SECTION-01 - BE-01

BASICS OF SCIENCE AND ENGINEERING

PHYSICS

1. Units and Measurements
2. Classical Mechanics
3. Electric Current
4. Heat and Thermometry
5. Weave Motion, Optics and Acoustics

CHEMISTRY

6. Chemical Reactions and Equations
7. Acids, Bases and Salts
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3. Electric Current

[1] Electric Charge :

You know that every substance is made up of atoms or molecules. Each atom is made up of electrons moving in fixed orbits around its nucleus. There are positively charged protons and neutral neutrons inside the nucleus. Thus, every substance is made up of electrons, protons and neutrons, called Fundamental Particles. Here, the mass of an electron is $M_e = 9.1 \times 10^{-31}$ kg, the mass of a proton and a neutron are considered to be nearly the same, i.e. $M_p \cong M_n = 1.6 \times 10^{-27}$ kg.

As you know about Newton's law of gravitation (Every particle/body in the universe attracts every other particle/body with a force whose magnitude is directly proportional to the product of their masses and inversely proportional to the square of the distance between them, $Fg = G\frac{m_1 m_2}{R^2}$. According to this, when two electrons are 1 cm apart, they exert a gravitational force of 5.5×10^{-67} N on each other. However, at the same distance, a repulsive force called electric force of $Fe = 2.24 \times 10^{-24}$ N exists between two electrons. Electric force is 10^{43} times greater than the gravitational force. Thus, electric force is very strong. Even when two protons are placed at a distance of (apart from each other) 1 cm, an electric repulsive force of an equal value exists. However, the electric force of attraction between a proton and an electron at a distance of 1 cm seems to be of equal value. Thus, just as mass is the main cause of gravitational force, the property of particles due to which an electric force exists between them is called the 'electric charge' of the particle. The force acting between two like charges is repulsive and it is attractive between two, unlike charges.

From the above discussion, it is clear that the magnitude of the charge on an electron and a proton is the same but they are of the opposite type. Conventionally charge of an electron is considered negative and that of a proton is positive. However, if the sign convention of electronic charge (on proton and electron) is changed, it makes no difference whatsoever to the field of science and technology! And, the value of this charge is $e = 1.6 \times 10^{-19}$ C. The SI unit of electric charge is coulomb, abbreviated as C.

Only electrons are transferred during any chemical process or when a charge is transferred. Thus, the substance which receives electrons becomes negatively charged and the substance which loses electrons becomes positively charged. In general, every object is neutral.

Since the charge on an electron is $e = 1.6 \times 10^{-19}$ C, the value of 1 Coulomb charge or number of electrons in 1 coulomb (1C) electric charge,

$$n = \frac{1}{e} = \frac{1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18} \text{ electrons} \quad \dots (1)$$

[2] Coulomb's Law :

French scientist Charles Coulomb conducted many experiments to find the force between two electric charges and deduced that "The electric force (Couloumbian force) between two stationary point charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between them." This is Coulomb's law. This force is along the line of joining the two charges.

Let two stationary point charges q_1 and q_2 are separated by a distance r. The coulombian electric force between them,

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

$$\therefore \quad F = k\frac{q_1 q_2}{r^2} \quad \dots (2)$$

When there is vacuum or air medium between the charges, the electric force constant or coulomb's constant $k = 8.9875 \times 10^9 \approx 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$ in SI system. In CGS system, $k = 1$ dyne cm C^2.

Coulomb's law is a basic law of nature. This is true only for static point (electric) charges. However, this rule can also be applied to large charged objects, if the distance between them is much larger than their size.

Here, Coulomb's constant, $k = \left(\frac{1}{4\pi\varepsilon_0}\right) \quad \dots (3)$

Where, Permittivity of Free Space,

$$\varepsilon_0 = \left(\frac{1}{4\pi k}\right) = 8.854 \times 10^{-12}\ C^2/Nm^2.$$

Here, Permittivity is the resistance of the medium that impedes the electric field of the charge. If the Columbian force between two charges in a given medium is F_m then,

In a vacuum, $$F = \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{q_1q_2}{r^2}\right) \quad ...(4)$$

In the medium, $$F_m = \left(\frac{1}{4\pi\varepsilon}\right)\left(\frac{q_1q_2}{r^2}\right) \quad ...(5)$$

$$\therefore \frac{F}{F_m} = \frac{\left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{q_1q_2}{r^2}\right)}{\left(\frac{1}{4\pi\varepsilon}\right)\left(\frac{q_1q_2}{r^2}\right)} = \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r = K \quad ...(6)$$

Where, ε_r = Relative Permittivity of medium or dielectric constant (K).

$$\varepsilon_r = \frac{\text{Permittivity of medium } (\varepsilon)}{\text{Permittivity of Free Space or Vacuum } (\varepsilon_0)} = K$$

Since the relative permeability of the medium (ε_r), is always greater than one, the Columbian force (F_m) in a given medium is less than the force exerted in a vacuum (F). Thus, $\varepsilon_r > 1 \Rightarrow F_m < F$.

Example-1 : Calculate the total electric charge on an object that has 20 extra electrons.

Solution :

Number of electrons, $n = 20$,

Charge of an electrone $e = -1.6 \times 10^{-19}C$

The total electrical charge of 20 electrons

$q = ne = (20)(-1.6 \times 10^{-19}) = -3.2 \times 10^{-18}C$

Example-2 : An object emits 10^9 electrons per second. So how long will it take to emit 1 C charge ?

