U}{Ad}$$

$$= \frac{1}{2}\varepsilon_r\varepsilon_o E^2 \qquad \text{... (11.40)}$$

11.13 CHARGING AND DISCHARGING A CAPACITOR

Electronic flashguns for cameras have to be left for a short period of time between flashes.

There is a capacitor inside that stores energy,it needs to be charged up again by the battery in the flashgun. The time taken for this depends on the rate at which the charge is flowing, which in turn is determined by the resistance of the circuit.It can take a couple of seconds before the capacitor is fully charged.

Fig.(11.35)shows a resistor capacitor circuit called *RC* circuit.

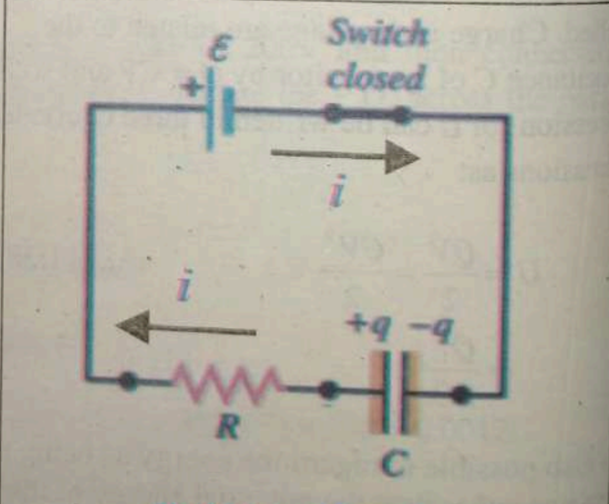


Fig: 11.35 : RC circuit

When the switch S is closed to connect the upper circuit, a battery of voltage V, starts charging the capacitor through the resistor *R*.

The charge builds up gradually on the plates to the maximum value of q_o. Suppose at $t = 0$ charge on a capacitor is zero .i.e $q = 0$.
It can be shown that after time t, as charge builds up on the plates, it repels more charge than is arriving, and the current drops as the charge on the plates increases. Charging will stop when the P.D. between the capacitor plates is equal to the e.m.f. of the battery.

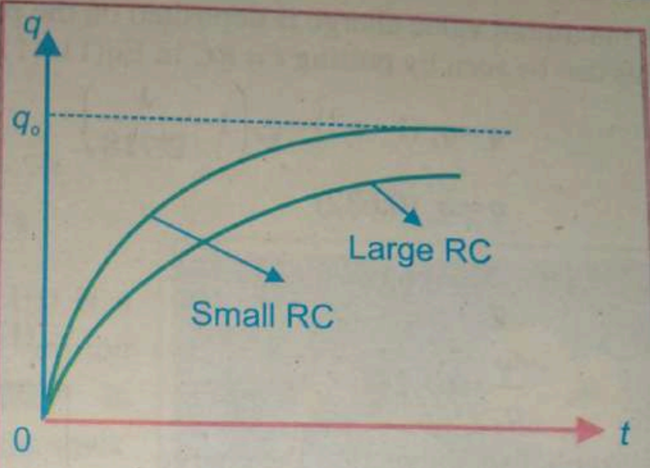


Fig: 11.36 : Growth of charge on the capacitor

maximum charge on capacitor = capacitance × e.m.f. of battery
Experiments shows that the charging process of a capacitor exhibits the exponential behavior therefore we can write its Eq: as

$$q = q_o\,(1 - e^{-t/RC}) \qquad \text{... (11.41)}$$

where e is a constant. Its value is 2.7182 Fig. (11.35) shows a graph between time t and charge q. According to this graph, $q = 0$ at $t = 0$ and increases gradually to its maximum value q_o.

