PHY 104

COMPILED BY OLAKUNLE

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7. ELECTROSTATICS

7.1 Production of Electric Charges

Experimental discovery shows that whenever two bodies are rubbed together, they acquire attracting property on some light objects such as paper. Consider one ebonite rod rubbed with a fur; they are seen to attract each other. The two bodies are said to be electrified. Other examples are glass and silk.

Let us consider two ebonite rods rubbed with fur and brought together. They are seen to repel each other. When a rod of ebonite rubbed with fur attracts a glass rod rubbed with silk, it shows that electrification of the ebonite rod is different from the electrification of the glass rod. The two different charges are called *positive charge* and *negative charge*. Glass rod is said to acquire positive (+ve) charge while ebonite acquires negative (-ve) charge.

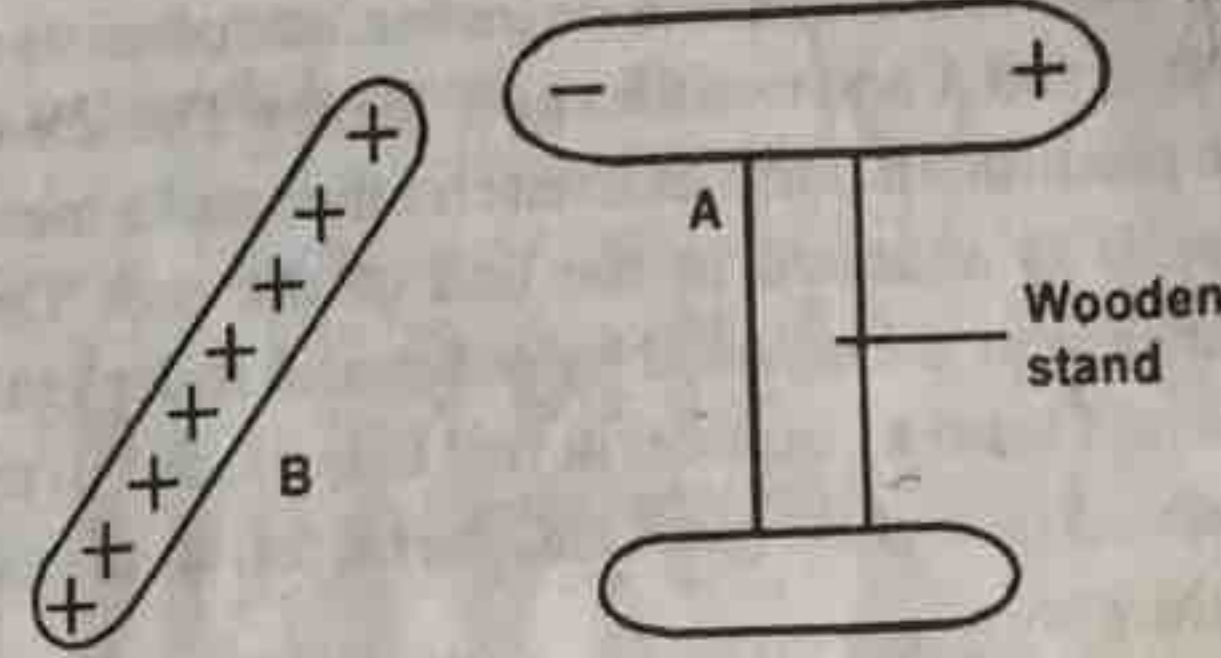
In conclusion, negative charge of ebonite is equal to the +ve charge of the glass when brought together, i.e. they attract each other.

The law of electrostatic states that like charges repel each other and unlike charges attract each other.