Solution :

Number of electrons, $n = 10^9$ electron/second

Charge of an electron

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

$q = ne = (10^9)(1.6 \times 10^{-19}) = 1.6 \times 10^{-10}$ C/s

Electric charge produced per second $= 1.6 \times 10^{-10}$ C

Time required to produce 1C charge

$$t = \frac{1}{1.6 \times 10^{-10}} = 6.25 \times 10^9 \text{ s}$$

$$= \frac{6.25 \times 10^9 \text{ s}}{3.154 \times 10^7} = 198.16 \text{ years}$$

Example-3 : The electric force between two positive ions of equal magnitude at a distance of 5Å from each other is 3.7×10^{-9} N. How many electrons would have been removed from each atom ?

Solution :

Force, $F = 3.7 \times 10^{-9}$ N

Distance, $r = 5\ A^o = 5 \times 10^{-10}$ m

No. of electrons, $n = ?$

Coulombian constant,

$k = 8.8975 \times 10^9\ Nm^2C^{-2}$

Charge of an electron,

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

Let $q_1 = q_2 = Q$

Electric force, $$F = k\frac{q_1q_2}{r^2} = k\frac{Q^2}{r^2} \Rightarrow \therefore Q = r\sqrt{F/k}$$

$$Q = (5 \times 10^{-10})\sqrt{\frac{3.7 \times 10^{-9}}{8.8975 \times 10^9}}$$

$$\therefore Q = (5 \times 10^{-10})(0.6449 \times 10^{-9}) = 3.22 \times 10^{-19}C$$

No. of electrons,

$$n = \frac{Q}{e} = \frac{3.22 \times 10^{-19}\,C}{1.6 \times 10^{-19}} = 2.01 \approx 2 \text{ electrons}$$

Example- 5 : Find the ratio of gravitational force to electrostatic force between the protons in the nucleus of an atom and the electrons revolving around it in an orbit of average r radius. Mass of a proton and an electron are $m_p = 1.67 \times 10^{-27}$ kg and $m_e = 9.11 \times 10^{-31}$ kg respectively. The fundamental charge of proton and electron is 1.6×10^{-19} C. Gravitational constant $G = 6.67 \times 10^{-11}\ Nm^2/kg^{-2}$ and Coulombian constant $k = 8.9875 \times 10^9\ Nm^2 C^{-2}$.

Solution :

Between proton and electron, the Gravitational force is $F_G = G\frac{m_e m_p}{r^2}$ and Electrostatic force is $F_e = k\frac{q_e q_p}{r^2}$.

Their ratio is $\frac{F_e}{F_G} = \frac{kq_eq_p/r^2}{Gm_em_p/r^2} = \frac{kq_eq_p}{Gm_em_p} = \frac{kq_eq_p}{Gm_em_p}$

$$= \frac{(8.8975 \times 10^9)(1.6 \times 10^{-19})^2}{(6.67 \times 10^{-11})(9.11 \times 10^{-31})(1.67 \times 10^{-27})} = \frac{8.8975 \times 1.6 \times 1.6}{6.67 \times 9.11 \times 1.67} \times 10^{9-38+11+31+27}$$

$$= \frac{22.7776}{101.4754} \times 10^{40} = 0.2245 \times 10^{40} = 2.245 \times 10^{39}$$

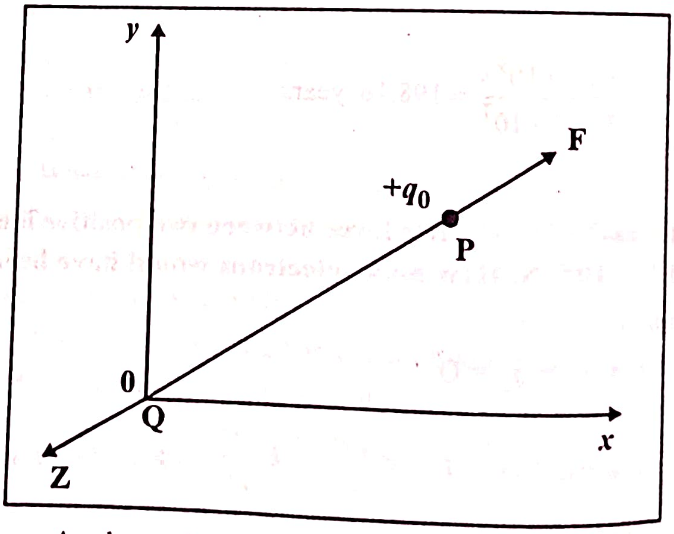
This shows that electrostatic forces are $\sim 2.25 \times 10^{39}$ times higher than gravitational forces.

[3] Electric Field :

Coulomb's law determines the electric force acting between (two electrically) charged objects. However, if the number of charged objects (or electric charges) is large and the charge on each is different then this calculation becomes very complex and tedious.

Suppose a charge (or set of charges) Q is at a certain point in space. The test charge q_0, placed at r distance, will experience electric force according to coulomb's law. What remains there around Q if q_0 is removed ? One can smell the blooming flowers when a garden is nearby. One feels heat up to a certain distance around the fire. So, everything shows their effect in the nearest area. Similarly, Electric charge also produces its own effect in its immediate vicinity in space. This effect is felt more near the charge and gradually reduced with distance. Thus the electric field depends only on the distance from a given charge. This effect of an electric charge felt in the vicinity of space is called the (intensity of) electric field. The SI unit of (intensity of) electric field is newton/coulomb (N/C). The calculation of the force between electric charges has become quite easy due to electric field concept.

