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FUNDAMENTALS OF ELELCTRICAL ENGINEERING(FEE) [22212]

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CH.3 CAPACITOR

Contents: CH.3 CAPACITOR (12/70)

- Capacitor, Parallel Plate Capacitor.
- Various connections of capacitor.
- Energy Stored in Capacitor.
- Charging and Discharging of Capacitor.
- Breakdown voltage and Di-electric strength.
- Types of Capacitor and Application.

- **Electric field:** Region around a charged body where another body experiences force is called electric field

- **Electric flux:** The no of lines of force in electric field is called electric flux

  electric flux= Q coulomb charge Unit: coulomb

- **Electric flux density(D):** electric flux per unit area is called as electric flux density

  D=flux/Area Unit: C/m^2

- **Electric field strength(E):** force experienced by unit charge in electric field is called as electric field strength

  E= Force/ charge Unit: Newton/coulomb

- **Permittivity:** Ability of dielectric material to carry electric flux is called as permittivity

- **Absolute permittivity (ϵ):** The ratio of electric flux density(D) to electric field strength(E).

  $\epsilon = D/E$ $\epsilon = \epsilon_0 \epsilon_r$ Unit: Farad/meter

- **Permittivity of free space(ϵ_0):** The ratio of electric flux density(D) in air or vacuum to electric field strength(E) in air or vacuum.

  $\epsilon_0 = D_0/E_0$ $\epsilon_0 = 8.85 * 10^{-12}$ Unit: Farad/meter

- **Relative permittivity(ϵ_r):** The ratio of electric flux density(D) in any medium to electric flux density in air or vacuum(D_0).

  $\epsilon_r = D/D_0$ Unit less quantity

  the value of relative permittivity of air or vacuum is =1

- **Capacitors:**“ *Capacitor or condenser is formed if two conducting surfaces or plates are separated by an insulating medium.”*

dielectric material may be mica, glass, paraffin paper, oil, etc, some time air.

- **Capacitance(C):** *“It is defined as the property of capacitors to store electric energy in the form of static charge.”*

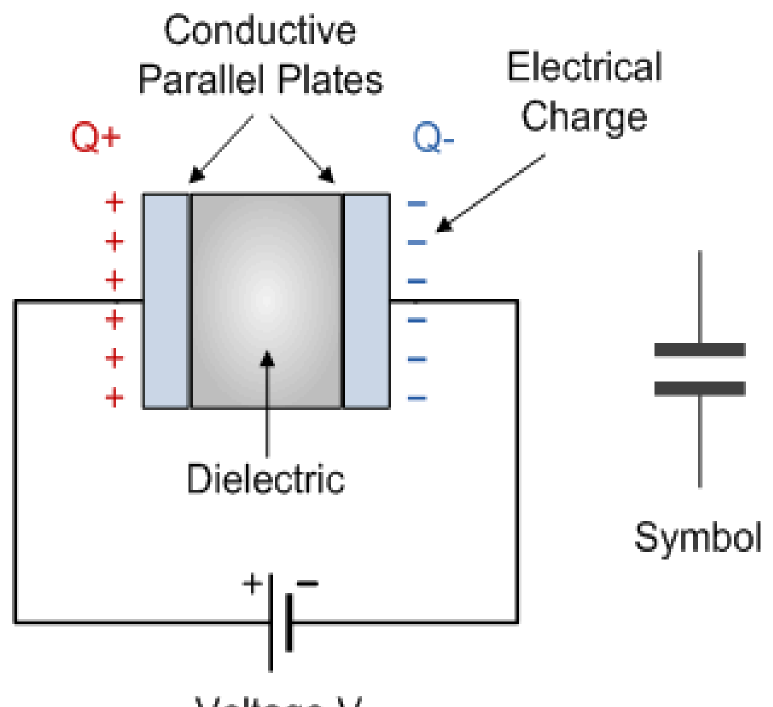
Capacitance C= Q/V

Unit: farads(F)

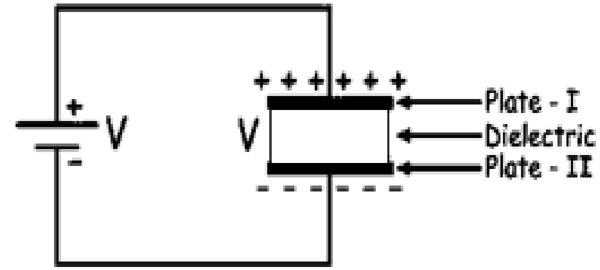
Where C is capacitance in farad

Q is charge in coulomb

V is potential difference in voltage.



Working of Capacitor:



- When we connect a battery (DC Voltage Source) across the capacitor, one plate (plate-I) gets attached to the positive terminal and another plate (plate- II) to the negative terminal of the battery.
- the electrons from plate-I are attracted towards positive terminal of battery. When electrons move from plate-I, the net charge on plate-I becomes positive. The electrons received at positive terminal are then sent to plate-II. This work is done by the battery, hence its energy is transferred to the capacitor.
- The plate-II becomes negatively charged since it receives negatively charged electrons.
- As time passes, plate-I becomes more & more positively charged by losing its electrons, whereas plate-II becomes more & more negatively charged by accepting the electrons from the battery.
- capacitor holds maximum amount of charge as per its capacitance with respect to battery voltage. This time span is called charging time of this capacitor.
- After disconnecting the battery the charged capacitor acts as a source electrical energy.

- **Dielectric strength:** The voltage which a dielectric material can withstand without breaking down (without losing its dielectric property) is called its dielectric strength. It is represented by kV/mm or kV/cm.

  e.g. dielectric strength of air is @ 30 kV/cm or 3 kV/mm.

- **Breakdown Voltage:** The voltage at which the dielectric material breaks down (Start conducting or is no longer an insulator) for a specified thickness, is its breakdown voltage.

Energy stored in capacitor

Let C be the capacitance of a capacitor in farad.

v be the potential difference across capacitor in volt at a particular instant.

q be the charge on the capacitor at that instant.

Therefore, potential difference $v = \frac{q}{c}$ or charge $q = Cv$

When the potential difference across capacitor is v and if small amount of charge dq is shifted from one plate to other, the voltage is changed by dv. Therefore, $dq = C.dv$

The work done in shifting a small charge dq against P. D. of v volt is given by,

$$dW = v.dq = \left(\frac{q}{c}\right) dq \quad \text{OR} \quad dW = v.dq = v.C.dv$$

The work done is stored as potential energy in the electrostatic field by the capacitor.

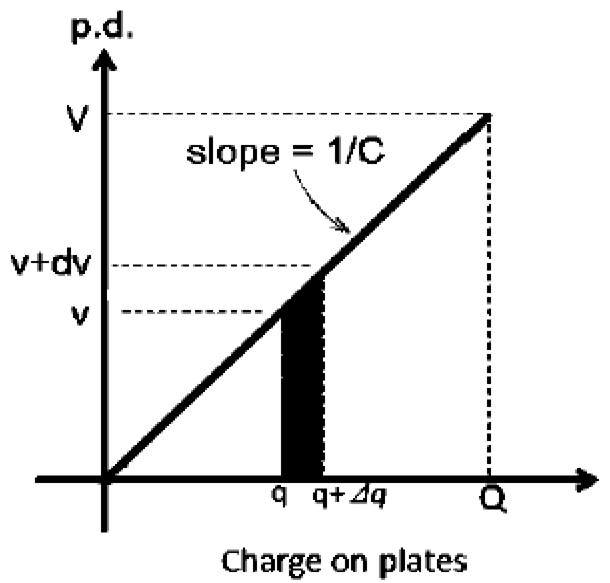
Therefore, total energy stored by the capacitor is given by,

$$E = \text{work done } W = \int dW = \int \left(\frac{q}{c}\right) dq = \frac{1}{2c} q^2$$

$$= \frac{1}{2} C \left(\frac{q}{c}\right)^2 = \frac{1}{2} C v^2 \quad \text{joules}$$

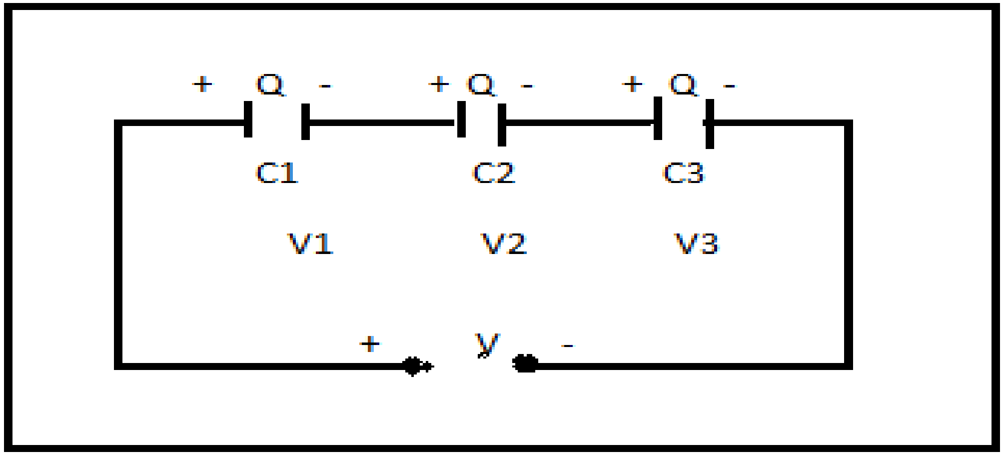
OR

$$W = \int dW = \int Cv\, dv = \frac{1}{2} C v^2 \quad \text{joules}$$



E= $\boldsymbol{\frac{1}{2}Cv2}$ joules where, C is the capacitance in farad, Q is the charge on capacitor in coulomb. v is the voltage across capacitor in volt