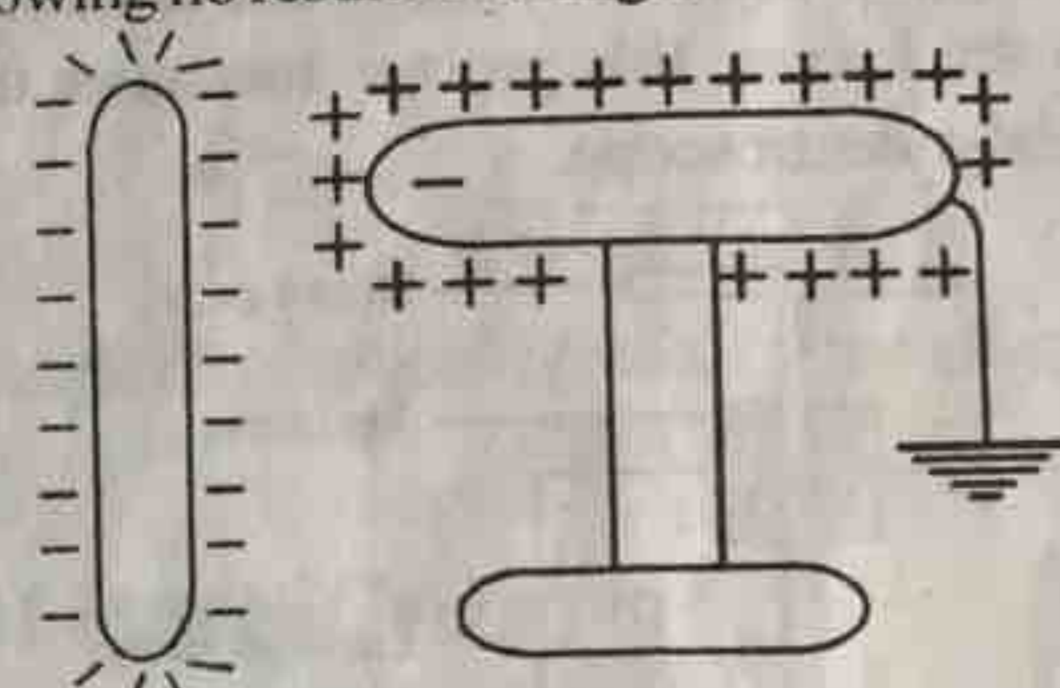
7.2 Electrostatic Induction

Electrostatic induction is a method of charging a body by introducing a charged body to a neutral body. When this is done, the body is said to be *induced with a charge.*

To charge a body, the neutral body A is made to stand on an insulator not on a conductor. A charged body B is introduced to the neutral body of A by electrostatic induction. The nearer side of A gets reversely charged while the further side gets similarly charged.