[4] Electric Field (Intensity) of a Point Charge :



As shown in **Figure** let a point electric charge Q be placed at the origin O of the axes. Now a positive test charge $+q_0$ is placed at the point P at a distance r in the vicinity of it. Charge Q will exert a repulsive force on it in the direction of O to P. Position of Q should not be changed due to q_0. Test charge experiences an electric force that depends only upon the electric field (intensity) of Q at the r distance away from it. The test charge q_0 is very small ($q_0 \to 0$), the otherwise electric field of q_0 may react with that of Q. Therefore we cannot find electric field of charge Q. Also note that q_0 cannot be less than the elementary charge of an electron (or proton) (= 1.6×10^{-19} C). Thus, by placing a positive charge q_0 at point P at a distance r from Q, it experiences an electric force in the electric field of Q. This is simply called the electric field of Q.

$$\text{Electric field, } E = \frac{F}{q_0} \quad \text{.... (1)}$$

The SI unit of an electric field is newton/coulomb (N/C). At a given point, if the test charge does not experience electric force, then the electric field of the charge somewhere near that point can be said to be zero.

In equation (9), F is the electrical force acting between Q and q_0

$$E = \frac{kQ}{r^2} = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{Q}{r^2} \quad \text{... (2)}$$

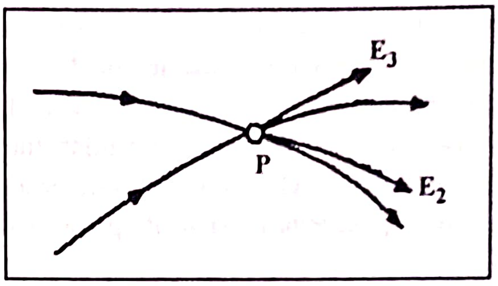
Where r distance is the distance between charge Q and point P where the electric field is to be measured.

It was Faraday who first conceptualized the electric field. The charge (or a set of charges) that produces an electric field is called the source charge and the charge used to measure the electric field is called the test charge. Taking $q_0 = 1$ C in equation (10), E = F occurs. From this, the electric field can be defined as follows.

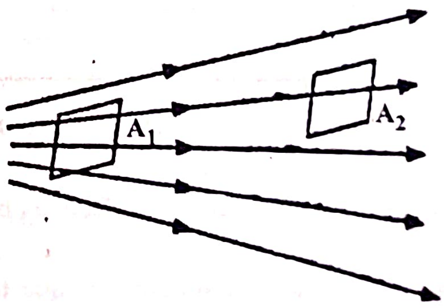
The force experienced by a unit positive charge at a distance r from a charge Q (or a system of charges) is called electric field (or electric field intensity) E at that point.

- **Characteristics of Electric Field Lines :**

1. Electric field lines start from positive charges and end at negative charges.
2 The tangent drawn at any point on the electric field lines indicates the direction of the electric field at that point.
3. Two electric field lines never cross (intersect) each other. As shown in **Figure,** if two electric field lines intersect each other at any point, then $+q$ charge at that point experiences the force in both $\vec{E_1}$ and $\vec{E_2}$ directions, which is not possible. i.e. at the intersection point of two electric field lines, two tangents can be drawn which indicate two directions of electric field and this is impossible.



4. The distance between the electric field lines indicates the intensity of the electric field in that area. The closely (Densely) arranged electric field lines indicates a strong (high) electric field (intensity) and vice versa. Spaciously arranged (scattered) electric field lines indicates weak (poor) electric field (intensity) and vice versa. As per **Figure,** the number of electric field lines passing through a plane A_1 is higher than those through a plane A_2. Therefore, (the intensity of) the electric field is higher in A_1 than that in A_2.



Intensity of electric field

5. Electric field lines of the uniform electric field are mutually parallel and equidistant.
6. Electric field lines are imaginary, but electric field is reality.
7. Electric Field lines are always perpendicular to the conducting surface– in both cases, leaving

the electric charge or entering the electric charge. This is the reason why the electric field in the direction parallel to the conducting surface is zero. That is, electric force does not exist parallel to the conducting surface.

8. Electric field lines do not form closed paths.

[5] Electric Flux :

Flux is the amount of matter passing through (perpendicular to) the surface. When a rectangular frame of wire is kept perpendicular to the flow of water, the amount of water passing through it is called the 'flux' of water associated with that rectangular frame. When a simple paper–fan (flickering) rotates in the air, the amount of air passing perpendicular to its plane is called the air flux.

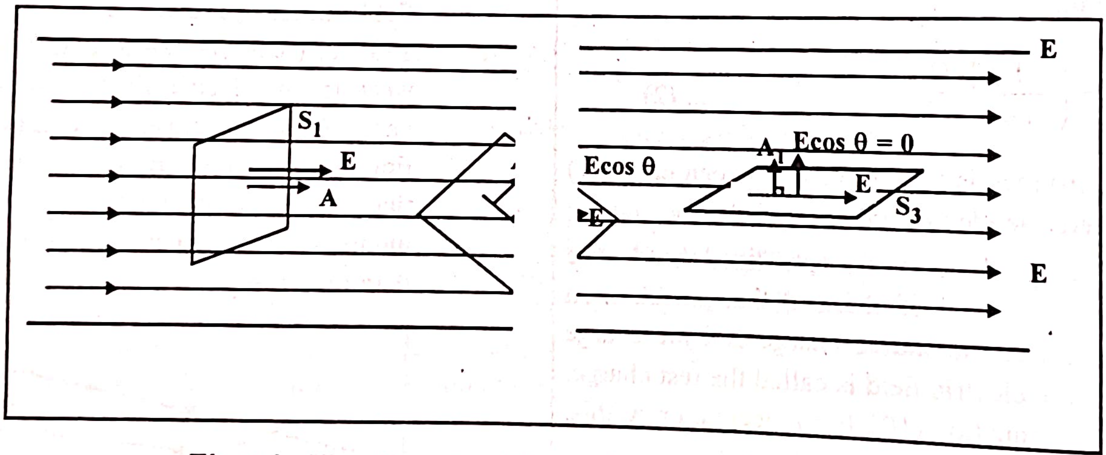
As we have discussed earlier, the number of electric field lines passing through a given area determines whether the intensity of the electric field in that area is high or low. The concept of electric flux is based on the same principle. Figure shows the electric field lines and the different surfaces (whose surface area is A). The electric flux is a quantity equal to the number of electric field lines passing through (perpendicular to) a given surface area. An electric field is the number of field lines passing perpendicular to the surface of a unit area. So the number of field lines having an area A is equal to EA.

