Electric Circuits

There are two types of electric circuits

i) Passive circuits ii) Active circuits

The circuits which contains resistors, capacitors and inductors are called passive circuits. And the circuits contain diode, transistors, integrated circuits are called active circuits.

In resistors circuits, current is directly proportional to applied voltage. The capacitors require current is directly proportional to the rate of change of voltage and in inductors the voltage required is directly proportional to the rate of change of current

Resistors

The resistors are the electric component which have some value of resistance. It means it is a current limiting component. So every circuit act as a short circuit without resistor.

Some uses of resistors are:

i) To establish proper values of circuit voltage due to **IR** drops
ii) To limit current
iii) To provide load

Types of resistors

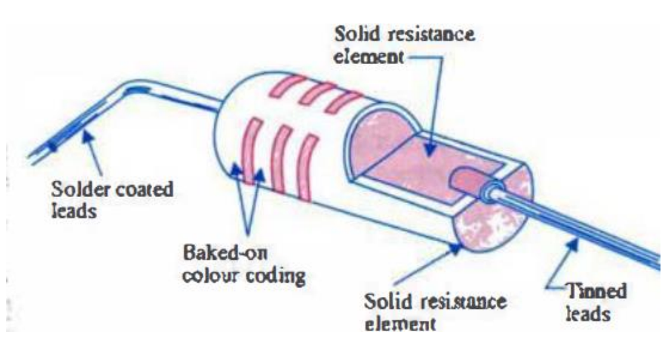
There are mainly two types

i) Wire-wound resistors
ii) Carbon resistors

Wire-wound resistors

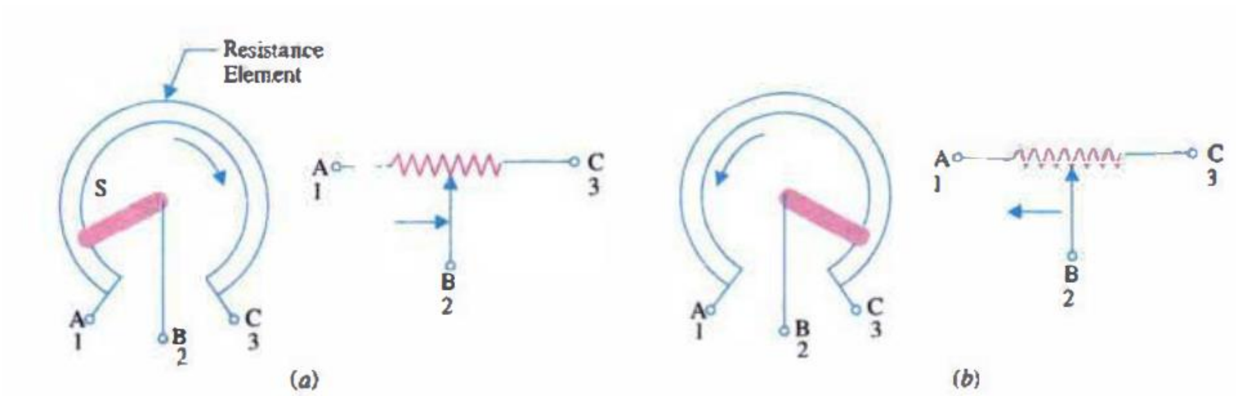
They are constructed from a long wire wounded on a ceramic core. The length of wire and its resistivity determine the resistance. The Rheostat is one of example.The wire-wound resistors where large power dissipation is required and for shunting the meter.

Carbon composition resistors They are made by fine carbon mixed with a powered insulating material with a proper ratio. This material is enclosed in a plastic case for insulation and mechanical strength. The two ends of the carbon resistance element are joined to metal caps with leads of thin wire for connection in a circuit as shown