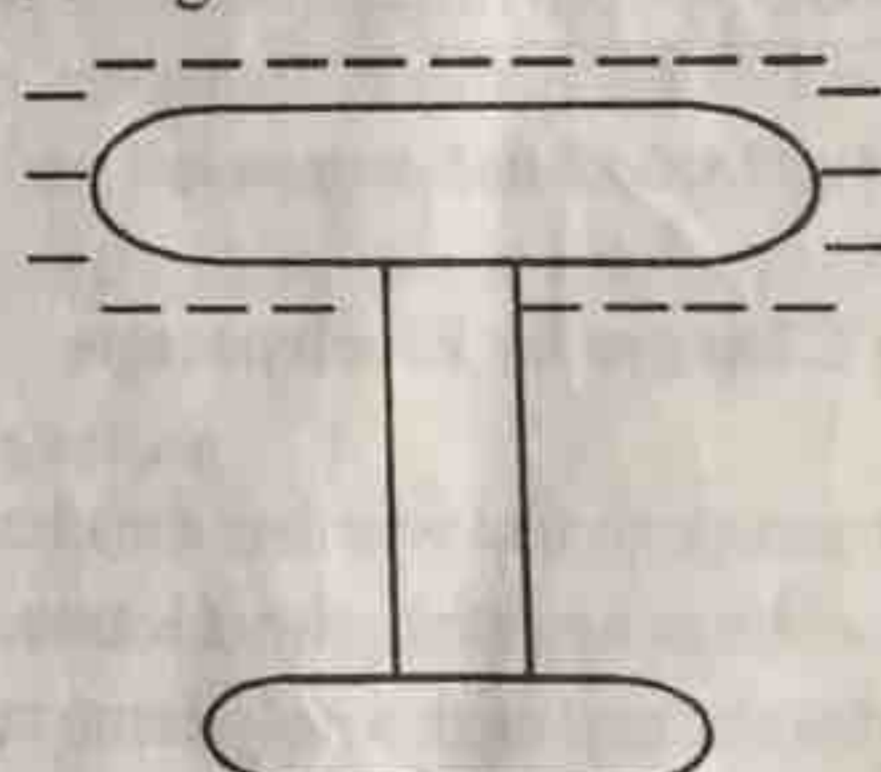


When the charged body B is removed, the induced positive and negative charges are neutralized, showing no resultant charge.



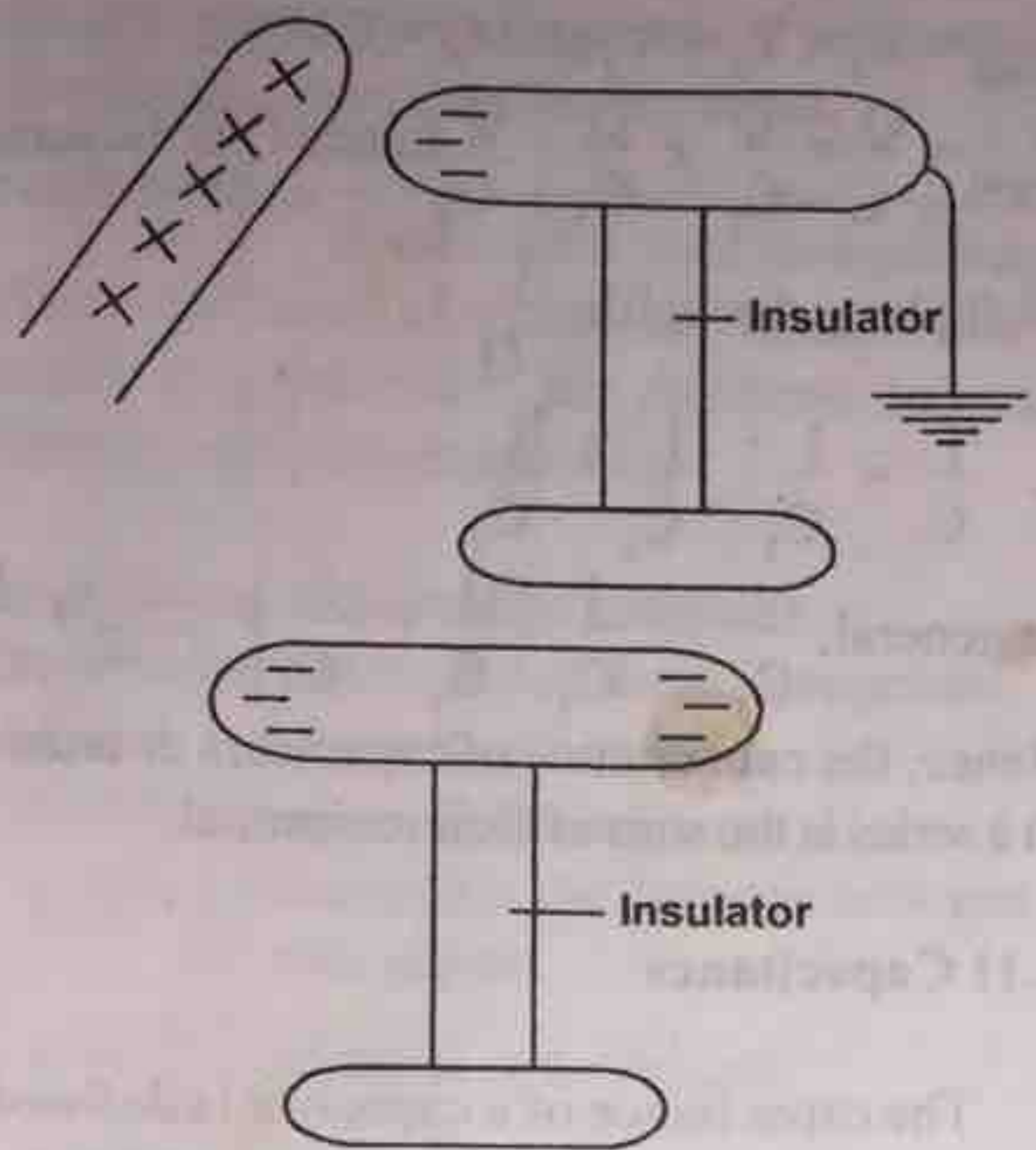
When the body is touched, the positive charge flows to the earth through the hand but the negative charge does not flow to the earth.