Thus, electric flux passing perpendicular to surface of area A

$$\varphi = \vec{E} \cdot \vec{A} \qquad \text{.... (3)}$$

$$\therefore \ \varphi = EA \cos \theta \qquad \text{.... (4)}$$

Let a surface S_2 is kept slanting to electric field as shown in **Figure.** The electric flux passing perpendicular to S_2 is $\varphi = EA \ \cos\theta$ where θ is the angle formed between the electric field $\vec{E}$ and the surface $\vec{S}$. Actually, angle θ is formed between the normal to the surface and the electric field E.



Electric Flux Passing Through Different Surfaces

Consider the third single surface S_3 placed in the direction parallel to the electric field $\vec{E}$ in **Figure.** Here, the angle between the direction perpendicular to S_3 and $\vec{E}$ is = 90° so the electric flux associated with the surface is,

$$\varphi = EA \cos\theta = EA \cos 90^\circ = EA(0) = 0$$

Similarly, the angle between the direction perpendicular to S_1 and $\vec{E}$ is = 0° so the electric flux associated with S_1 is,

$$\varphi = EA \cos\theta = EA \cos 0^\circ = EA\,(1) = EA$$

This is denoted by Equation (13). Thus, placing any surface in an electric field, if the angle between the normal to the surface and the electric field is θ, then the flux (i.e. the number of suspended electric lines from that surface) associated with that surface, can be equated to $\phi = EA \cos\theta$. Electrical flux is a scalar quantity and its SI unit is V_m or Nm^2/C.

· If the flux associated with a surface is zero means the number of electric field lines passing through that surface is zero, i.e. the electric field line does not pass through that surface.

When a rectangular wire–frame is kept slanting in the water flow, the water flowing through it is less than the same frame is kept perpendicular in the water flow. Because when the frame is kept parallel to the water flow, no water passes through it. Similarly, when a paper–fan is kept perpendicular to (in front of flowing) wind/air flow, it rotates fast. When it is tilted it slowed down, and when it is in the direction of the wind, it almost stops rotating. Thus, the concept of flux is very useful for understanding many laws and their applications in electronics.

[6] Electric Potential :

As discussed above, the work done by and in the electric field in moving a unit positive charge (+ 1C) from one point to other, depends only on the location (position) of these two points, but not on the path connecting them. Now suppose if we displace (move) a unit positive charge first from point A to B, then from point A to C, then from A to D ...etc. in the electric field, then the work done by the electric field will be obtained as...

$W_{AB} = Er_{AB} \qquad W_{AC} = Er_{AC}$

$W_{AD} = Er_{AD}$ ... etc.

Here if point A is taken as a reference point then the above–mentioned work depends on the location (position) of that point (B, C, D, ...) only. For the sake of simplicity, taking such a reference point at infinite distances from the source of the electric field, is the work required to bring the unit positive electric charge from that point to a point in the field is given by,

$W_{\infty B} = Er_B$

If the electric charge is shifted in the opposite direction to the electric force, the work done upon it is,

$W'_{\infty B} = Er_B$

Such a position–based work is called "electric potential" at that point. **"Work required to be done against the electric field in bringing a unit positive charge from infinity to the given point in the electric field of a charge (or of a group of charges) is called electric potential at that point."**

Electric potential is denoted by V. Thus, the electric potential at a point A

$$V_E = -E \cdot r$$

$$\therefore \quad V_A = -k\frac{Q}{r^2} \cdot r$$

$$\therefore \quad V_A = -k\frac{Q}{r}$$

$$\therefore \quad \text{Electric potential} = \frac{\text{The work done on charge}}{\text{Electric charge}}$$

$$\therefore \quad V_A = -\frac{W}{q_0}$$

The unit of Electric potential :

$$V_A = \frac{\text{Joule (J)}}{\text{Coulomb (c)}} = \text{Volt (V)}$$

One thing to keep in mind is that the potential at point A is not important. But only the potential difference (PD) between the given points A and B matters, which are as follows.

$$V_B - V_A = -k\frac{Q}{r_{AB}} = -\frac{W_{AB}}{q_0}$$

When two charged objects are brought into contact with each other, the charge will be transmitted from one object at higher potential to another object at lower potential. This conduction will take place until the potentials of the two objects are equal.

As stated earlier, a point is taken as a reference. The potentials of the rest of the points are calculated by taking the potential of the earth's surface to be zero.

[7] Capacitance :

As the positive charge (+Q) on the surface of an isolated conductive sphere is gradually increased, the electric potential (V) on the surface of the sphere and the electric field (E) around the sphere also go on increasing accordingly. In this process, at one stage, the sphere becomes electrically saturated, means the sphere can no longer store more electricity than its capacity. So, the electric field due to the sphere becomes sufficiently strong that it can ionize the surrounding air particles that the insulating property of the air gets destroyed. Because, at this point, an electric charge in addition to its capacity leaks from the sphere and causes ionization (separation of atomic positive and negative electric charges) of the surrounding air. Throughout this process, the ratio (Q/V) of the electric charge (Q) on the sphere and its magnitude (V) remains constant. This ratio is called its capacitance (C). Here, conductors of any shape can be taken instead of spheres.

$$\text{Capacitance (C)} = \frac{\text{Electric charge (Q)}}{\text{Electroc Potential (V)}}$$

$\therefore C = Q/V$

Potential Difference (pd) arises between two conductors when they are placed at a short distance apart from each other and same magnitude (Q coulomb) of opposite charge (one is positively charged and another is negatively charged) is stored upon them. Here, the ratio of electric charge (Q coulomb) and potential difference (V volt) between the two identical but oppositely charged conductive plates kept at a very small distance apart is called capacitance of the system made up of these conductors. The magnitude of capacitance depends on the dimensions of the two conductors, their relative arrangement, the dielectric medium between them and the distance between the two.