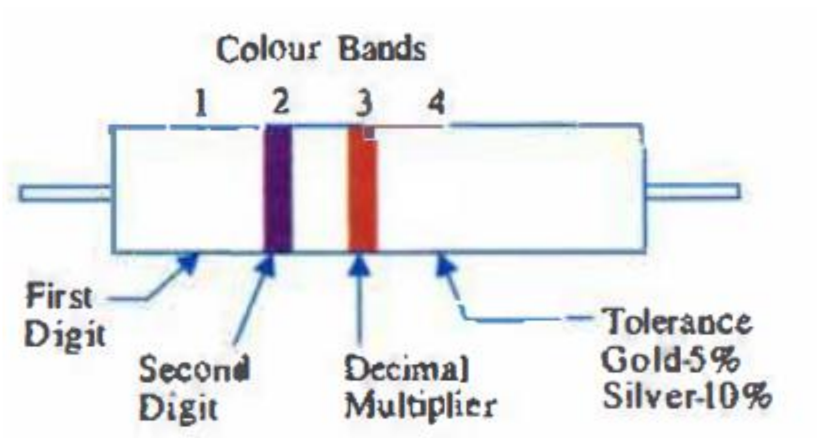
Variable Resistors

These are the resistors whose resistance can be changed between zero and a certain maximum value. This is wire or carbon type.as shown in the fig. the sliding arm is attached to the shaft which can be rotated almost in a complete circle. As the shaft rotates, the point of contact of the sliding arm on the circular carbon resistance, which changes the resistance from terminal B and the terminal of stationary resistance. If fig(a) the resistance between A and B increases, where as between B and C decreses. But in fig(b) the resistance between B and C increases and decreases between B and A.



Resistors Colour Code

The resistance of the carbon resitors can be determined by using colour code



Colour	*Value*
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

Starting from left to right, the colour bands (Fig. 5.9) are interpreted as follows :

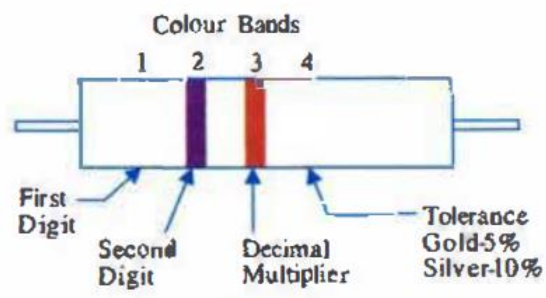
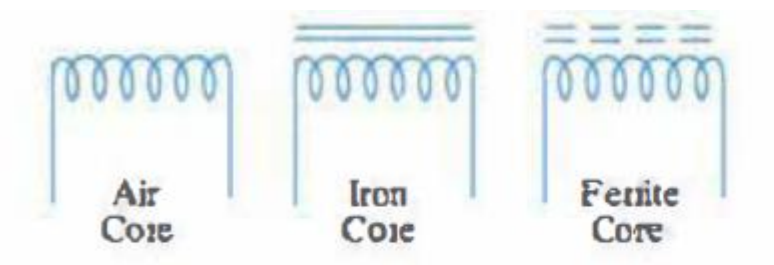


Fig. 5.9

1. The first band close to the edge indicates the first digit in the numerical value of the resistance.
2. The second band gives the second digit.
3. The third band is *decimal multiplier i.e.*, it gives the number of zeros after the two digits. It is important to note that if the third band is black, it means *"do not add zeros to the first two digits"*. The resulting number is the resistance in ohms.
4. The fourth band gives resistance tolerance. If there is no fourth band, tolerance is under-

Inductor it is another basic electric component, it is simply a coil wound on a core of suitable material. There are different types (a) air core inductor (b) iron core inductor and ferrite-core inductor.

In the air core inductors, the wire wounded on insulating material like cardboard or air. The air core inductor has the least inductance. Where as in iron-core the coil is wound over a solid or laminated iron-core. The iron core inductor increases the inductance.



Ferrite-core Inductor

In this type of inductors, the coil is wound on feromagnetic called ferrite. The ferrite is a solid material consisting of fine particle of iron powder embedded in an insulting binder.the firrite minmize the eddy current loss. These inductors have high inductance value.

Inductance of an inductor

Inductance is the property of the coil which opposes any change of current through it, it is represented by **L** and its unit is Henry(H). the inductance of the coil is given

$$L = \mu_o \frac{N^2.A}{\ell}$$

Where:

L is in Henries

μ_o is the Permeability of Free Space ($4.\pi.10^{-7}$)

N is the Number of turns

A is the Inner Core Area (πr^2) in m^2

ℓ is the length of the Coil in metres

The inductance of iron core inductor is

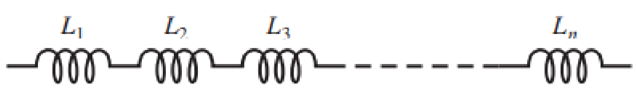
$$L = \frac{\mu_0 \mu_r A N^2}{l} \text{ henrys}$$