If the hand is removed first, and then rod B is introduced, the whole surface will be bound with negative charge.



Neutral body can be charged either positively or negatively.

Conclusion: To charge a body positively, a negatively charged rod is brought near and to charge a body negatively, a positively charged rod is brought near.



The negative charge spreads round, leaving the body as a negatively charged body.

7.6 Conductors and Insulators

Conductors are substances, mostly metals, that allow the passage of electricity while insulators are substances which do not allow the passage of electricity.

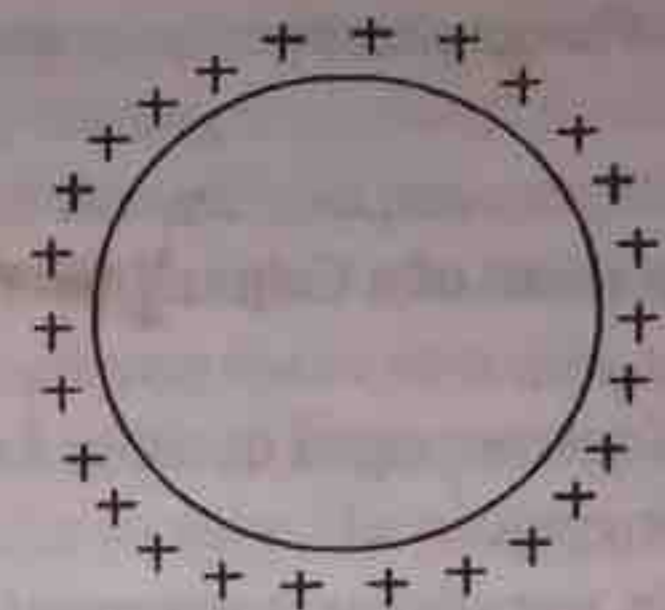
Examples of conductors are: (i) All metals (ii) Human body.

Insulators are: (i) Plastic (ii) Paper (iii) Wood (iv) Cotton.