Time constant

The time taken to charge a capacitor in a given circuit is determined by the time constant of the circuit. The bigger the capacitance, the longer it takes to charge the capacitor. The larger the resistance, the smaller the current, which also increases the charging time. The factor RC is called 'time constant. The time constant is the duration of time for the capacitor in which 63.2 % of

For your information

In principle, a capacitor can never charge up fully, because the rate of charging decreases as the charge increases. In practice, after a finite time the charging current becomes too small to measure, and the capacitor is effectively fully charged.

its maximum value charge is deposited on the plates.
This can be seen by putting $t = RC$ in Eq(11.41)

$$q = q_o(1-e^{-1}) = q_o\left(1-\frac{1}{2.718}\right)$$

$$q = q_o(0.632)$$

$$\Rightarrow \frac{q}{q_o} = 0.632 = 0.632 \times \frac{100}{100} \quad \text{... (11.42)}$$

$$\frac{q}{q_o} = 63.2\%$$

The graph also shows that the charge reaches its maximum value sooner when the time constant is small.
Fig.11.37 : illustrates the discharging of a charged capacitor through a resistor. When the switch S is closed. the charge $+q$ on the right plate can now flow clockwise through the resistance and neutralize the charge $-q$ on the left plate. Assuming the fully charged capacitor begins discharging at time $t = 0$, it can be shown that charge left on either plate at time t is

$$q = q_o e^{-t/RC} \quad \text{... (11.43)}$$

The corresponding graph in fig. 11.38 shows that discharging begins at $t = 0$ when $q = q_o$, and decreases gradually.

Smaller values of time constant RC lead to a more rapid discharge. When $t = RC$, the magnitude of charge remaining on each plate is,

$$q = q_o(0.367)$$

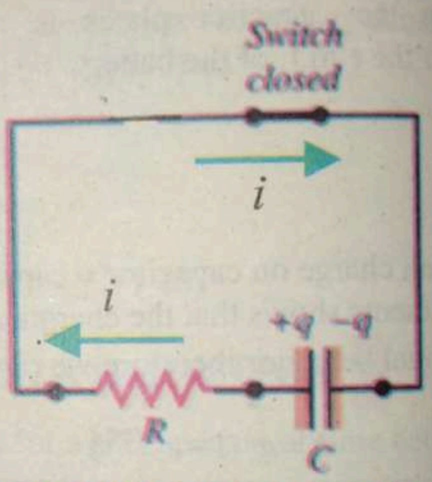


Fig: 11.37: Discharging a capacitor

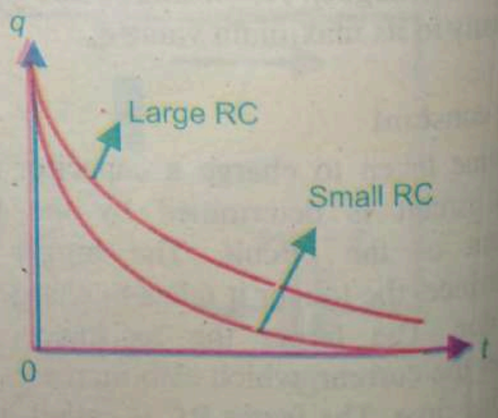


Fig: 11.38: decay of charge on capacitor

$$\Rightarrow \frac{q}{q_o} = 0.367$$

Thus,

$$\frac{q}{q_o} = 36.7\% \quad ...(11.44)$$

The charging and discharging of a capacitor has many applications. Capacitor discharge ignition (CDI) is a type of automotive electronic ignition system which is widely used in motorcycles, lawn mowers, chain saws, small engines, turbine powered aircraft, and some cars. It was originally developed to overcome the long charging times associated with high inductance coils used in inductive ignition systems, making the ignition system more suitable for high engine speeds (for small engines, racing engines and rotary piston engines). It can enhance the capability of power supply and make the spark much stronger.