The inductance is also defined as the ratio of induced voltage to the rate of change of current. The unit of inductance is henry(H) and defined as the emf of 1 volt is induced if the current changes at the of 1 amp/sec

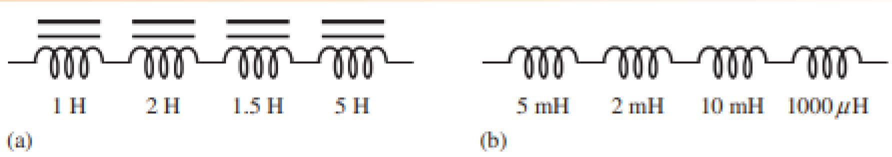
Total Series Inductance

When inductors are connected in series, as in Figure the total inductance, L_T, is the sum of the individual inductances. The formula for L_T is expressed in the following equation for the general case of n inductors in series:

$$L_T = L_1 + L_2 + L_3 + \cdots + L_n$$



Determine the total inductance for each of the series connections in Figure .



Total Parallel Inductance

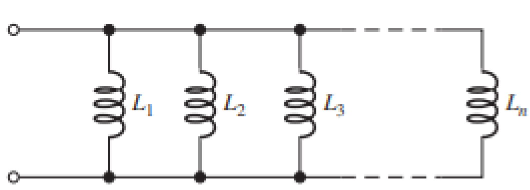
When inductors are connected in parallel, as in Figure 15, the total inductance is less than the smallest inductance. The general formula states that the reciprocal of the total inductance is equal to the sum of the reciprocals of the individual inductances.

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \cdots + \frac{1}{L_n}$$

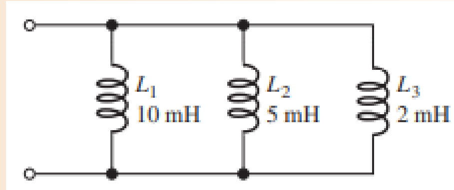
You can calculate total inductance, L_T, by taking the reciprocals of both sides of the previous equation.

$$L_T = \frac{1}{\dfrac{1}{L_1} + \dfrac{1}{L_2} + \dfrac{1}{L_3} + \cdots + \dfrac{1}{L_n}}$$

This calculation for total inductance in parallel is analogous to the calculations of total parallel resistance and total series capacitance. For series-parallel combinations of inductors, determine the total inductance in the same way as total resistance in series-parallel resistive circuits.



Determine L_T in Figure



Inductive Reactance, X_L

By inductive reactance means the resistance of the inductor. As inductor is an AC component that it only respond upon the frequencies of AC signal where as it behave as close switch for DC source because the frequeny of DC source is zero.

Thus inductive reactance is the opposition to the sinusoidal current in an inductor. The symbol for inductive reactance is $\mathbf{X_L}$ and its unit is ohm(Ω).

The formula for inductive reactance is $\mathbf{X_L = 2\pi f L}$

Example

A sinusoidal voltage of 10kHz is apllied across an inductor of inductance 5mH. Determine the inductive reactance?

Solution Convert 10 kHz to 10×10^3 Hz and 5 mH to 5×10^{-3} H. Then, the inductive reactance is

$$X_L = 2\pi f L = 2\pi(10 \times 10^3 \text{ Hz})(5 \times 10^{-3} \text{ H}) = \mathbf{314\ \Omega}$$

Example 5.2. *Calculate the inductive reactance offered by a coil of inductance 250 μH to radio-frequency currents of frequencies (i) 1 MHz and (ii) 10 MHz.*

Solution. (*i*) $X_L = 2\pi f L$

$= 2\pi \times (1 \times 10^6) \times (250 \times 10^{-6}) = \mathbf{1570\ \Omega}$

(*ii*) $X_L = 2\pi \times (10 \times 10^6) \times (250 \times 10^{-6}) = \mathbf{15{,}700\ \Omega}$

As seen, X_L increase proportionally with increase in frequency.