Series capacitor



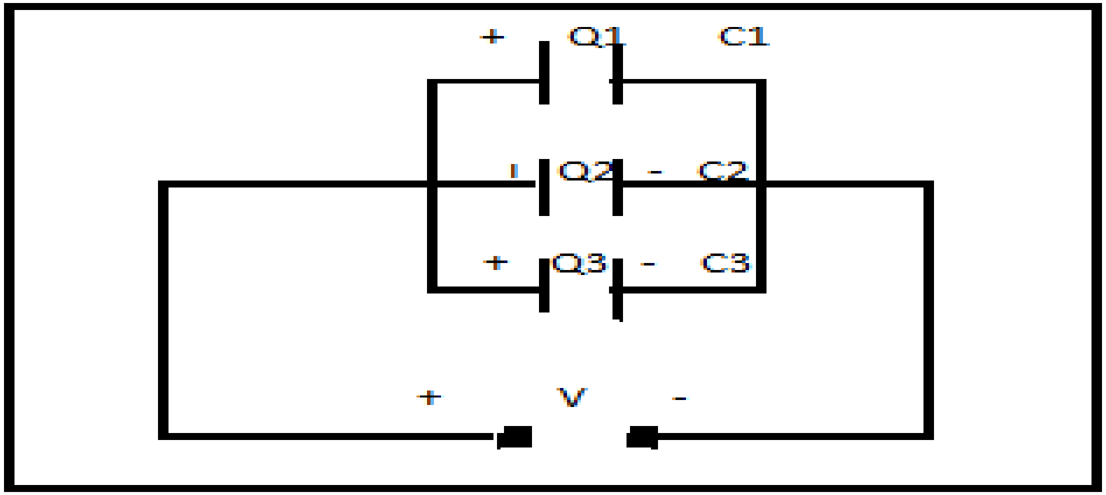
$$V=V_1+V_2+V_3 \;=\frac{Q}{C1}+\frac{Q}{C2}+\frac{Q}{C3}$$

$$V= Q[\frac{1}{C1}+\frac{1}{C2}+\frac{1}{C3}]$$

$$\therefore \frac{V}{Q}=\frac{1}{C1}+\frac{1}{C2}+\frac{1}{C3}$$

$$\frac{\mathbf{1}}{\boldsymbol{Ct}}=\frac{\mathbf{1}}{\boldsymbol{C1}}+\frac{\mathbf{1}}{\boldsymbol{C2}}+\frac{\mathbf{1}}{\boldsymbol{C3}}$$

Parallel capacitor



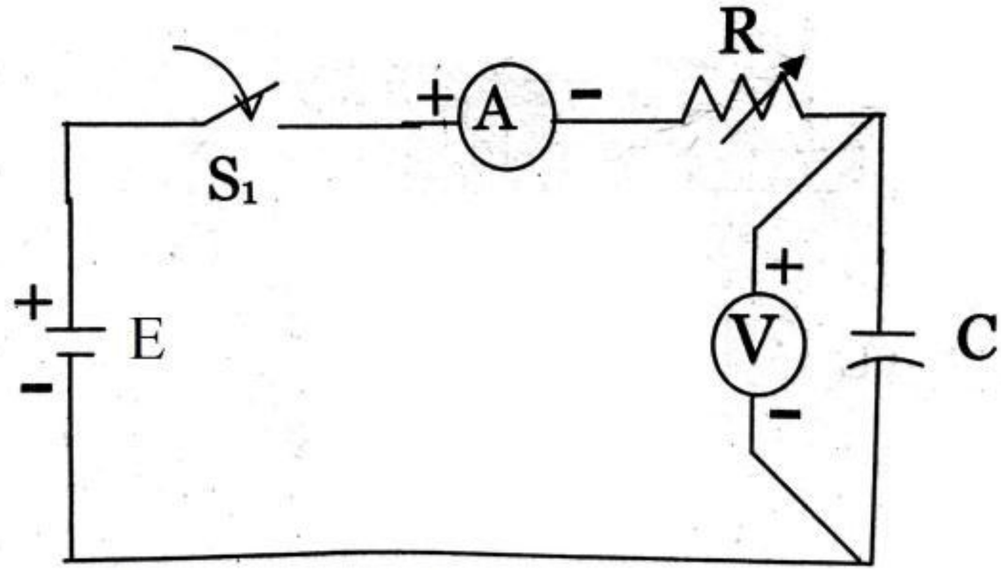
$$\therefore Q = Q1 + Q2 + Q3 \quad = C_1V + C_2V + C_3V$$

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

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

$$\mathbf{C_T = C_1 + C_2 + C_3}$$

Charging of capacitor



Practical setup to plot Charging Curve of Capacitor

- The charging of a capacitor is shown in fig. Here a resistor R and Capacitor C are connected in series with each other. V is the dc voltage source s1 is the switch which will connect or disconnect voltage source to the RC series circuit.
- We assume that initially the switch S1 is open there is no charge on the capacitor and the initial current through the circuit is zero. At t=0 the switch is closed to connect the dc voltage source to the R-C series circuit. The charging current starts flowing through R and C and the capacitor starts accumulating the charge.

Charging of capacitor

- Initial charging current at t=0:

$$I_0 = \frac{V}{R}$$

- capacitor voltage:

$$V_C = V\,(1-e^{-t/RC})$$

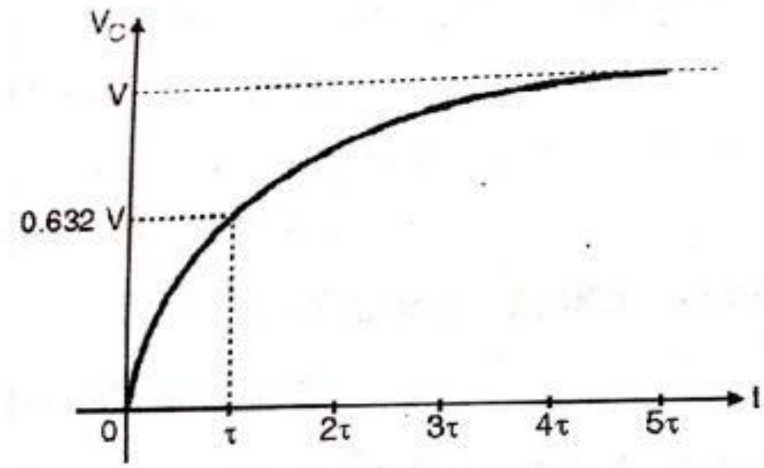
- charging current:

$$ic = I_0 e^{-t/RC}$$

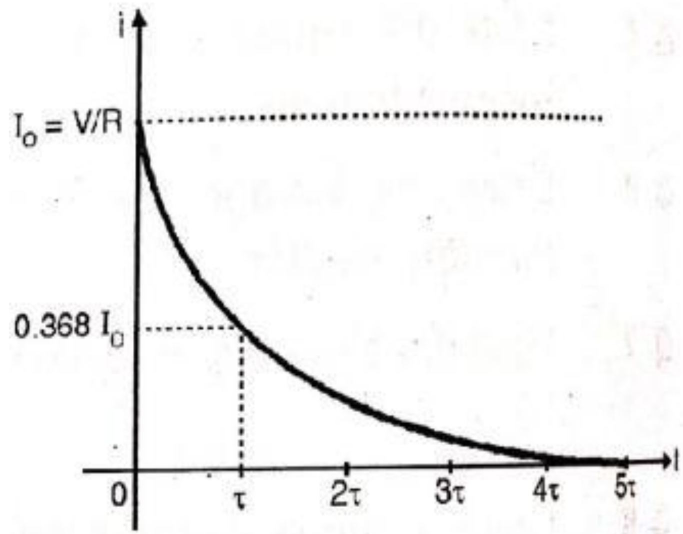
- Time Constant"τ" as the time taken by the ic to drop to 0.3678 of its initial Maximum value or

it is defined as the time required for Vc to rise from 0 to 0.632 of its final value V volts or

it can be defined as the product of R and C. its unit is seconds.