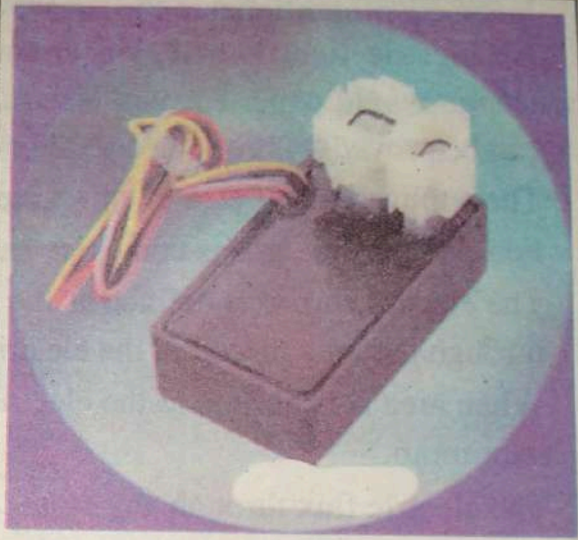


Figure 11.39 : Electronic Ignition CdI

Key points

- According to Coulomb law the electric force between two point charges is directly proportional to the product of magnitudes of the charges and inversely proportional to the square of the distance between them.
- An electric field is a region around a charge in which an electric test charge would experience an electric force. The existence of electric field can be proved by bringing a test charge q_o into its field.
- The applications of electrostatics are photocopier and inkject printer.
- For electric flux area is considered as vector quantity.
- The electric flux Φ is defined as the number of lines of force that pass through the area placed in the electric field. $\Phi = E.A = EA\cos\theta$
- When area A is normal to the electric field E then electric flux is maximum.
- The electric flux through any closed surface is $1/\varepsilon_o$ times the total charge enclosed in it.
- A device which is used for storing electric charges is called capacitor. The SI unit of capacitance is called farad.
- The electron volt (eV) is another unit of energy and is related to joule as $1\ eV = 1.602 \times 10^{-19}\ J$
- The dielectric materials are made up of the two types of molecules ;polar and non polar molecules.
- The system in which two charges of equal magnitude but of opposite sign separated by the distance d are present is termed as a dipole.
- the energy stored between the plates of a capactor is in the form of electric field. $U = \frac{1}{2}\varepsilon_r \varepsilon_o E^2 \times (Ad)$
- The charging process of a capacitor exhibits the exponential behavior so we can write its Eq: as $q = q_o(1 - e^{-t/RC})$
- The time constant is the duration of time for the capacitor in which 63.2 % of its maximum value charge is deposited on the plates.

Exercise ?

Multiple choice questions:

Each of the following questions is followed by four answers. Select the correct answer in each case.

1. A charge Q is divided into two parts q and $Q-q$ and separated by a distance R. The force of repulsion between them will be maximum when:
   a. $q = Q/4$
   b. $q = Q/2$
   c. $q = Q$
   d. None of these

2. Some charge is being given to a conductor. Then its potential
   a. Is maximum at surface
   b. Is maximum at centre
   c. Is remain same throughout the conductor
   d. Is maximum somewhere between surface and centre

3. Electric potential of earth is taken to be zero because the earth is good:
   a. Semiconductor
   b. Conductor
   c. Insulator
   d. Dielectric

4. A proton is about 1840 time heavier than an electron. When it is accelerated by a potential difference if 1 kV, its kinetic energy will be:
   a. 1840 keV
   b. 1/1840 keV
   c. 1 keV
   d. 920 keV

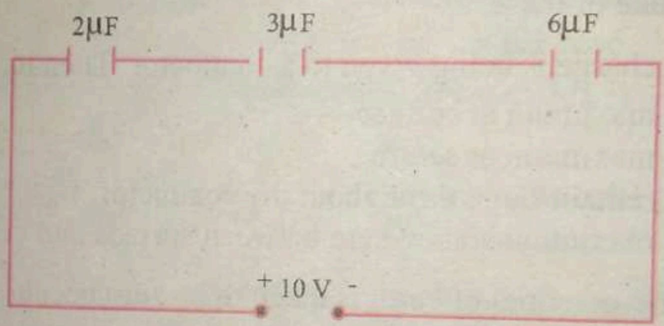
5. A capacitor is charged with a battery and then it is disconnected. A slab of dielectric is now inserted between the plates, then
   a. The charge in the plates reduces and potential difference increase
   b. Potential difference between the plates increase, stored energy decreases and charge remains the same

c. Potential difference between the plates decreases, stored energy decreases and charge remains unchanged
d. None of the above

6. A one microfarad capacitor of a TV is subjected to 4000 V potential difference. The energy stored in capacitor is
a. 8 j
b. 16 j
c. 4×10^{-3} j
d. 2×10^{-3} j

7. In the figure below, the charge on 3 μF capacitor is

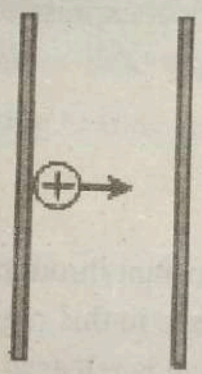
a. 5 μC
b. 10 μC
c. 3 μC
d. 6 μC



8. The electric potential between two points A and B is ΔV. The work done W by the field in moving a charge q from A to B is
a. $W = -q\ \Delta V$
b. $W = q\ \Delta V$
c. $W = -\Delta V/q$
d. $W = \Delta V/q$