Reactance for series or parallel inductors

If the number of inductors are connected in series, the total reactance can be determined as

$$X_{L(tot)} = X_{L1} + X_{L2} + X_{L3} + \cdots + X_{Ln}$$

But if the inductors are connected in parallel, then the total reactance is

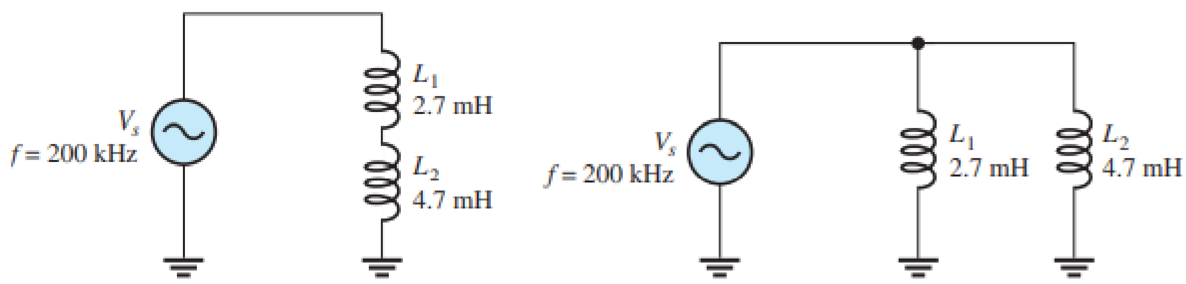
$$X_{L(tot)} = \cfrac{1}{\cfrac{1}{X_{L1}} + \cfrac{1}{X_{L2}} + \cfrac{1}{X_{L3}} + \cdots + \cfrac{1}{X_{Ln}}}$$

For two inductors in parallel, the reactance can be determined as

$$X_{L(tot)} = \frac{X_{L1}X_{L2}}{X_{L1} + X_{L2}}$$

Example

Wtat is the total reactance of the following circuits.



(a) (b)

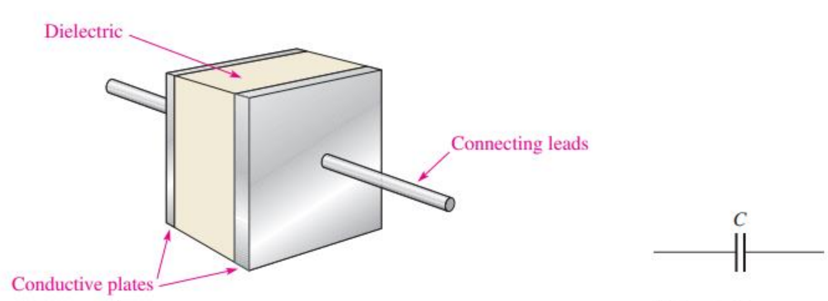
Ohm's Law for Inductors

Ohm's Law The reactance of an inductor is analogous to the resistance of a resistor. In fact, X_L, just like X_C and R, is expressed in ohms. Since inductive reactance is a form of opposition to current, Ohm's law applies to inductive circuits as well as to resistive circuits and capacitive circuits; and it is stated as follows:

$$I = \frac{V}{X_L}$$

Capacitor

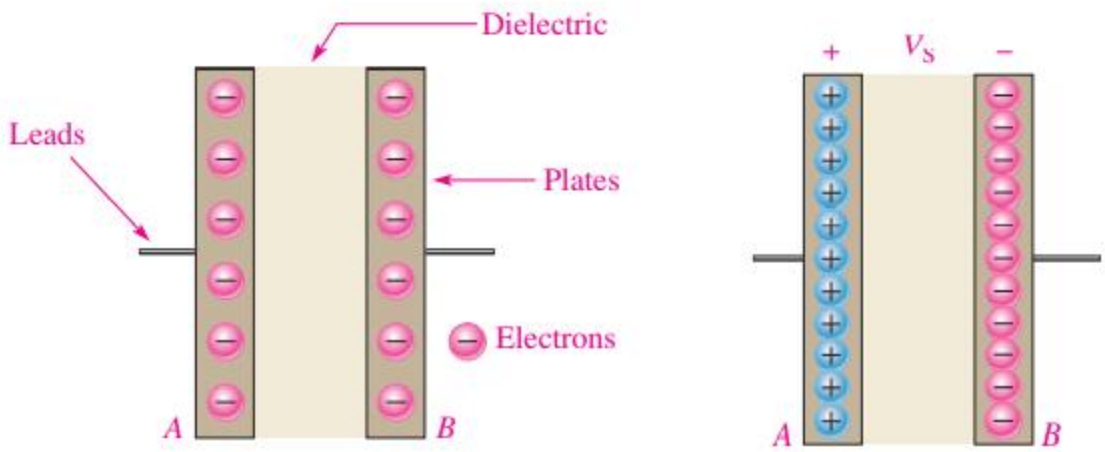
Capacitor is an other passive component that is used in electric circuit. It is used to store charge.A capacitor consists of two conducting parallel plates seperated by an insulating matrial called dielectric for example air, mica,ceramic,paper etc.The construction and symbolic representation of capacitor is



(a) Construction (b) Symbol

Charging of Capacitor

When the conducting plates of a parallel plate capacitor are connected with a DC source,one plate become positively charged and other become negatively charged as shown in fig. the left fig show an uncharged capacitor and the right fig show charged capacitor.