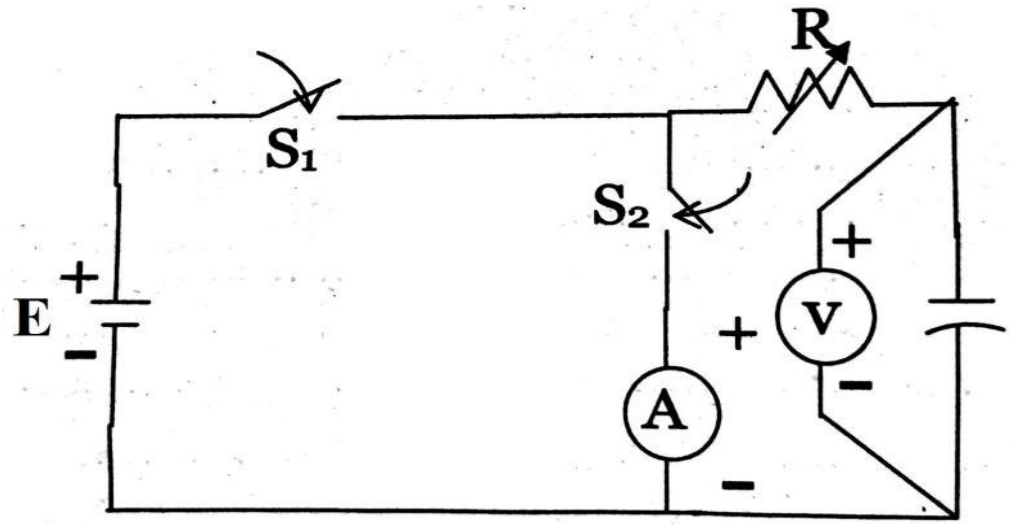


Variation in capacitor voltage while charging



Variation in capacitor current while charging

Discharging of capacitor



Experimental setup to plot Discharging Curve of Capacitor

- The discharging circuit for a charged capacitor is shown in figure. The Switch S2 is closed as t=0 to connect the charged capacitor across resistor R and the discharging current ic starts flowing through the circuit. The discharging current flows in the opposite direction to that of the charging current.
- We assume that the switch S2 initially open and that the capacitor is charge to V volts. i.e. Vc=V at t=0
- At t=0, the switch is closed to connect the charged capacitor across the resistor R. the discharging current I stars flowing in the circuit and the capacitor stars losing its charge. The capacitor voltage will starts decreasing exponentially

Discharging of capacitor

- Initial discharging current:

$$I_0 = \frac{V}{R}$$

- capacitor voltage:

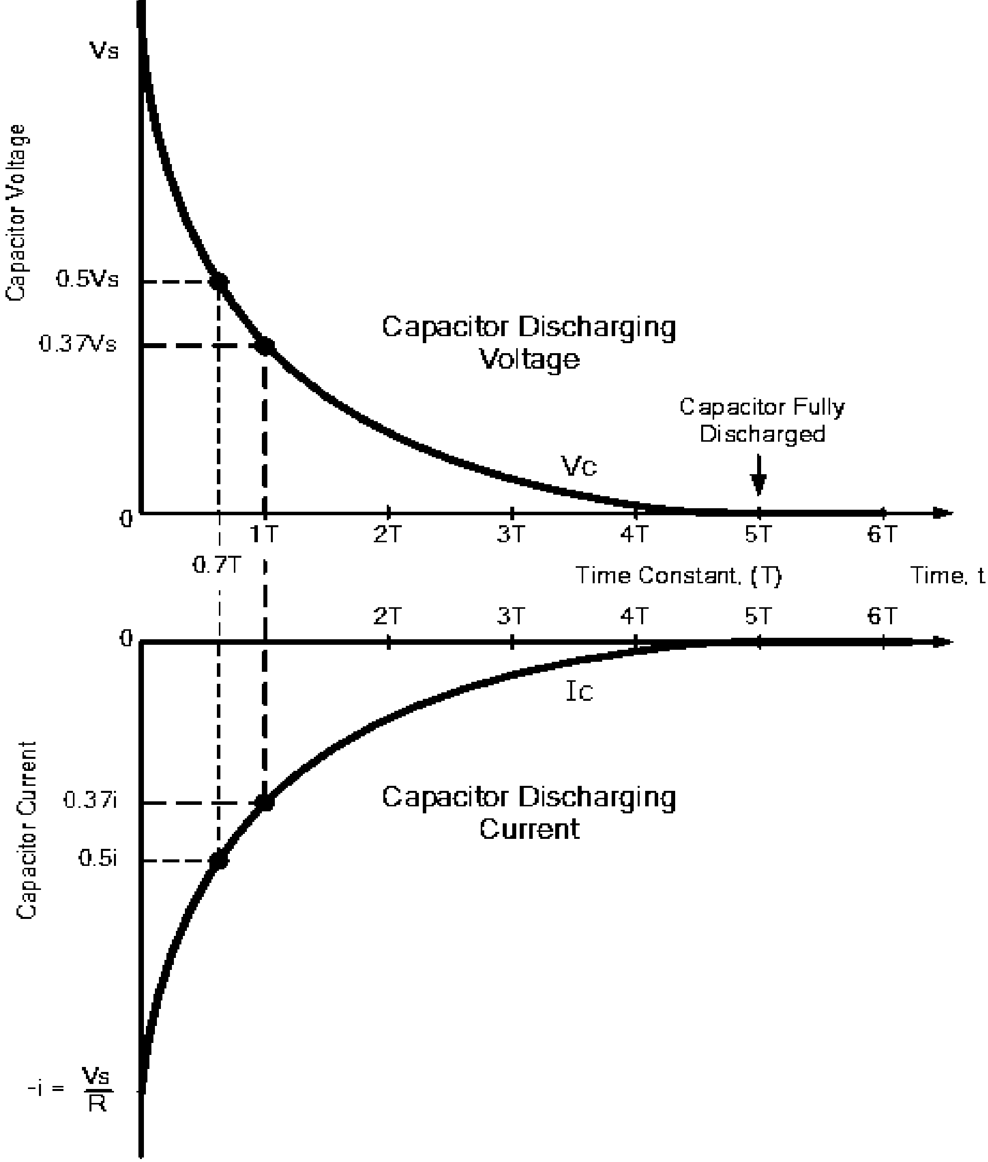
$$Vc = Ve^{-t/RC}$$

- discharging current:

$$i_c = -I_0 e^{-t/Rc}$$

- We can define the time constant τ

of a Rc discharging circuit as the time required for the **V*c*** to drop to 0.3678 of its initial voltage or the time constant can be defined as the time required for the capacitor current to drop to 0.3678 of its initial maximum value or it can be defined as the product of R and C. its unit is second.



Capacitance of parallel plate capacitor with uniform dielectric medium

- The charge stored by plate A be "Q" coulomb.

  $\Psi = Q$

- The electric flux density $D = \frac{\Psi}{A} = \frac{Q}{A}$
- The electric field intensity $E = \frac{V}{d}$ volt/meter
- $\in = \frac{D}{E}$ $D = \in * E$
- $\frac{Q}{A} = = \in \frac{V}{d}$
- $\frac{Q}{V} = = \in \frac{A}{d}$
- **Capacitance C =** $\frac{Q}{V} = \frac{\in o . \in r . A}{d}$

Capacitance of parallel plate capacitor with medium partly air

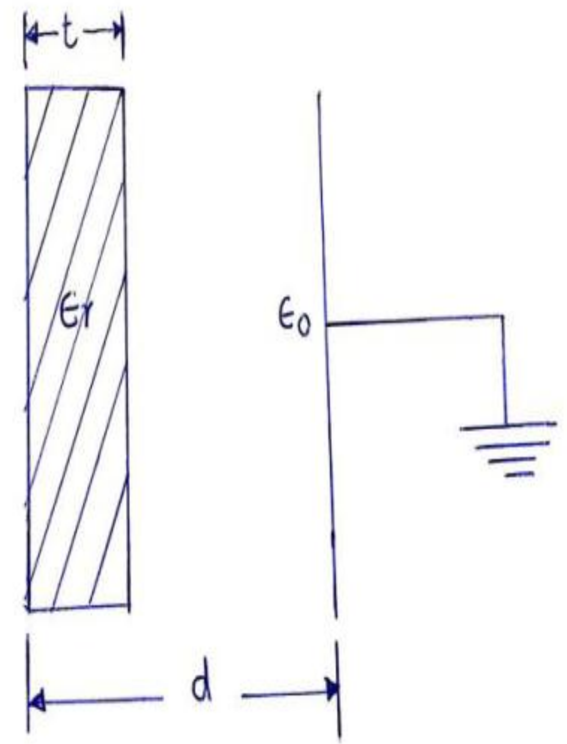
- As shown in figure, the medium consists partly air parallel sided dielectric slab of thickness 't' and relative permittivity.
- The electric flux density D = Q/A is the same in both media. But electric intensities are different.
- E1 = $D/\epsilon o \epsilon r$ .... in the dielectric medium
- E2 = $D/\epsilon o$ .... in the air
- P.D. between plates, V = E1.t + E2(d - t)

$$V = \left(\frac{D}{\epsilon o \epsilon r}\right)\times t + \left(\frac{D}{\epsilon o}\right)\times(d - t)$$

$$V = \left(\frac{D}{\epsilon o}\right)\left[\frac{t}{\epsilon r}+d-t\right]$$

$$V = \frac{Q}{\epsilon o A}\left[d-\left(t-\frac{t}{\epsilon r}\right)\right]$$

- **Capacitance C =** $\frac{Q}{V} = \frac{\epsilon o.A}{[d-(t-\frac{t}{\epsilon r})]}$



Factors affecting the capacitance of capacitor:

The capacitance of a capacitor is given by,

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

i) **Area of Plates**: Greater the area (A) of capacitor plates, more is the value of capacitance and vice versa.