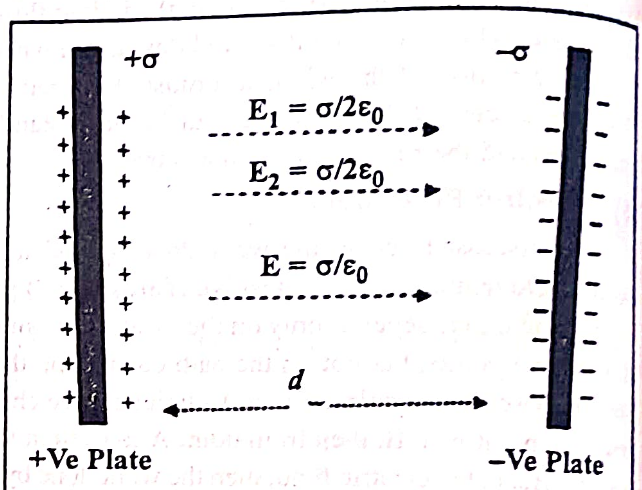
[8] Types of Capacitors [Only for Information] :

There are different types of capacitors depending on the material used in their fabrication. Such as : Electrolytic Capacitor, Mica Capacitor, Paper Capacitor, Film Capacitor, Non–Polarized Capacitor and Ceramic Capacitor. An Electrolytic capacitor uses a thin metallic film as anode and a paste of electrolyte chemical as a cathode, where the thin layer of oxide is dielectric. A mica capacitor is made by sandwiching a thin mica sheet between the conductor plates. A Paper capacitor is made by placing a waxpaper between tin plates. A film capacitor is made by placing a plastic film between a thin films of conductive metal. A non–polarized capacitor is made by placing plastic foil in it or two electrolytic capacitors are arranged in series connection. Ceramic capacitors contain ceramic dielectric material.

The types of capacitors depending on the shape of the conductive plate used in it are : In a Parallel–Plate Capacitor, the flat conductor plates are kept parallel to each other. A capacitor in which the conductive plates are spherical is called a spherical capacitor. In the cylindrical capacitor, the cylindrical conductor plates are used.

[9] Parallel Plate Capacitor and Its Capacitance :

Parallel plate capacitors are the most widely used. In a parallel plate capacitor, two parallel conducting plates of the same area (A) are separated at very short distance (d) from each other where a dielectric medium (insulating material) is placed between the two plates. Here the distance between two plates is kept very short in comparison to the dimensions (length, width or radius) of that plate (d^2 << A).



A Parallel Plate Capacitor

Let us derive the formula for the capacitance of a parallel plate capacitor with vacuum or as a dielectric medium, as shown in **Figure.** The charge of one plate is + Q and that of the other is – Q. The distance between two plates (d) is too short for their linear length so that $d^2 << A$.

Area of capacitor = A M^2

Distance between two plates of the capacitor = d metre

Capacitor plate charge = Q coulomb

Charge density = σ = Q/A coulomb/metre^2

The uniform electric field in the region between two plates due to positive plate in the direction from positive plate to the negative plate is $E_1 = \sigma/2\varepsilon_0$.

The uniform electric field in the region between two plates due to negtive plate in the direction from positive plate to the negative plate is $E_2 = \sigma/2\,\varepsilon_0$.

Since both the electric fields are in the same direction, the resultant uniform electric field

$$E = E_1 + E_2$$

$$\therefore \quad E = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0}$$

$$\therefore \quad E = \frac{(Q/A)}{\varepsilon_0} + \frac{Q}{A\varepsilon_0}$$

In the regions on the other side of the capacitor plates, electric fields E_1 and E_2 being equal and in opposite direction, the resultant electric field becomes zero.

$$\therefore \quad E = E_1 - E_2 = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = 0$$

The potential difference between the two plates is, V = E.d

$$\therefore \quad V = \frac{Qd}{A\varepsilon_0}$$

Now, the capacitance of the capacitor is $C = \frac{Q}{V}$

$$\therefore \quad C = \frac{Q}{\left(\frac{Qd}{A\varepsilon_0}\right)}$$

$$\therefore \quad C = \frac{A\varepsilon_0}{d}$$

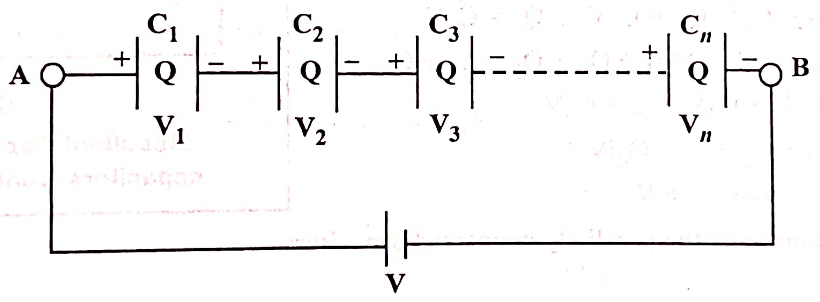
The capacitance of a parallel plate capacitor depends on the plate area dielectric meduim and the distance between two plates.