Capacitance

The capacitance measures the capacitor's ability to store charge. It is the ratio charge to applied voltage.

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

By rearranging this equation we get anpther two formula i.e. **Q = CV** and $\boldsymbol{V = \frac{Q}{C}}$

Unit of capacitance

The farad (F) is the basic unit of capacitance. One farad is the amount of capacitance when one coulomb of charge is stored with one volt across the plates.

Most capacitors used in electronics circuits have capacitance values in microfarads (μF) and picofarad (pF). **1 μF = 1x10^{-6}F** and **1 pF = 1x10^{-12}F**

Capacitance of a capacitor may also defined in terms of its property to oppose the rate of change of voltage in the circuit. In this case

$$C = \frac{I}{dV/dt}$$

Where $\;dV/dt$ = rate of change of voltage

I = charging current

If I= 1Amp and dV/dt = 1volt/sec, then C= 1Farad

Hence 1 Farad may be defined as capacitance when 1 Amp current flow as the applied voltage changes 1volt/1 sec.

Example 5.4. *What is the capacitance of a capacitor if a charging current of 100 mA flows when the applied voltage changes 20 V at a frequency of 50 Hz?*

Solution. $C = \frac{i}{dv/dt}$

Now, $i = 100\text{ mA} = 100 \times 10^{-3}\text{ A} = 0.1\text{ A}$

$dv = 20\text{ V},\; dt = 1/50 = 0.02\text{ s}$

$C = \frac{0.1}{20/0.02} = 0.1 \times 10^{-3}\text{ F}$

$= 100 \times 10^{-6}\text{ F} = \mathbf{100\ \mu F}$

Example

(a) A certain capacitor stores 50 microcoulombs (50 μC) when 10 V are applied across its plates. What is its capacitance?

(b) A 2.2 μF capacitor has 100 V across its plates. How much charge does it store?

(c) Determine the voltage across a 100 pF capacitor that is storing 2 μC of charge.

Solution **(a)** $C = \frac{Q}{V} = \frac{50\ \mu\text{C}}{10\ \text{V}} = \mathbf{5\ \mu F}$

(b) $Q = CV = (2.2\ \mu\text{F})(100\ \text{V}) = \mathbf{220\ \mu C}$

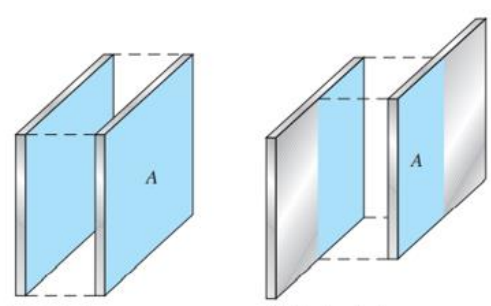
(c) $V = \frac{Q}{C} = \frac{2\ \mu\text{C}}{100\ \text{pF}} = \mathbf{20\ kV}$

Physical Characteristics of a capacitor

The following parameters upon which the capacitance of a capacitor depend (i) plate area (ii) plate seperation (iii) medium or dielectric constant.

(i) Plate area

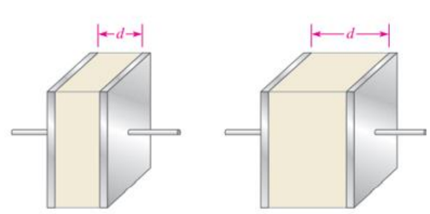
Capacitance is directly propertional to the physical size of the plates as determined by the plate area. The greater the effective area the more charge store so more capactance, the smaller the effective area, small charge store hence less capacitance as shown in fig.



(a) Full plate area: more capacitance (b) Reduced plate area: less capacitance

(ii) Plate seperation

Capacitance is inversely propertional to the seperation between the plates. A greater seperation store less charge.