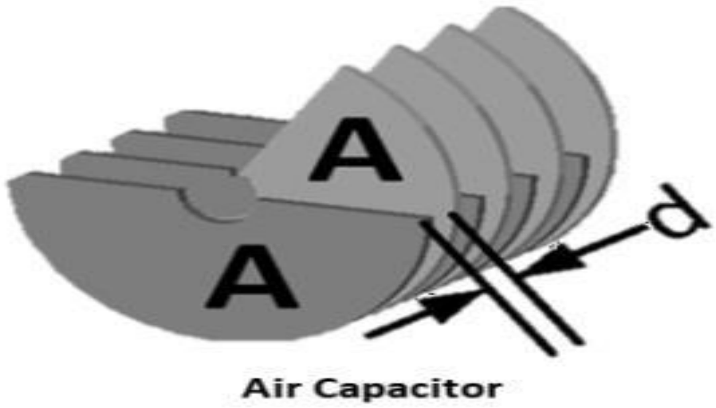
ii) **Thickness of dielectric:** Smaller the thickness (d) of dielectric, more is the value of a capacitance and vice versa.

iii) **Relative permittivity of dielectric:** Greater the relative permittivity ($\in$) of dielectric material more is the value of capacitance and vice versa.

Types of capacitor with Application

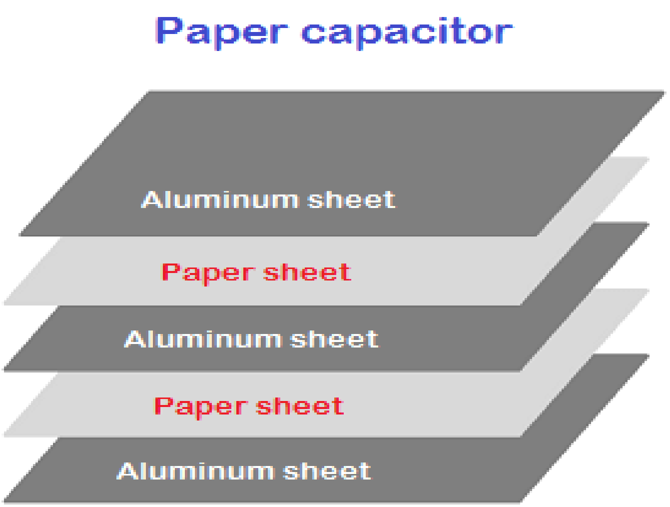
1. **Air capacitors:** Radio tuning applications, Antenna tuning, RF matching networks, MRI medical scanners.
2. **Paper capacitors:** High voltage and high current applications.
3. **Mica capacitors:** High frequency tuned circuits, such as filters and oscillators.
4. **Ceramic Capacitors:** Tone compensation, Automatic volume control filtering, Antenna coupling, Resonant circuit, Volume control RF bypass,ballasts.
5. **Electrolytic capacitors:** Reduce voltage fluctuations in various filtering devices, For noise filtering or decoupling in power supplies, For coupling signals between amplifier stages, To store energy in flash lamps.
6. **Film Capacitor:** A/D converters, Filters, snubber circuits, In DC link circuits.
7. **Glass capacitors:** High power amplifier, Filters, R-F oscillator, Energy storage, Power factor correction, High voltage capacitors, Power electronic filters.
8. **Polycarbonate capacitor:** Filters, Timing and precision coupling circuits, Switching power supplies, AC applications to avoid corona.

i. Air capacitors



- Air capacitors are capacitors which use air as their dielectric.
- The simplest air capacitors are made of two conductive plates separated by an air gap.
- Air capacitors can be made in a variable or fixed capacitance form.
- Fixed capacitance air capacitors are rarely used since there are many other types with superior characteristics.
- Variable air capacitors are used more often because of their simple construction.
- They are usually made of two sets of semicircular metal plates separated by air gaps. One set is fixed and the other is attached to a shaft which allows the user to rotate the assembly, The maximum capacitance state is achieved when the overlap between the two sets of plates is highest, while the lowest capacitance state is achieved when there is no overlap.

ii) Paper capacitors:



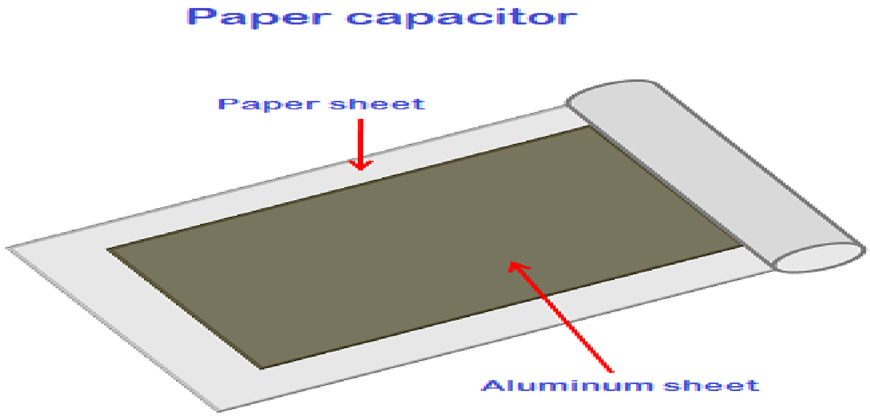
- Paper capacitor uses paper as the dielectric.
- Paper capacitors are the fixed type of capacitors

Paper capacitors are classified into two :

- ✓ Paper sheet capacitor
- ✓ Metalized paper capacitor

Paper sheet capacitor:

- The paper sheet capacitor is made by taking two or more aluminum sheets and placing a paper sheet between them.
- The paper placed between the aluminum sheets acts as dielectric and the aluminum sheets acts as electrodes.
- The paper sheet is poor conductor of electricity so it does not allow flow of electric current or electric charges between two aluminum sheets.
- The paper sheets and aluminum sheets are rolled in the form of cylinder and wire leads are attached to both ends of the aluminum sheets.
- The entire cylinder is then coated with wax or plastic resin to protect it from moisture in the air.
- The paper sheet capacitors are used in the high voltage and high current applications.



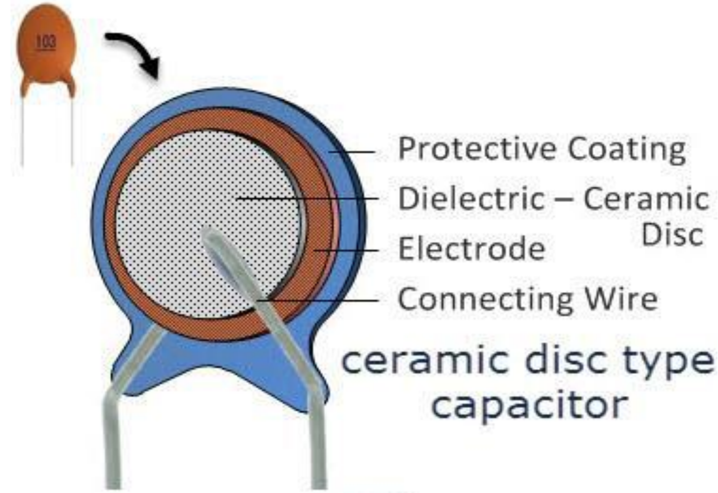
Metalized paper capacitor:

- In metalized paper capacitor,

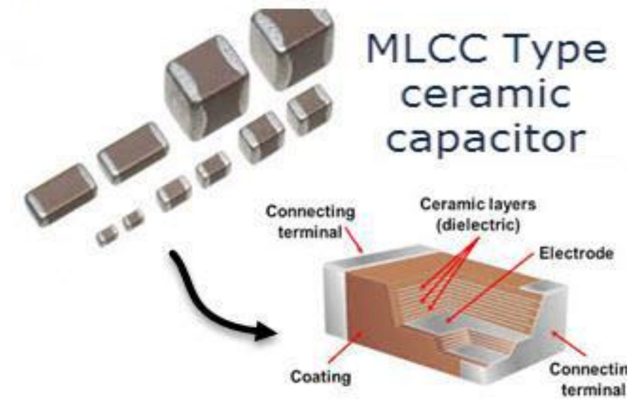
the paper is coated with thin layer of zinc or aluminum.