- **Combinations of Capacitors :**

There are two types of connections of different capacitors having capacitances. Two or more capacitors can be connected in series combination or parallel combination. Equivalent, effective or resultant capacitance (C) of a system formed by series combination or parallel combination of two or more capacitors can be found.

[10] Series Combination of Capacitors :

As shown in Figure, capacitors having capacitances $C_1, C_2, C_3, C_4, \ldots C_n$ are connected in series by conducting wires and potential difference V is given to the system. We intend to obtain the resultant capacitance C_s in the series combination of capacitors.



Resultant Capacitance of the Capacitors Connected in Series

Let the left side plate of capacitor C_1 is given a + Q charge. Electrostatic induction gives a – Q charge on the inside and + Q charge on the outside of the right side plate of capacitor C_1. This + Q electric charge is transmitted to the plate on the left. And this process continues. (In the same way a negatively charged electron–current flows in the opposite direction.) Thus, each capacitor will receive an equal charge of + Q magnitude. Since the capacitance of each capacitor is different, the potential difference with respect to each capacitor is different. If potential difference across $C_1, C_2, C_3, \ldots, C_n$ are $V_1, V_2, V_3, \ldots V_n$ respectively. Then $V_1 = Q/C_1$, $V_2 = Q/C_2$, $V_3 = Q/C_3$.....

In series combination of capacitors, the net (effective) potential difference (V) is the sum total of individual potential difference across each capacitor.

$$\therefore \quad V = V_1 + V_2 + V_3 + \ldots + V_n$$

The resultant capacitance in the series combination of capacitors is $C_s = \frac{Q}{V}$

$$\therefore \frac{Q}{C_s} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} + ... + \frac{Q}{C_n} = Q\left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_n}\right]$$

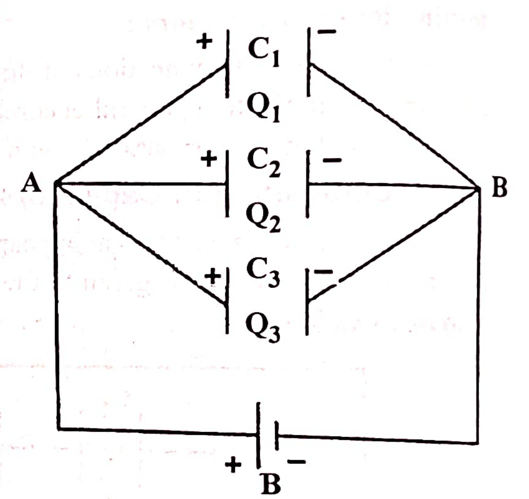
$$\therefore \frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_n}$$

$$\therefore \frac{1}{C_s} = \sum_{i=1}^{n} \frac{1}{C_i}$$

The value of the effective (net or equivalent) capacitance C_s of the series connection of capacitors is obtained by summing the multiplicative inverse of the capacitance values of each of the capacitors. The value of effective capacitance in series connection is even smaller than the smallest value of capacitance in the combination.

[11] Parallel Combination of Capacitors :

As shown in **Figure** capacitors having capacitances $C_1, C_2, C_3, C_4, ..., C_n$ are connected parallel to eachother by conducting wires and potential difference V is given to the two common joining points of all capacitors. We intend to obtain the resultant capacitance C_p in the parallel combination of capacitors. In parallel combination of capacitors, the potential difference (V) between the plates of every capacitor is the same and it is equal to the potential difference between their common points, however the electric charge on each capacitor is different.



Resultant Capacitance of the capacitors Connected in Series

Here, $Q_1 = C_1V, Q_2 = C_2V, Q_3 = C_3V, ... Q_n = C_nV$

The total electric charge $Q_p = Q_1 + Q_2 + Q_3 + ... + Q_n$

$$\therefore \quad Q_p = C_1V + C_2V + C_3V + ... + C_nV$$

$$= [C_1 + C_2 + C_3 + ... + C_n]V$$

$$\therefore \quad V = V_1 + V_2 + V_3 + ... + V_n$$

The effective capacitance of the parallelly connected capacitors

$$C_p = \frac{Q}{V} = C_1 + C_2 + C_3 + ... + C_n$$

$$\therefore \quad C_p = \sum_{i=1}^{n} C_i$$

The value of the effective (net or equivalent) capacitance C_p of the parallel connection of capacitors is obtained by summing the capacitance each of these capacitors. The value of effective capacitance is even higher than the largest value of capacitance in the combination.

In a series or parallel connection capacitor, the electric current is generated only where the battery is connected to the capacitor plate. In the rest of the plates, only the shifting of the charge occurs.

Example-1 : Calculate the capacitance of a parallel plate capacitor if 1 mm distance is kept between the plates of 1 mm sides.

Solution :

Side = Length = Width =1 mm = 10^{-3} m

Area of each plate, A = $1 mm^2 = 10^{-6} m^2$

Distance between two plates, d = 1 mm = 10^{-3} m

Absolute permittivity, $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m

Capacitance of a parallel plate capacitor,

$$C = \frac{\varepsilon_0 A}{d}$$

$$= \frac{8.85 \times 10^{-12} \times 10^{-6}}{10^{-3}}$$

$$= 8.85 \times 10^{-9} F = 8.85 nF$$

Example-2 : What should be the length and width of two parallel plates separated by a distance of 1 mm in a capacitor to obtain 1 F capacitance ?

Solution :

Distance between two plates, d = 1 mm = 10^{-3} m

Absolute Permittivity, $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m

Length = Width = Side of the plate = ?