9. The electric flux through the surface of a sphere due to a charge q placed at its centre depends upon
a. the radius of the sphere
b. the quantity of charge outside the sphere
c. the surface area of the sphere
d. the quantity of charge inside the sphere

10. Two parallel, metal plates are a distance 8.00 m apart. The electric field between the plates is uniform, directed toward the right, and has a magnitude of 4.00 N/C. If an ion of charge+2e is released at rest at the left-hand plate, what is its kinetic energy when it reaches the right-hand plate?
a. 4 eV.
b. 64 eV.
c. 32 eV.
d. 16 eV



Comprehensive questions

1. State and explain coulombs law. Do include the case when the charges are placed in dielectrics. Discuss how the unit of charge coulomb is defined?
2. Explain the concept of electric field and hence define electric field intensity. Discuss the direction as well as the unit of $\vec{E}$
3. Explain the concept of electric flux. Using mathematical expressions of electric flux to show that how electric flux is maximum and minimum.

4. State and prove the Gauss law for electrostatics. Also discuss its applications with daily life example.
5. Explain the concept of electric potential. Derive an expression for electric potential at a field point due to a source charge.
6. Describe the construction of capacitor and derive an expression for the energy stored in a capacitor.
7. Describe the concept of equipotential surfaces and derive an expression for electric field as a negative of potential gradient.
8. Explain the phenomenon of electric polarization. Discuss how the phenomenon of polarization account for the increase in capacitance of a capacitor when instead of air, dielectric is inserted between its plates?
9. Derive an expression for the capacitance of a parallel plate capacitor when a dielectric is inserted between the plates of a capacitor.
10. Describe the process of charging and discharging a capacitor. Give the diagram and mathematical expressions for the growth and decay of charge on the capacitor.

Conceptual questions

1. The electric potential is constant through a given region of space. Is the electric field zero or non-zero in this region? Explain.
2. If a point charge q of mass m is released in a non-uniform electric field with field lines pointing in the same direction, will it make a rectilinear motion?
3. What is the relationship between voltage and energy? More precisely, what is the relationship between potential difference and electric potential energy?
4. Voltages are always measured between two points. Why?
5. How are units of volts and electron volts related? How do they differ?
6. In what region of space is the potential due to a uniformly charged sphere the same as that of a point charge? In what region does it differ from that of a point charge?

7. Can the potential of a non-uniformly charged sphere be the same as that of a point charge? Explain.
8. What is an equipotential line and equipotential surface?
9. Can different equipotential lines cross each other ? Explain.
10. Water has a large dielectric constant, but it is rarely used in capacitors. Explain why?
11. A capacitor is connected in series with a resistor and charged. Explain why the potential difference across the resistor decreases with time during the charging.
12. Sketch the graphs of potential difference against time for (a) a discharging capacitor (b) a charging capacitor.
13. Compare the formula for capacitors in series and parallel with those for resistors in series and parallel. Explain why the pattern is different.
14. Explain why capacitors are of little use for storage of energy for normal domestic purposes of lighting heating and so on.

Numerical problems

1. What is the magnitude of the force of attraction between an iron nucleus bearing charge $q = 26e$ and its innermost electron, if the distance between them is 1×10^{-12} m. (6×10^{-3} N)
2. Charges 2 μC, -3 μC, and 4 μC are placed in air at the vertices of an equilateral triangle of sides 10 cm. what is the magnitude of resultant force acting on 4 μC charge?

(15.7N)

3. A charge q is placed at the centre of the line joining the two charges, each of magnitude Q. Prove that the system of three charges will be in equilibrium if $q = -Q/4$.

4. Two equal and opposite charges of magnitude 2×10^{-7} C are placed 15cm apart. What is the magnitude and direction of electric intensity (E) at a point mid-way between the charges? What force would act on a proton (charge = $+1.6\times10^{-19}$ C) placed there?

($.64\times10^{6}$ N/C along AB, 1.024×10^{-13} N along AB)

5. Two positive point charges of 15×10^{-10} C and 13×10^{-10}C are placed 12cm apart. Find the work done in bringing the two charges 4 cm closer. (7.31×10^{-8} J)

6. A hollow sphere is charged to 14μC. Find the potential (a) at its surface (b) inside the sphere (c) at a distance of 0.2m from the surface. The radius of the sphere is 0.3m.