- The paper coated with zinc or aluminum is rolled in the form of cylinder.
- The entire cylinder is then coated with wax or plastic resin to protect it from moisture.
- The zinc or aluminum coated on the paper acts as electrodes and the paper acts as dielectric.
- Aluminum is widely used for the construction of paper capacitors.
- The size of metalized paper capacitor is very small compared to the paper sheet capacitor.
- In metalized paper capacitor, the aluminum is directly coated on the paper. Therefore, aluminum layer of metalized paper capacitor is very thin compared to the aluminum layer of paper sheet capacitor.

iii) Ceramic Capacitors:



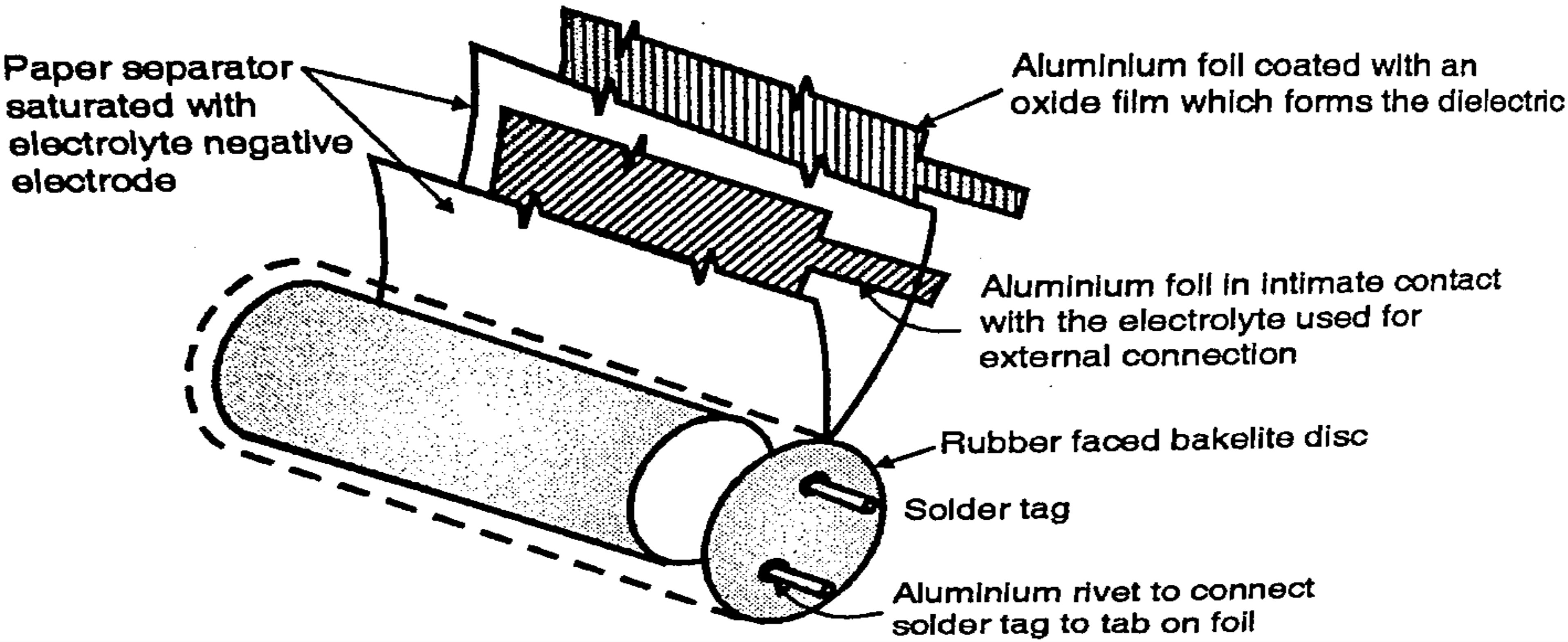
- Ceramic Capacitor is a capacitor that uses ceramic as the dielectric.
- It is made by coating two sides of a small porcelain or ceramic disc with silver and are then stacked together to make a capacitor.
- Ceramic capacitors have a high dielectric constant so that relatively high capacitance can be obtained in a small physical size.
- In order to gain higher capacitances, the capacitor can be made from multiple layers. The **Multi-Layer Ceramic Capacitors (MLCC)** are made with Paraelectric and Ferroelectric materials mix and alternatively layered with metal contacts.



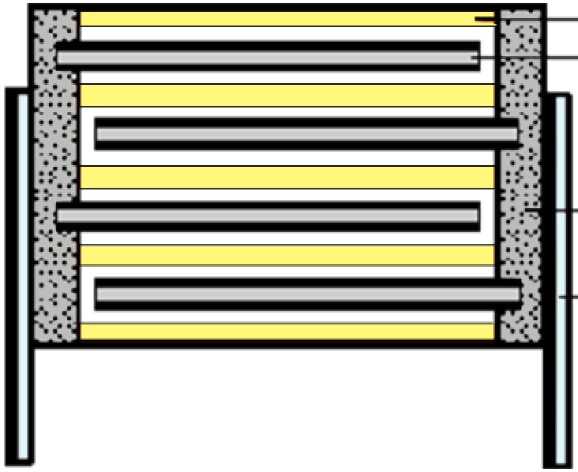
- After completion of the layering process, the device is brought to a high temperature
- Resulting capacitor basically consists of many smaller capacitors connected in parallel, this leads to increase in capacitance. MLCCs consist of more than 500 layers, with the minimum layer thickness of approximately 0.5 microns.

iv) Electrolytic capacitor

- These are large value, high voltage polarized capacitors.
- A plain foil dry electrolytic capacitor is made by forming a coating of aluminum oxide on both sides of an aluminum foil.
- Two strips of aluminum foil used are then seperated by two layers of porous paper soaked with electrolyte.
- This assembly is rolled up, the end are closed with wax and then sealed in to an aluminum container.

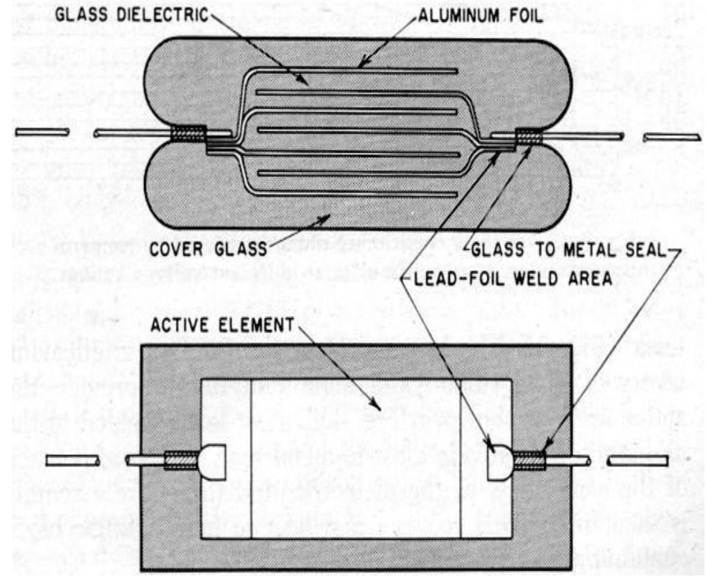


v) Film Capacitor:



- Film capacitors are capacitors which use a thin plastic film as the dielectric.
- The film is extremely thin, with the thickness being under 1 µm.
- After the film is drawn to the desired thickness, the film is cut into ribbons.
- Two ribbons of film are wound together into a roll, which is often pressed into an oval shape so that it can fit into a rectangular case.
- This is important because rectangular components save precious space on the printed circuit board.
- Electrodes are added by connecting each of the two electrodes to one of the films.
- The case is then sealed using silicon oil to protect the film roll against moisture, and dipped in plastic to hermetically seal the interior.
- Electrodes are then added and the assembly is mounted into a case which protects it from environmental factors.
- They are used in many applications because of their stability, low inductance and low cost. There are many types of film capacitors, including polyester film, metallized film, polypropylene film, PTFE film and polystyrene film.

vi) Glass capacitors:



- The capacitor consists of three basic elements:
- the glass dielectric, aluminium electrodes and the encapsulation.
- However the assembly of the glass capacitors is undertaken in a manner that ensures the required performance is obtained.
- As the capacitance between two plates is not always sufficient to provide the required level of performance, the majority of capacitors use a multi-layer construction to provide several layers of plates with interspersed dielectric to give the required capacitance.
- Although the glass plates are always flat, and tubular forms of construction are not applicable, the glass capacitors are usually available with lead emanating in either a radial or axial form.
- Essentially the leads either exit the encapsulation at the side or the end.