Area of each plate in the parallel plate capacitor,

$$A = \frac{C_d}{\varepsilon_0} = \frac{1 \times 10^{-3}}{8.85 \times 10^{-12}} = 1.13 \times 10^8 m^2$$

Length = Width = Side of the capacitor

$$l = \sqrt{A} = \sqrt{1.13 \times 10^8} \approx 1.06 \times 10^4 m$$

Each plate should have atleast 10 km sides.

Example-3 : Calculate the capacitance of two plates of 100 cm × 100 cm of a parallel plate capacitor separated by a 2 mm thick glass plate of dielectric constant, K = 4.

Solution :

Area of each capacitor plate

A = 100 × 100 = $10^4 cm^2 = 1 m^2$

Distance btween two plates,

d = 2 mm = 2×10^{-3} m

Dielectric constant, $K = \varepsilon_r = 4$

Absolute permittivity,

$\varepsilon_0 = 8.85 \times 10^{-12}$ F/m

Capacitance due to medium of dielectric consant K is given by,

$$C = \frac{K\varepsilon_0 A}{d}$$

$$\therefore C = \frac{4 \times 8.85 \times 10^{-12} \times 1}{2 \times 10^{-3}} = 1.77 \times 10^{-8} \text{ farad}$$

Example-4 : Obtain equivalent capacitance for series and parallel combination of 3 capacitors having capacitances 5 μF, 10 μF and 15 μF respectively, where a potential difference of 4 V is given by the battery.

Solution :

Equivalent capcacitance for the series combination $\frac{1}{C_s} = \sum_{i=1}^{n} \frac{1}{C_i}$

$$\frac{1}{C_s} = \frac{1}{5} + \frac{1}{10} + \frac{1}{15} = \frac{6+3+2}{30} = \frac{11}{30}$$

$C_s = 30/11 = 2.72$ μF

Equivalent capcacitance for the parallel combination,

$$C_p = \sum_{i=1}^{n} \frac{1}{C_i}$$

$$C_p = C_1 + C_2 + C_3$$

$$C_p = 5 + 10 + 15 = 30 \mu F$$

Multiple Choise Questions (MCQs)

1. If the distance between two charges is doubled then the force between them becomes...
(A) 1/4th (B) Double
(C) Half (D) Four times

Ans. : (A)

2. The SI unit of electric permittivity is....
(A) Nm^2/C^2 (B) A/m
(C) Nm^2/C (D) C^2/Nm^2

Ans. : (D)

3. The SI unit of electric field is......
(A) C/m (B) A/m
(C) C/m^2 (D) N/C

Ans. : (D)

4. If a force of 2.25 N is applied to a charge, the intensity of the electric field at that point is .....
(A) 1500 N/C (B) 15000 N/C
(C) 200 N/C (D) 150 N/C

Ans. : (A)

5. Electric field lines are ....
(A) Imaginary
(B) omnipresent
(C) found near charge only
(D) exist only when positive and negative charges come closer.

Ans. : (A)

6. The potential difference between two point is .... when a 5 C charge is displaced by 0.5 m, and the work done on it is 10 J.
(A) 25 V (B) 0.25 V
(C) 2 V (D) 1 V

Ans. : (A)

7. An object receives ....C charge when 10^8 electrons are placed on it.
(A) -1.6×10^{-11} (B) -1.6×10^{-19}
(C) 1.6×10^{-11} (D) 1.6×10^{-19}

Ans. : (A)

8. When the electric charges of two point charges are doubled, the electric force between them will be ....
(A) double (B) half
(C) qudruple (D) zero

Ans. : (C)

9. The SI unit of electric flux is ....
(A) Vm (B) Nm^2/C
(C) (A) and (B) both (D) None

Ans. : (C)

10. The fundamental electric charge, e = ... C
(A) 1.6×10^{19} (B) 1.6×10^{-31}
(C) 1.6×10^{-9} (D) 1.6×10^{-19}

Ans. : (D)

11. One coulomb charge = ... electrons.
(A) 6.25×10^{28} (B) 0.625×10^{18}
(C) 6.25×10^{18} (D) 62.5×10^{18}

Ans. : (C)

12. The electric force acting between two point charges is directly proportional to the ...... of their charges and the inversely proportional to the.......... of the distance between them.
(A) addition, difference (B) product, square
(C) difference, square (D) ratio, sqare

Ans. : (B)

13. Coulomb constant, k = ...
(A) $1/4\pi\varepsilon_0$ (B) $\sqrt{\dfrac{1}{4\pi\varepsilon_0}}$
(C) $\left(\dfrac{1}{4\pi\varepsilon_0}\right)^2$ (D) $4\pi\varepsilon_0$

Ans. : (A)

14. If an object has an extra 10^{10} electrons, what is the total number of coulomb charges on it ?
(A) -1.6×10^{-19}C (B) -1.6×10^{-9}C
(C) 1.6×10^{19}C (D) 1.6×10^{-9}C

Ans. : (A)

15. How long will an object take to emit 1 C charge if it emits 10^{10} electrons per second ?
(A) 6.52×10^8s (B) 6.25×10^8s
(C) 0.625×10^8s (D) 62.5×10^8s

Ans. : (B)

16. A tangent drawn at any point on an electric field line, indicates the direction of ....at that point.
(A) magnetic field
(B) electromagnetic forces
(C) electric current
(D) electric field
Ans. : (D)

17. Electric flux, (φ) = ...
(A) $\vec{E}\,\vec{A}$ (B) EA cos θ
(C) (A) and (B) both (D) None
Ans. : (C)

18. The SI unit of electric potential is ....
(A) J/C (B) Volt
(C) (A) and (B) both (D) None
Ans. : (C)

19. Absolute permittivity or permittivity of free space is, ε_0 = ... × 10^{-12} and its unit is............
(A) 8.854; C^2/Nm^2 (B) 8.854; F/m
(C) 8.854; Nm^2/C^2 (D) (A) and (B) both
Ans. : (D)