(a) Plates closer together: more capacitance (b) Plates further apart: less capacitance

Dielecrtic Constant

The insulating material between the plates of capacitor is called dielectric. Every dielectric material has ability to establish the electric field is called dielectric constant or relative permittivity. Capacitance is directly propertional to dielectric constant. For air its value is nearly 1. Some typically values

MATERIAL	TYPICAL ε_r VALUE
Air (vacuum)	1.0
Teflon®	2.0
Paper (paraffined)	2.5
Oil	4.0
Mica	5.0
Glass	7.5
Ceramic	1200

The dielectric constant (relative permittivity) is dimensionless because it is a relative measure. It is a ratio of the absolute permittivity of a material, ε, to the absolute permittivity of a vacuum, ε_0, as expressed by the following formula:

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

The value of ε_0 is 8.85×10^{-12} F/m (farads per meter).

Formula for Capacitance You have seen how capacitance is directly related to plate area, A, and the dielectric constant, ε_r, and inversely related to plate separation, d. An exact formula for calculating the capacitance in terms of these three quantities is

$$C = \frac{A\varepsilon_r(8.85 \times 10^{-12}\ \text{F/m})}{d}$$

where A is in square meters (m^2), d is in meters (m), and C is in farads (F).

Example

Determine the capacitance in μF of a parallel plate capacitor having a plate area of 0.01 m^2 and a plate separation of 0.5 mil (1.27×10^{-5} m). The dielectric is mica, which has a dielectric constant of 5.0.

$$C = \frac{A\varepsilon_r(8.85 \times 10^{-12}\ \text{F/m})}{d} = \frac{(0.01\ \text{m}^2)(5.0)(8.85 \times 10^{-12}\ \text{F/m})}{1.27 \times 10^{-5}\ \text{m}} = \mathbf{0.035\ \mu F}$$

Example 5.5. *What is the capacitance of a parallel-plate capacitor of plate area 0.01 m^2 and air dielectric of thickness 0.01 m ?*

If the capacitor is given a charge of 500 $\mu\mu$C, what will be the p.d. between its plates?

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

Remembering that for air, $\varepsilon_r = 1$, we get

$$C = \frac{8.854 \times 10^{-12} \times 1 \times 0.01}{0.01} = 8.854 \times 10^{-12}\ \text{F} = \mathbf{8.854\ \mu\mu F}$$

Now, $$C = \frac{Q}{V} \quad \text{or} \quad V = \frac{Q}{C}$$

$\therefore$ $$V = \frac{500\ \mu\mu C}{8.854\ \mu\mu F} = \mathbf{56.5\ V}$$

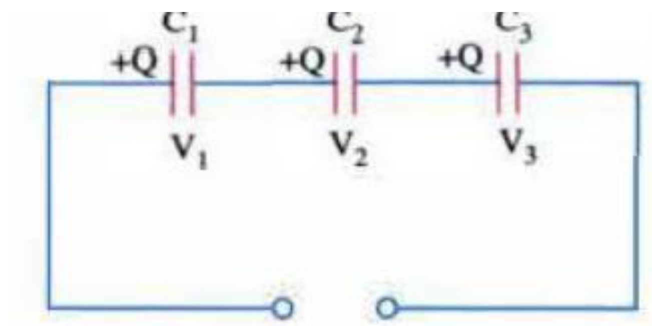
Combination of capacitors

There are two combinations (i) series combination (ii) parallel combination.

Series Combination

By series combination means the capacitors are placed side by side as shown in fig.

The following points should be noted when capacitor are connected in series,



1. Charge on each capacitor will be same irrespective of its capacitance.
2. Potential difference across each capacitor is different and inversely propertional to its capacitance.
3. Sum of voltages across each capacitor equal the applied voltage.

$$\mathbf{V = V_1+V_2+V_3}$$

4. The combined capacitance is given as

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

Thus in series arrangment the combined capacitance will be less than individal capacitance.

In the case of two capacitors in series, the charge on each capacitor is same but voltages are different. Then

1. $$C = \frac{C_1 C_2}{C_1 + C_2}$$
2. $$V_1 = V \frac{C_2}{C_1 + C_2}$$
3. $$V_2 = V \frac{C_1}{C_1 + C_2}$$

5.47. Capacitors in Parallel

Connecting capacitors in parallel is equivalent to *adding their plate areas.* Hence, combined capacitance equals the sum of individual capacitances.