- ***A capacitor of 12μF is connected across a battery of 6 volt. Determine energy stored in this capacitor.***

Ans: Given : $C = 12\ \mu F = 12 \times 10^{-6}$ F, $v = 6$ Volt

The energy stored in capacitor is given by ,

$E = 1/2 Cv^2$ $E = 1/2 \times 12 \times 10^{-6} \times (6^2) = 2.16 \times 10^{-4}$ J

- ***Three capacitors 15μf, 18μf and 12μf are connected in a circuit. Find equivalent capacitance when they are connected in 1) Series 2) Parallel***

Ans: Given: $C_1 = 15\mu F$, $C_2 = 18\ \mu F$, $C_3 = 12\mu F$

i) For Series combination of capacitors:

$1/C_s = (1/C_1) + (1/C_2) + (1/C_3) = (1/15) + (1/18) + (1/12)$

$1/C_s = 0.0666 + 0.0555 + 0.0833$ $1/C_s = 0.2054$ $C_s = 4.868\ \mu F$

ii) For parallel combination of capacitors:

$C_p = C_1 + C_2 + C_3 = 15 + 18 + 12 = 45\ \mu F$

- ***Three capacitors 1μF, 2 μF and 3 μF respectively are connected in a circuit. Determine the equivalent capacitance when they are connected in i) Series ii) Parallel***

Ans: Value of equivalent capacitance:

Given: $C1 = 1\mu F$, $C2 = 2\ \mu F$, $C3 = 3\mu F$

i) For Series combination of capacitors:

$1/Cs = (1/C1) + (1/C2) + (1/C3) = (1/1) + (1/2) + (1/3)$

$1/Cs = 1 + 0.5 + 0.3333$

$1/Cs = 1.8333$

$\therefore Cs = 0.545\ \mu F$

ii) For Parallel combination of capacitors:

$Cp = C1 + C2 + C3 = 1 + 2 + 3 = 6\ \mu F$

Calculate the value of equivalent capacitance of the combination given in Figure No. 3.

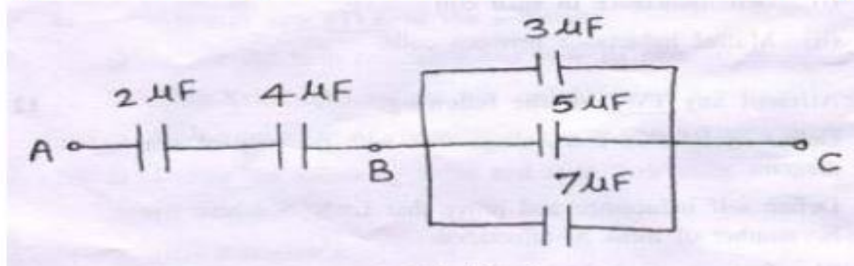
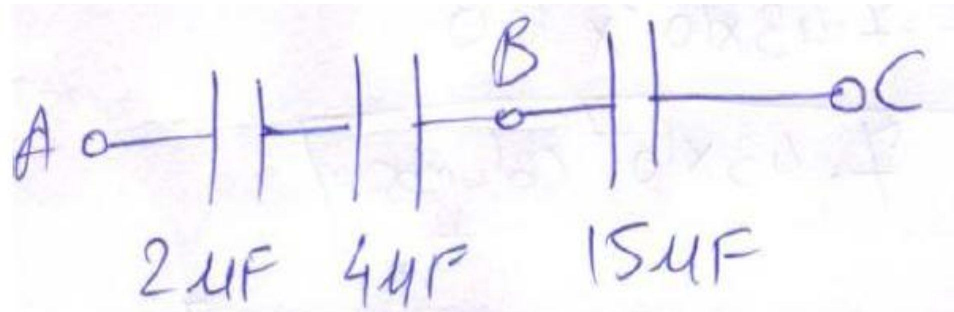


Fig. No. 3

Value of equivalent capacitance:



i) $3\ \mu F, 5\ \mu F\ and\ 7\ \mu F$ for parallel combination

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

$$C_{eq} = 3 + 5 + 7$$

$$C_{eq} = 15\ \mu F$$

ii) $2\ \mu F, 4\ \mu F\ and\ 15\ \mu F$ for Series combination with each other

$$\frac{1}{Ceq} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\frac{1}{Ceq} = \frac{1}{2} + \frac{1}{4} + \frac{1}{15}$$

$$\frac{1}{Ceq} = 0.87$$

$$C_{eq} = 1.22\,\mu F$$

Calculate the capacitance, charge, electric flux density and energy stored in a parallel plate capacitor of two metal plates 60 cm x 60 cm separated by a dielectric of 1.5 mm and relative permittivity is 3.5. The potential difference of 100 V is applied across it.

Given Data:

A = 60 cm x 60 cm = 3600cm^2 = 3600 x 10^{-4} m^2

d= 1.5 mm = 1.5 x10^{-3}m

Relative permittivity Er = 3.5 and voltage V = 100V

i) Calculate Capacitance C =

$$C = \frac{E_0 \times E_r \times A}{d}$$

$$C = \frac{8.85\times10^{-12}\times3.5\times3600\times10^{-4}}{1.5\times10^{-3}}$$

$$C = 7.43\times10^{-9}\ F$$

ii) Calculate Charge Q =

$$Q = C\,V$$

$$Q = 7.43\times10^{-9}\times100$$

$$Q = 7.43\times10^{-7}\ colombs$$

iii) Calculate Flux density =

$$D = \frac{Q}{A}$$

$$D = \frac{7.43\times10^{-7}}{3600\times10^{-4}}$$

$$D = 2.065\times10^{-6}\ c/m^2$$

iv) Calculate energy stored in parallel plate =

$$E = \frac{1}{2}C\,V^2$$

$$E = \frac{1}{2}\times7.43\times10-3\times(100)^2$$

$$E = 37.15\ J$$

Calculate the capacitance of a parallel plate capacitor of two metal plates 60 cm × 60 cm separated by a dielectric of 1.5 mm and relative permittivity is 3.5. If the P-d of 100 V is applied between the plate. Calculate :

1. Charge 2. Electric flux density
3. Electric field strength

Given : $l = 60\text{ cm} = 0.6\text{ m}$, $W = 60\text{ cm} = 0.6\text{ m}$

$d = 1.5\text{ mm} = 1.5 \times 10^{-3}\text{ m}$, $\epsilon_r = 3.5$

$V = 100\text{ V}$

To find : 1. Capacitance 2. Charge 3. Electric flux density. 4. Electric field strength.

1. Capacitance :

$$C = \frac{\epsilon_0 \epsilon_r A}{d} = \frac{8.854 \times 10^{-12} \times 3.5 \times (0.6 \times 0.6)}{1.5 \times 10^{-3}}$$

$$\therefore \quad C = 7.44 \times 10^{-9}\text{ F}$$ ...Ans.

2. Charge :

$$Q = CV = 7.44 \times 10^{-9} \times 100$$

$$= 7.44 \times 10^{-7}\text{ coulomb}$$

3. Electric flux density :

$$D = \frac{Q}{A} = \frac{7.44 \times 10^{-7}}{(0.6 \times 0.6)} = 2.066 \times 10^{-6}\text{ C/m}^2$$

4. Electric field intensity :

$$D = \epsilon_0 \epsilon_r E$$

$$\therefore \quad E = \frac{D}{\epsilon_0 \epsilon_r} = \frac{2.066 \times 10^{-6}}{8.854 \times 10^{-12} \times 3.5}$$

$$= 66668.81\text{ N/C}$$

Ex. 3.3.3 : A capacitor consists of two parallel plates 0.5mm apart in air and each of effective area 500 cm^2 is connected to 500 V DC. Calculate : 1. Capacitance 2. Charge

W-10, S-13, 4 Marks

Soln. :

Given : Parallel plate air capacitor, d = 0.5 mm and a = 500 cm^2,
V = 500 Volts D.C.

Find : 1. Capacitance 2. Charge

Step 1 : Find capacitance :

$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$

$$\epsilon_0 = 8.854 \times 10^{-12}, \quad \epsilon_r = 1 \text{(Air capacitor)}$$

$$A = 500 \times 10^{-4}\ m^2$$

$$d = 0.5 \times 10^{-3}\ m$$

$$\therefore \quad C = \frac{8.854 \times 10^{-12} \times 500 \times 10^{-4}}{0.5 \times 10^{-3}}$$

$$= 8.854 \times 10^{-10}\ F \text{ or } 885.4\ pF \quad \text{...Ans.}$$

Step 2 : Find charge :

$$Q = C \times V = 885.4 \times 10^{-12} \times 500$$

$$Q = 4.427 \times 10^{-7} \text{ Coulombs or } 0.4427\ \mu C \text{ ...Ans.}$$

Ex. 3.3.4 : Calculate capacitance of a capacitor with a plate area of 400 cm^2 and a dielectric thickness of 1 mm. Dielectric is air.