20. A glass rod when rubbed with silk cloth, caries an electric charge of 8×10^{-12} C. In this process, ... electrons have been .... by the glass rod.
(A) 5×10^{-7}, received (B) 5×10^{7}, lost
(C) 2×10^{-8}, lost (D) -8×10^{-12}, lost
Ans. : (B)

21. The electric field (intensity) of a point at a distance of 2 m from a point charge is 400 V/m. At what distance will this intensity becomes 100 V/m ?
(A) 50 cm (B) 4 cm
(C) 4 m (D) 1.5 m
Ans. : (C)

22. Two point charges + 4Q and + Q are kept 30 cm apart. At what point does the electric field intensity, on the straight line joining them, becomes zero ?
(A) 25 cm from charge Q
(B) 7.5 cm from charge Q
(C) 15 cm from charge Q
(D) 5 cm from charge Q
Ans. : (C)

23. The charge density of two oppositely charged and parallel plane conductor plates is σ. The electric field intensity outside them will be ....
(A) 0 (B) $+\sigma / 2\varepsilon_0$
(C) $-\sigma/2\varepsilon_0$ (D) σ/ε_0
Ans. : (A)

24. The electric field intensity E at the distance d from an electric charge will be...................
(A) k^2q^2/r^2 (B) kq/r^2
(C) K^2q^2/r^2 (D) Kq/r^2
Ans. : (B)

25. An electric field is a......... quantity, and its SI unit is ....
(A) Vector , N/C (B) Scalar, N/C
(C) Scalara, C/N (D) Vector, N/C^2
Ans. : (A)

26. The number of electric field lines passing .... through a given surface is known as electric ....
(A) parallel, flux
(B) perpendicular, density
(C) perpendicular, flux
(D) perpendicular, density
Ans. : (C)

27. An electric flux is a .... quantity having SI unit .... or ....
(A) scalar , V/m, Nm^2C^{-1}
(B) vector, Vm, Nm^2C^{-2}
(C) vector, V/m, $Nm^{-2}C^{-1}$
(D) scalar, Vm, Nm^2C^{-1}
Ans. : (D)

28. Electric flux, φ = ... = ...
(A) $\vec{E}\,\vec{A}$, EA sin θ (B) $\vec{E}\,\vec{A}$, EA cos θ
(C) $\vec{E}\,\vec{B}$, EB cos θ (D) None
Ans. : (B)

29. If two capacitor plates of length *l*, width *b* and thickness *t* and area A are separated by distance *d*, then ....
(A) $d > l$ and $d > b$ (B) $d = 1$ and $d = b$
(C) $d^2 >> A$ (D) $A >> d^2$
Ans. : (D)

30. The unit of capacitance is ...., it is also called ....

(A) Q/C, F (B) C/V, °F
(C) Q/V, F (D) C, F

Ans. : (C)

31. The law, governing the force between electric charges is known as ....

(A) Ampere's law (B) Ohm's law
(C) Faraday's law (D) Coulomb's law

Ans. : (D)

32. The capacitance of a capacitor..............if an insulating dielectric material is placed between two plates of it.

(A) decreases (B) increases
(C) does not change (D) becomes zero

Ans. : (B)

33. The effective capacitance C_p of the parallel combination of capacitors is obtained by summing the capacitance each of these capacitors.

(A) summing multiplicative inverse
(B) summing squares of
(C) taking product
(D) summing

Ans. : (D)

34. The effective capacitance of the series connection of capacitors is obtained by .... of each individual capacitor.

(A) summing multiplicative inverse
(B) summing squares of
(C) taking product
(D) summing

Ans. : (A)

35. The capacitance of a parallel plate capacitor is 5 μF. Its capacitance is 60 μF if a dielectric object is placed between its two plates. Obtain the dielectric constant (K) of the material.

(A) 12 (B) 120
(C) 1200 (D) 1.2

Ans. : (A)

36. When a slab with K = 3 dielectric constant is placed between two plates of a capacitor, its capacitance is 15 μF. If there is air between the plates of this capacitor, what will be its capacity ?

(A) 5 pF (B) 5 nF
(C) 5 μF (D) 5 F

Ans. : (C)

37. The force exerted by one plate on another plate in a parallel plate capacitor is given by F =....

(A) $\frac{2CV^2}{d}$ (B) $\frac{CV^2}{2d}$
(C) $\frac{C^2V^2}{2d}$ (D) $\frac{CV}{2d}$

Ans. : (B)

38. Calculate the electric flux passing through a square of 100 cm^2 area that is kept perpendicular to an electric field of 100 N/C at some point in space.

(A) 1 $Nm^{-2}C^{-1}$ (B) 0.1 Nm^2C^{-1}
(C) 10 Nm^2C^{-1} (D) 1 Nm^2C^2

Ans. : (A)

39. The fundamental electric charge on an electron or a proton is ....

(A) 1.6×10^{19} (B) 6.1×10^{-19}
(C) 9.11×10^{-31} (D) 1.6×10^{-19}

Ans. : (D)

40. The relation between joule and volt is ....

(A) $1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$

(B) $1 \text{ volt} = \frac{1 \text{ coulomb}}{1 \text{ joule}}$

(C) $1 \text{ joule} = \frac{1 \text{ volt}}{1 \text{ coulomb}}$

(D) $1 \text{ joule} = \frac{1 \text{ coulomb}}{1 \text{ volt}}$

Ans. : (A)

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