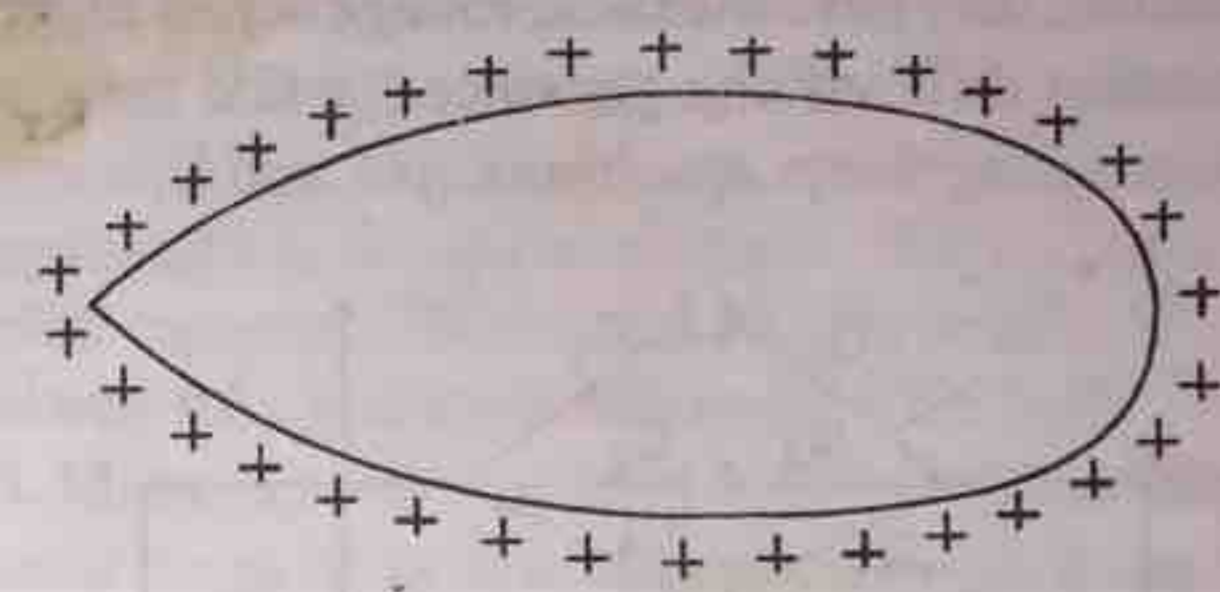
7.7 Distribution of Charges on Conductors

Experimental works have shown that charges are distributed where there is a sharp curve. The density of these charges are greater at the surface of sharp curve. The charge per unit area of a charged surface is called *surface density.*

Surface density is greater at the corner or pointed edge than at the plain surface.



Example of equal charge distribution



Charge distribution is greater at the edge (sharp edge)

7.8 Lightning Conductor

Lightning conductor is used to prevent a tall building from being damaged when it is struck by lightning. The conductor is a long metal rod installed or connected to the earth by means of a cable. The sharp outer point of the top gains an induced charge opposite to that in the thunder cloud. The charged ionizes the nearby air and the charged air molecules flow upwards from the point. This discharges the cloud before a lightning flash occurs.

7.9 Capacitor

A capacitor is a device for storing electrical charges. It consists of two conductors which are parallel to each other.

The storage of a capacitor is increased due to an increase in its conductivity.

Function of capacitor

1. A capacitor is used to separate a.c. from D.C
2. It is used to control current in an a.c.

3. Electrical charges or energy is stored in the capacitor.

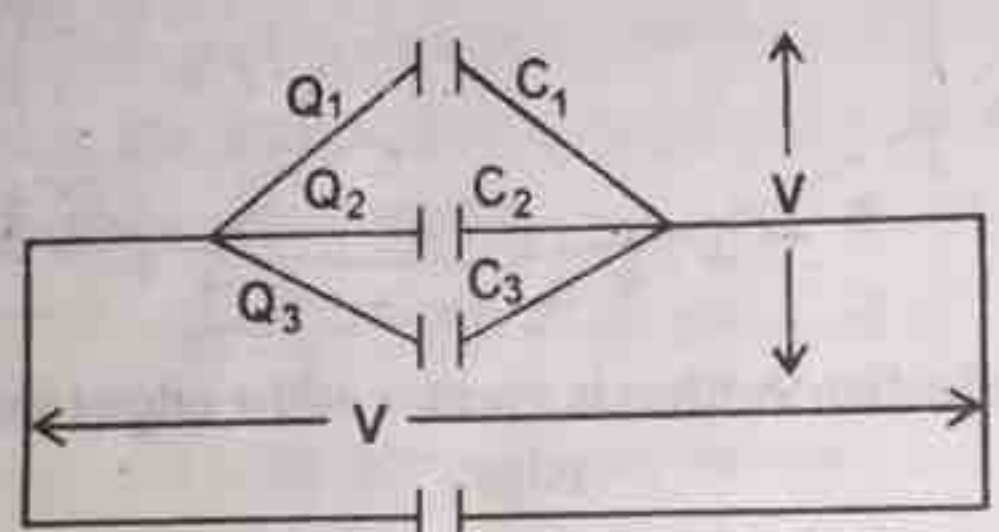
7.10 Arrangement of a Capacitor

A capacitor is arranged in either a series or in a parallel arrangement.