S-11, 4 Marks

Soln. :

Given : A = 400 cm^2 and d = 1mm, Air dielectric

Find : Capacitance

$$C = \frac{\epsilon_0 \epsilon_r \times A}{d}$$

$$\epsilon_0 = 8.854 \times 10^{-12}, \epsilon_r = 1, A = 400 \times 10^{-4}\ m^2,$$

$$d = 1 \times 10^{-3}\ m$$

$$\therefore \quad C = \frac{8.854 \times 10^{-12} \times 400 \times 10^{-4}}{1 \times 10^{-3}}$$

$$= 3.5416 \times 10^{-10}\ F \text{ or } 354.16\ pF \quad \text{...Ans.}$$

Ex. 3.7.4 : Three capacitors have capacitances of 2 μF, 4 μF and 8 μF. Find the total capacitance when they are connected :

1. In series 2. In parallel

S-03, 8 Marks, S-12, 4 Marks

Soln. :

Given : $C_1 = 2\ \mu F$, $C_2 = 4\ \mu F$, $C_3 = 8\ \mu F$

To find : 1. C_S (Series combination) 2. C_P (Parallel combination).

1. Series combination :

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\therefore \frac{1}{C_S} = \frac{1}{2} + \frac{1}{4} + \frac{1}{8}$$

$$\therefore \frac{1}{C_S} = \frac{4+2+1}{8} = 0.875$$

$$\therefore C_S = \frac{1}{0.875} = 1.1428\ \mu F$$ **...Ans.**

2. Parallel combination :

$$C_P = C_1 + C_2 + C_3 = 2 + 4 + 8 = 14\ \mu F$$ **...Ans.**

Ex. 3.7.5 : Three capacitors have capacitances of 2 μF, 5 μF and 10 μF respectively.

Find resultant capacitance when they are connected –

1. In parallel 2. In series

W-03, 8 Marks

Soln. :

Given : $C_1 = 2\ \mu F$, $C_2 = 5\ \mu F$, $C_3 = 10\ \mu F$

To find :
1. C_S (Series combination)
2. C_P (Parallel combination)

1. Series combination :

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\therefore \frac{1}{C_S} = \frac{1}{2} + \frac{1}{5} + \frac{1}{10} = \frac{5+2+1}{10} = 0.8$$

$$\therefore C_S = \frac{1}{0.8} = 1.25\ \mu F$$ ...**Ans.**

2. Parallel combination :

$$C_P = C_1 + C_2 + C_3 = 2 + 5 + 10 = 17\ \mu F$$ ...**Ans.**

Ex. 3.7.6 : Three capacitors have capacitances of 2 μF, 5 μF and 10 μF respectively. Find resultant capacitance when they are connected.

1. In parallel 2. In series

Also find charge on each capacitor in both cases.

S-04, 8 Marks

Soln. :

Capacitance :

For the capacitance of series and parallel combination, Refer Ex. 3.7.5.

$$\therefore C_S = 1.25\ \mu F \text{ and } C_P = 17\ \mu F$$

Charge :

1. When the capacitors are connected in series, they will carry the same charge Q.
2. When the capacitors are in parallel, the voltage across them is same i.e. V volts. And $Q = C \times V$

$$\therefore Q_1 = C_1 V = 2 \times 10^{-6}\ V \text{ coulomb.}$$

$$Q_2 = C_2 V = 5 \times 10^{-6}\ V \text{ coulomb.}$$

$$\text{and } Q_3 = C_3 V = 10 \times 10^{-6}\ V \text{ coulomb.}$$

Ex. 3.7.7 : Three capacitors of values 4 μF, 8 μF and 16 μF respectively are connected in series across a 240 V d.c. supply. Calculate the resultant capacitance and p.d. across each capacitor.

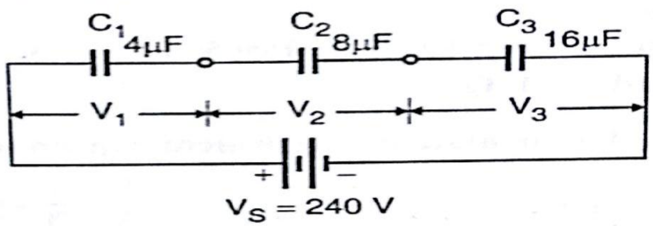
W-04, 8 Marks

Soln. :

Given : $C_1 = 4\ \mu F$, $C_2 = 8\ \mu F$, $C_3 = 16\ \mu F$, $V_S = 240$ V.

To find : 1. Resultant capacitance.

2. V_1, V_2, V_3.



(A-2877) **Fig. P. 3.7.7**

1. Resultant capacitance C_S :

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\therefore \frac{1}{C_S} = \frac{1}{4} + \frac{1}{8} + \frac{1}{16} = \frac{4+2+1}{16} = 0.4375$$

$$\therefore C_S = \frac{1}{0.4375} = 2.2857\ \mu F \quad \text{...Ans.}$$

2. P.D. across each capacitor :

The charge on each capacitor and the resultant capacitance will be the same i.e. Q.

$$\therefore Q = C_S V_S = 2.2857 \times 10^{-6} \times 240$$

$$\therefore Q = 5.4857 \times 10^{-4} \text{ coulomb.}$$

$$\text{Also } Q = C_1 V_1$$

$$\therefore V_1 = \frac{Q}{C_1} = \frac{5.4857 \times 10^{-4}}{4 \times 10^{-6}}$$

$$\therefore V_1 = 137.14 \text{ volts} \quad \text{...Ans.}$$

$$\text{Similarly, } V_2 = \frac{Q}{C_2} = \frac{5.4857 \times 10^{-4}}{8 \times 10^{-6}} = 68.57 \text{ volts ...Ans.}$$

$$V_3 = \frac{Q}{C_3} = \frac{5.4857 \times 10^{-4}}{16 \times 10^{-6}} = 34.28 \text{ volts ...Ans.}$$

Ex. 3.7.8 : Three capacitors A, B, C have capacitances 10, 50 and 25 microfarad respectively. Calculate :

1. Charge on each when connected in parallel to a 250 volt supply.
2. Total capacitance.
3. Potential difference across each when connected in series.

S-05, 8 Marks

Soln. :

Given : $A = 10\ \mu F$, $B = 50\ \mu F$, $C = 25\ \mu F$, $V_S = 250\ V$.

To find : 1. Q 2. C_S 3. V_A, V_B, V_C.

1. To calculate the equivalent capacitance :

$$\frac{1}{C_S} = \frac{1}{A} + \frac{1}{B} + \frac{1}{C}$$

$$= \frac{1}{10} + \frac{1}{50} + \frac{1}{25} = \frac{5+1+2}{50}$$

$$\therefore \frac{1}{C_S} = 0.16$$

$$\therefore C_S = 6.25\ \mu F$$ ...Ans.

2. Charge on each capacitor :

In series connection, the charge on each capacitor and the equivalent capacitor is same i.e. Q.

$$\therefore Q = C_S V_S = 6.25 \times 10^{-6} \times 250$$

$$Q = 1.5625 \times 10^{-3} \text{ coulomb}$$ ...Ans.

3. P.D. across each capacitor :

Let V_A, V_B and V_C be the potential difference across capacitors A, B and C respectively.

$$\therefore V_A = \frac{Q}{A} = \frac{1.5625 \times 10^{-3}}{10 \times 10^{-6}} = 156.25 \text{ volts}$$ ...Ans.

$$V_B = \frac{Q}{B} = \frac{1.5625 \times 10^{-3}}{50 \times 10^{-6}} = 31.25 \text{ volts}$$ ...Ans.

$$V_C = \frac{Q}{C} = \frac{1.5625 \times 10^{-3}}{25 \times 10^{-6}} = 62.5 \text{ volts}$$ ...Ans.

Ex. 3.7.9 : There are three capacitors 6 μF, 8 μF, and 12 μF. Find their equivalent in series combination and parallel combination.

W-07, 4 Marks

Soln. :

Given : $C_1 = 6\ \mu F$, $C_2 = 8\ \mu F$, $C_3 = 12\ \mu F$

1. Series combination :

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{6} + \frac{1}{8} + \frac{1}{12} = 0.375$$

$$\therefore C_S = 2.667\ \mu F \quad \text{...Ans.}$$

2. Parallel combination :

$$C_p = C_1 + C_2 + C_3 = 6 + 8 + 12 = 26\ \mu F \text{...Ans.}$$

Ex. 3.7.10 : Two capacitors A and B are charged as follows :

Capacitor A → 15 μF, 100 volt,

Capacitor B → 15 μF, 150 volt,

They are connected in parallel with terminals of like polarity together. Find the voltage across the combination.