Following facts about parallel combination of capacitors (Fig. 5.35) should be noted :

1. charge across each capacitor is different, being directly proportional to its capacitance
   ($\because \quad Q = CV$)
2. p.d. across each capacitor is the same *i.e.*, the applied voltage V,
3. the sum of the individual charges is equal to the total charge supplied by the power source
   $$Q = Q_1 + Q_2 + Q_3$$
4. combined capacitance is equal to the sum of individual capacitances
   $$C = C_1 + C_2 + C_3$$

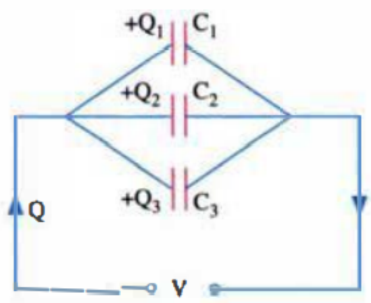


Fig. 5.35

5.48. Two Capacitors in Parallel

Consider the case when only two unequal capacitors are connected in parallel as shown in Fig. 5.36. In this case

1. since V is the same across both capacitors
   $$\because \qquad V = \frac{Q_1}{C_1} = \frac{Q_2}{C_2}$$
   $$\therefore \qquad \frac{Q_1}{C_1} = \frac{Q_2}{C_2} \text{ or } \frac{Q_1}{Q_2} = \frac{C_1}{C_2}$$
2. the two capacitor charges can be expressed in terms of the total charge Q taken from the power source.
   $$Q_1 = Q\frac{C_1}{C_1 + C_2}; \; Q_2 = Q\frac{C_2}{C_1 + C_2}$$

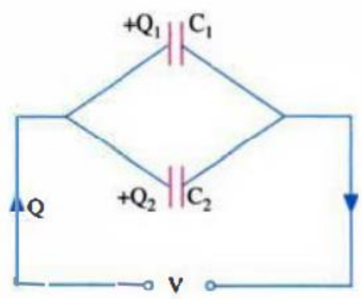


Fig. 5.36

Example 5.7. *Two capacitors of 4 μF and 12 μF capacitance and each of working-voltage rating of 24 V are connected in series across a 24 V battery. Calculate*

1. *charge across each,* 2. *voltage across each,* 3. *combined voltage rating.*

Solution. 1.
$$C = \frac{C_1 C_2}{C_1 + C_2} = \frac{4 \times 12}{4 + 12} = 3 \mu C$$
$$Q = CV = 3 \times 24 = 72 \ \mu C$$

Each of the two series-connected capacitors will have the same charge.

2.
$$V_1 = V\frac{C_2}{C_1 + C_3} = 24 \times \frac{12}{16} = \mathbf{18 \ V}$$
$$V_2 = V\frac{C_1}{C_1 + C_2} = 24 \times \frac{4}{16} = \mathbf{6 \ V}$$

Alternatively, since charge across each capacitor is 72 μC and their capacitances are known, values of V_1 and V_2 can be easily found from this data.

$$V_1 = Q/C_1 = 72/4 = 18 \text{ V}; \quad V_2 = Q/C_2 = 72/12 = 6 \text{ V}$$

3. Combined voltage rating is $= 24 + 24 = \mathbf{48 \ V}$

Example 5.7. *Two capacitors of 4 μF and 12 μF capacitance and each of working-voltage rating of 24 V are connected in series across a 24 V battery. Calculate*

1. *charge across each.* 2. *voltage across each,* 3. *combined voltage rating.*

Solution. 1.

$$C = \frac{C_1 C_2}{C_1 + C_2} = \frac{4 \times 12}{4 + 12} = \mathbf{3\,\mu C}$$

$$Q = CV = 3 \times 24 = \mathbf{72\,\mu C}$$

Each of the two series-connected capacitors will have the same charge.

2.

$$V_1 = V\frac{C_2}{C_1 + C_3} = 24 \times \frac{12}{16} = \mathbf{18\,V}$$

$$V_2 = V\frac{C_1}{C_1 + C_2} = 24 \times \frac{4}{16} = \mathbf{6\,V}$$

Alternatively, since charge across each capacitor is 72 μC and their capacitances are known, values of V_1 and V_2 can be easily found from this data.

$$V_1 = Q/C_1 = 72/4 = 18\text{ V}; \quad V_2 = Q/C_2 = 72/12 = 6\text{ V}$$

3. Combined voltage rating is = 24 + 24 = **48 V**