Capacitors in parallel arrangement

When two or more capacitors are connected in parallel, they have the same voltage across them, but store different charges since $Q = CV$

Connecting three capacitors C_1, C_2 and C_3



$$Q_{total} = Q_1 + Q_2 + Q_3$$
$$Q_{total} = C_1 v + C_2 v + C_3 v \text{ (since V is the same)}$$
$$Q_{Total} = V[C_1 + C_2 + C_3] \text{ (common term V)}$$
$$\text{Since } Q_{Total} = Cv$$
$$CV = V[C_1 + C_2 + C_3]$$
$$C = C_1 + C_2 + C_3$$

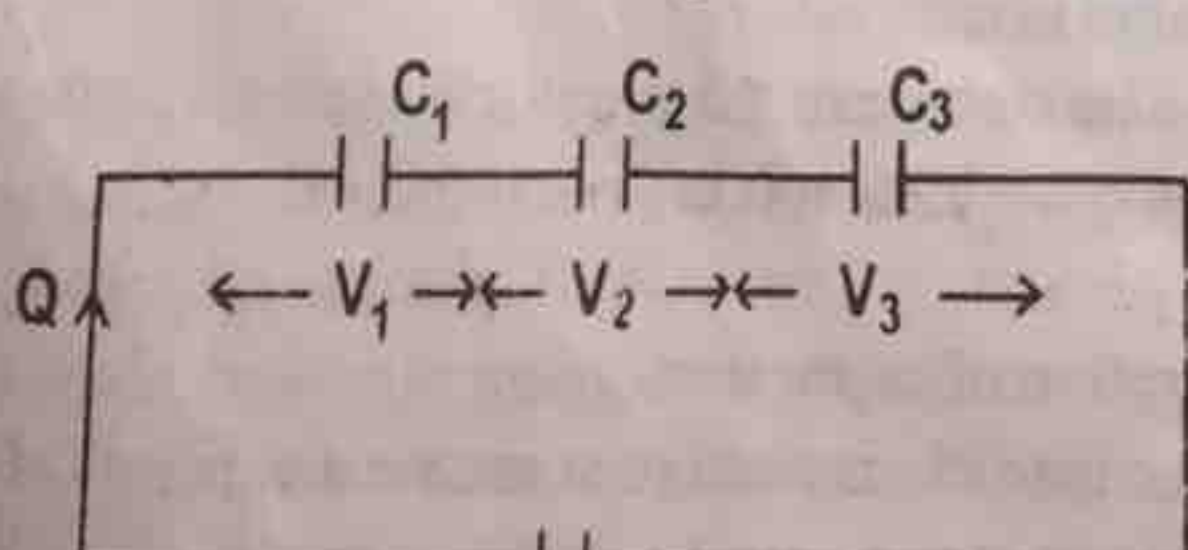
In general,

$$C_T = C_1 + C_2 + C_3 + \ldots\ldots\ldots\ldots\ldots\ldots + C_n$$

Hence, the capacitance of capacitors connected in parallel is the sum of their individual capacitance.

Capacitor in series arrangement

Three capacitors, C_1, C_2 and C_3 connected in a series across a p.d of V. The charge Q is the same but of different voltages



$$V_{total} = V_1 + V_2 + V_3 \text{ and } Q = CV$$
$$V_{total} = \frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} \text{ (since Q is the same)}$$

Multiplying through by $\frac{1}{Q}$

$$\therefore \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_2}$$

In general, $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots\ldots + \frac{1}{C_n}$

Hence, the capacitance of capacitors connected in a series is the sum of their reciprocal.