W-07, 4 Marks

Soln. :

- The circuit diagram for series combination as per the given description is shown in Fig. P. 3.7.10.
- Capacitor C_B will discharge through capacitor C_A untill the voltages across the capacitors become equal.
- The charge on a capacitor is $Q = CV$

$$\therefore Q_A = C_A V \qquad Q_B = C_B V$$

The charge on individual capacitors before paralleling is,

$$\therefore Q_A = 100 \times 15 \times 10^{-6} = 1.5\ mC$$

$$\text{and } Q_B = 150 \times 15 \times 10^{-6} = 2.25\ mC.$$

$$\therefore \text{Total charge} = Q = Q_A + Q_B = 1.5 + 2.25 = 3.75\ mC.$$

$$\text{Total capacitance } C = C_A + C_B = 15 + 15 = 30\ \mu F$$

To find : C_{eq}

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

$$= 2 + 9 + 8 = 19\ \mu F \qquad \text{...Ans.}$$

Ex. 3.7.13 : Three capacitors have capacitances 2μF, 4μF and 8μF respectively. What is the effective capacitance when they are connected

1. in series 2. in parallel

If 100 V is applied across the series combination, what is the charge on each capacitor ? **W-10, 4 Marks**

Soln. :

Given : $C_1 = 2\ \mu F$, $C_2 = 4\ \mu F$, $C_3 = 8\ \mu F$

Find : 1. C_S (Series combination) 2. C_P (Parallel combination).

1. Series combination :

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\therefore \frac{1}{C_S} = \frac{1}{2} + \frac{1}{4} + \frac{1}{8}$$

$$\therefore \frac{1}{C_S} = \frac{4+2+1}{8} = 0.875$$

$$\therefore C_S = \frac{1}{0.875} = 1.1428\ \mu F \qquad \text{...Ans.}$$

2. Parallel combination :

$$C_P = C_1 + C_2 + C_3 = 2 + 4 + 8 = 14\ \mu F \qquad \text{...Ans.}$$

3. Charge on each capacitor for series connection :

Due to series connection, charge on each capacitor is same i.e. Q.

$$Q = C_S \times V = 1.1428 \times 10^{-6} \times 100$$

$$\therefore Q = 114.28\ \mu C \qquad \text{...Ans.}$$

ASSIGNMENT-3

1) A capacitor of 12μF is connected across a battery of 6 volt. Determine energy stored in this capacitor.
2) Define : (i) Dielectric strength (ii) Breakdown voltage (iii) Capacitor
3) State the relation for energy stored in a capacitor.
4) State the relationship between permittivity of free space and relative permittivity of air.
5) Derive an expression for the capacitance of parallel plate capacitor with medium partly air.
6) Find the equivalent capacitance of series parallel combination of capacitance shown in Fig. no. 2

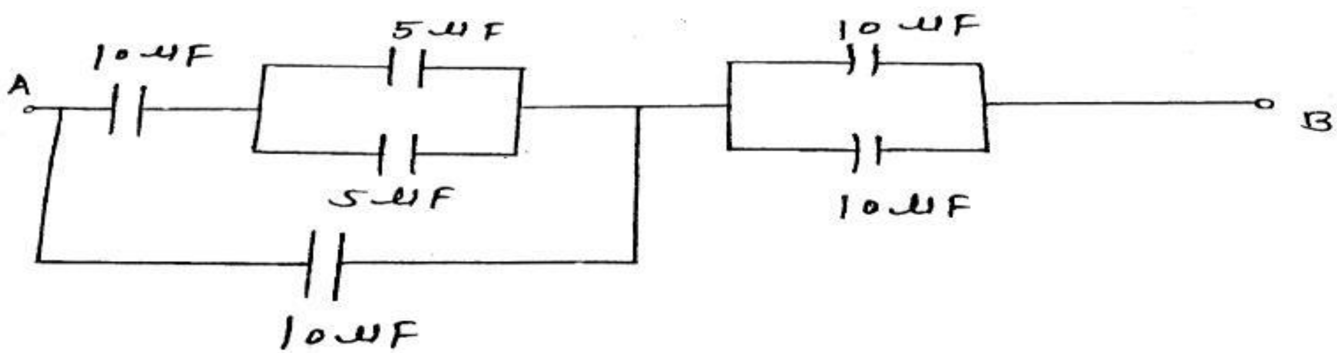
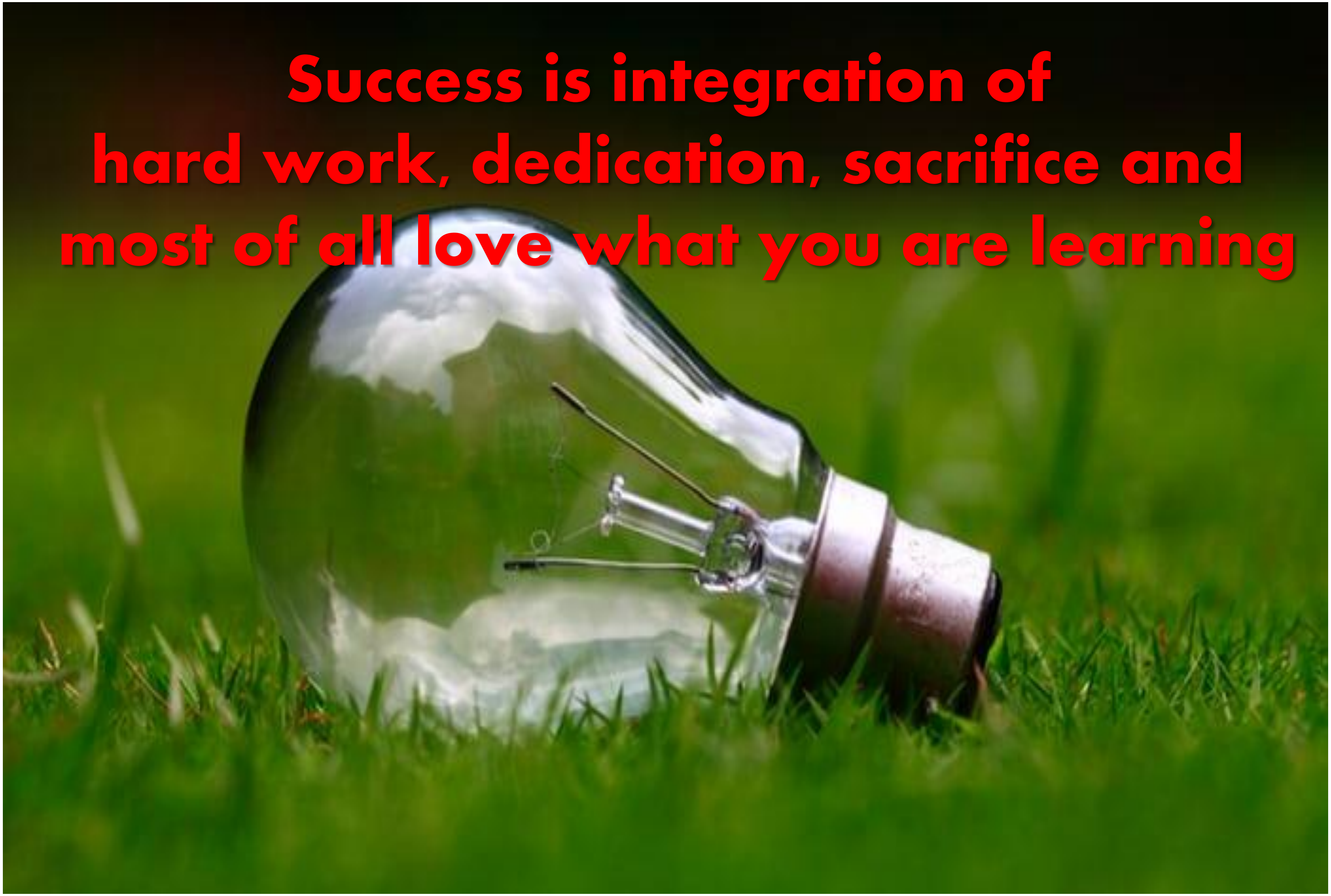


Fig. No. 2

7) The capacitance of capacitor formed by two parallel plates each of 200 cm2 area separated by dielectric of thickness 4 mm is 0.0004 μF. Voltage of 20,000 volt is applied to the capacitor. Calculate: i) Total charge on plates ii) Electric flux density.
8) State the applications of electrolytic capacitors. (any two)
9) Explain charging of a capacitor with neat circuit diagram.
10) Three capacitors having capacitance of 4μF, 6μF and 8μF respectively. Find the equivalent capacitance when they are connected in (i) Series (ii) Parallel.
11) Derive the expression for energy stored in the capacitor with the help of neat diagram.
12) Write two uses of Electrolytic capacitor.
13) The parallel plates of a capacitor each 460 cm using a dielectric material of permittivity 4.5. Calculate the capacitance and charge on each plate if voltage across plates is 415 V.
14) State relation for energy stored in a capacitor. A capacitor of 850 μF is charged to a voltage of 120 V. Calculate the energy stored by capacitor.
15) Three capacitors have capacitances 3μF, 5 μF and 7 μF. Find total capacitance when they are connected in i) series ii) parallel.
16) Explain electrolytic capacitor with neat diagram.


Success is integration of
hard work, dedication, sacrifice and
most of all love what you are learning