(42×10^{4} V, 42×10^{4} V, 25.2×10^{4} V)

7. If 280 J of work is done in carrying a charge of 2C from a place where the potential is -12V to another place where potential is V, calculate the value of V. (128 V)

8. Calculate the electric potential at the surface of a silver nucleus having radius 3.4×10^{-14} m. The atomic number of silver is 47 and charge on a proton = 1.6×10^{-19}C. (1.99×10^{6} V)

9. The electric field at a point due to a point charge is 26 N/C and the electric potential at that point is 13 J/C. Calculate the distance of the point from the charge and magnitude of charge.

(0.5 m, 0.722×10^{-9} C)

10. Two point charges of 8μC and -4μC are separated by a distance of 10cm in air. At what point on the line joining the two charges is the electric potential zero?

(6.6 cm from 8 μC and, 3.3 cm from −4μ F charge)

11. An electron with an initial speed of $29\times10^5 ms^{-1}$ is fired in the same direction as a uniform electric field with a magnitude of 80 NC^{-1}. How far does the electron travel before being brought to rest momentarily and turned back?

(.299m)

12. Two capacitors of capacitance 4 μF and 8 μF are first connected (a) in series and then (b) in parallel. In each case external source of voltage is 200 V. Calculate in each case the total capacitance, the potential drop across each capacitor, and the charge on each capacitor.

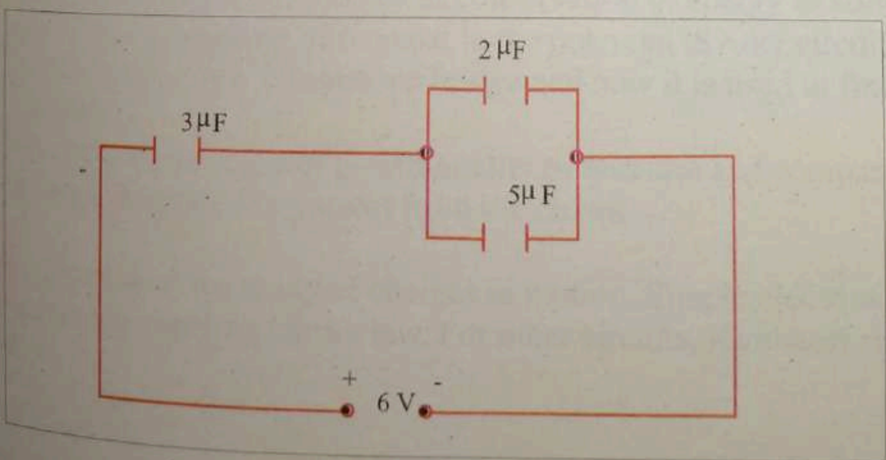
(2.66μF, 5.33×10^{-4}C, 133.2V, 66.6V, 12μF, 200V, .08μC, .16μC)

13. Three capacitors of capacitance 4μF, 6μF and 8μF respectively are connected in series to a 250V d.c. supply. Find (i) the total capacitance (ii) charge on each capacitor and (iii) P.D. across each capacitor.

(1.84 μ F, 460×10^{-6} C, 115 V, 76.6V and 57.7 V)

14. If C_1 = 14μF, C_2 = 20 μF, C_3 = 12μF and the insulated plate of C_1 be at potential of 100V, one plate of C_3 being earthed, what is the potential difference between the plates of C_2, three capacitors being connected in series? (24.4 μV)

15. Find the charge on 5μF capacitor in the circuit shown in Fig. .



(9 μ C)

16. Two parallel plate capacitors A and B having capacitance of 2 μF and 6 μF are charged separately to the same potential of 120V. Now positive plate of A is connected to the negative plate of B and the negative plate of A is connected to the positive of B. Find the final charge on each capacitor.

(120 μ C, 360 μ C)

17. A 6μF capacitor is charged to a P.D. of 120V and then connected to an un-charged 4 μF capacitor. Calculate the P.D. across the capacitors.

(72 V)

18. Two capacitor of capacitance 8μF and 10 μF respectively are connected in series across a P.D. of 180V. The capacitors are disconnected from the supply and are reconnected in parallel with each other. Calculate the new P.D. and charge on each capacitor.

(88.8 V, 710 μ C, 888 μ C)