7.11 Capacitance

The capacitance of a capacitor is defined as the ratio of electric charge to the potential difference (voltage) between or across the plates of the capacitors.

It is denoted by C, measured in farad (f) and a scalar quantity, thus, charge in any plate is directly proportional to the potential difference across the capacitor. It is expressed mathematically as

Charge (Q) α potential difference (V)

$Q \alpha V$

$Q = CV$ where C = constant, called *capacitance*

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

For a parallel plate capacitors, the capacitance is given as:

$C = \frac{A\varepsilon}{d}$ A = area of plate

d = distance apart

ε = permittivity of medium

N.B $\varepsilon_r = \varepsilon_0 \times \varepsilon$

where ε_r is relative permittivity or dielectric constant, ε_0 is permittivity of free space (vacuum).

7.12 Factors Affecting Parallel Connection Plate Capacitors

1. The capacitance of a parallel plate capacitor is directly proportional to the area, i.e. $C \alpha A$

2. Parallel plate capacitor is inversely proportional to the distance between the two plates.

i.e capacitance $\alpha \dfrac{1}{\text{Distance between two plates(d)}}$

3. The capacitance of a parallel plate capacitor is directly proportional to the dielectric constant relative permittivity capacitance.

Capacitance α dielectric constant

Mathematical expression of these three points

1. $C \alpha A$ where A is the area
   $C = KA$ where K is a constant
2. $C \alpha \dfrac{1}{D}$ where D is the distance between two plates.
   $C = \dfrac{k}{D}$ where K is a constant
3. $C \alpha K$ where K is a dielectric

Dielectric is an insulating medium which separates two metal plates. Examples of dielectric are air, mica, etc.

7.13 Energy Stored by a Capacitor

A capacitor of capacitance C, charge Q and potential difference of V, the workdone by raising it from its initial zero stage to final stage

Workdone = Average p.d x charge

$$\text{Average p.d} = \frac{0+V}{2} = \frac{V}{2}$$

total workdone given by

$$W = Q \times \frac{V}{2} = \frac{1}{2}QV$$

Thus, $w = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\dfrac{Q^2}{C}$, since $Q = CV$

The practical unit of a capacitor is the farad (f)

Thus, I micro farad = $I\mu F = 1 \times 10^{-6}F$
I pico farad = $IpF = 1 \times 10^{-12}F$
I nano farad = $InF = 1 \times 10^{-9}F$

7.14 Types of Capacitor

1. Variable air capacitor: This type of capacitor is commonly used in electric circuit. The capcity is varied by turning the knob of the capacitor. To aluminium plates are used, one part of the aluminiu is fixed while the other can be turned. The area overlaps between these two sets and is varied, leading to changes in the capacitor. The dielectric is air and the smaller the air gap, the larger the capacity of the capacitor.

2. Paper capacitor: This consists of thin strip of paraffin waxed paper rolled between the coatings of tin of aluminium foil, then rolled into a cylinder. The dielectric with the tin or aluminium foils rolled up in order to occupy small space. This is a parallel plate capacitor. The dielectric is very small and this is why the capacity of the condenser is high.

3. Mica capacitor: This type of capacitor has a solid material as its dielectric constant. It can be used where many capacitors are required. The arrangement is in parallel and the dielectric is a sheet of mica placed between the two sets of plates.

Worked example 7.1

Two capacitors of capacitance, 3μF and 6μF are connected in series. Calculate the equivalent capacitance

Solution

Given $C_1 = 3\mu F$ and $C_2 = 6\mu F$

Capacitors connected in series

$$\frac{1}{C} = \frac{1}{C_2} + \frac{1}{C_2}$$

$$= \frac{1}{3} + \frac{1}{6}$$

$$C = \frac{3 \times 6}{3+6}$$

$$C = \frac{18}{9} = 2\mu F$$

Worked example 7.2

A supply of 400V is connected across capacitors of 3μF and 6μF in series. Calculate the charge, energy stored in each capacitor and also the potential difference across each capacitor.

Solution