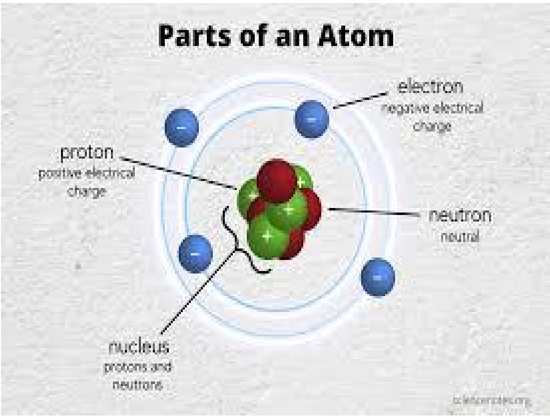
Brief history of electricity

Following are the prominent contributors to today's electrically energised world.

- In 1752 Benjamin Franklin ran his famous kite experiment that sparked the discovery of electricity
- In 1831 Michael Faraday (Also known as father of electricity) proved that electric current could be produced by passing a magnet through a copper wire
- In 1879 Thomas Edison invented electric bulb
- In 1900 Samuel Insull developed world's first modern power grid
- After 1900 s by understanding the importance of renewable energy a shift to alternative and renewable energy was observed. Hydroelectric projects and wind power plants were constructed
- AS we move towards 2025 electricity is being harnessed in ways few could have imagined. Tesla motors is revolutionised the way we drive with well advanced electric cars.

Nature of atom



- Matter composed of molecules.
- Molecules are made up of atoms.
- Atoms consist of positively charged central core – nucleus and negatively charged electrons revolving around it in fixed orbits.
- The nucleus contains positively charged protons and neutral neutrons.
- The number of protons and number of electrons is same in an atom
- The charge of proton is equal to the charge of proton
- An atom is electrically neutral.

CHARGE

- In a body if the no of electrons = no of protons, then the body is electrically neutral.
- If some electrons are removed from a neutral body then there is deficiency of electrons and the body attains positive charge.
- If some electrons are supplied to a neutral body then there is excess of electrons and the body attains negative charge.
- SI Unit of charge is Coulomb

Electric potential

- When a body is charged, work is done to develop charge

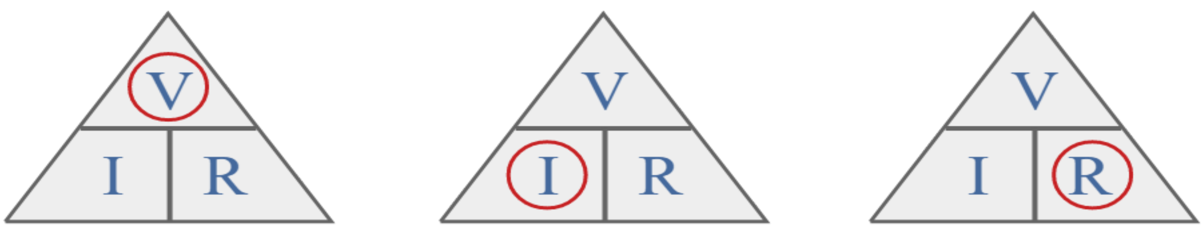
- Work done per unit charge to develop charge is called electric potential
- SI unit of electric potential is Volt

Electric potential difference/ Voltage
The difference in Electric potential between two bodies is called potential difference or voltage.
When we have electrical potential difference between two points in a conductor, electrons can flow from one point to another. The flow of electrons constitutes electric current.
SI unit of electric potential difference is **volt (V).**

- A device that maintains potential difference between two points is said to have electro motive force (emf).
  eg: electric cell

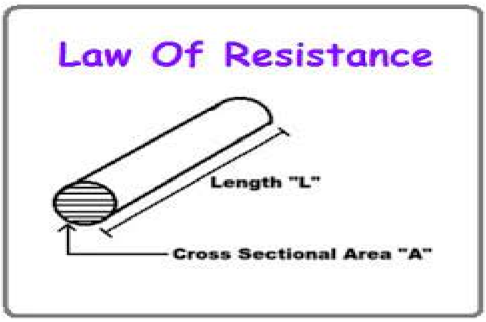
Electric current
Electric Current is the rate of flow of electrons in a conductor. The SI Unit of electric current is the **Ampere(A)**. The direction of electric current is opposite to the direction of electron flow or it is the direction of flow of a positive charge.
Resistance
Property of a material due to which it opposes the flow of electric current through it is called resistance unit of resistance is **Ohm(Ω)**
Electric energy
Energy generated by the movement of electrons from one point to another . SI unit is Joule(J)
Electric power
The rate at which work is done or energy is transferred from one point to another point in an electric circuit is called electric power. SI unit is Watts or Joules/second

Ohms law
At constant temperature, the current flowing through a conductor is directly proportional to potential difference applied across it.
$I \propto V$
V/I is a constant
V/I =R,
Where R is the resistance of the conductor.
Mathematical expressions of Ohm's law



$V = I R$ $\quad$ $I = \frac{V}{R}$ $\quad$ $R = \frac{V}{I}$

Laws of resistance

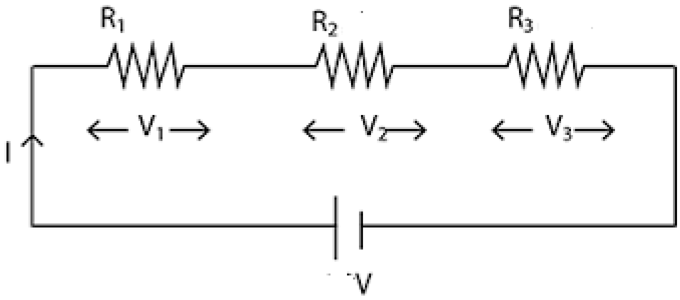


First law: The resistance offered by a conductor is directly proportional to length of the conductor ($R \propto L$)
Second law : The resistance offered by conductor is inversely proportional to its area of cross section($R \propto (1/A)$)
Third law: The resistance offered by a conductor depends upon the nature of the material
Fourth law: The resistance offered by a conductor depends upon temperature

Combining first and second law, we can write $R \propto (L/A)$
Multiplying with a proportionality constant ρ
$R= \rho L/A$
Where ρ(ro) is known as resistivity of the material
When $L=1m$ and $A= 1m^2$, then $R=\rho$
Hence resistivity can be defined as the resistance offered by a material of length 1m and area of cross section $1m^2$. Resistivity is also known as specific resistance and its unit is Ωm

Combination of resistors

Series combination of resistors derivation of equivalent resistance



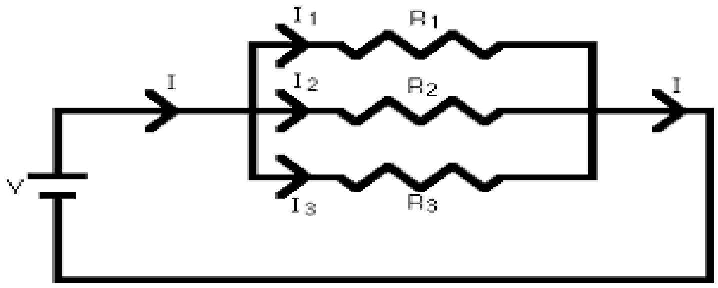
Consider a series circuit consisting of three resistors R1,R2 and R3 connected to a voltage source V. Let I be the current flowing through the resistors . Let V1, V2, V3 be the voltage across each individual resistor.
We have V=V1+V2+V3 and we know according to ohms law V=IR
If Req is the equivalent resistance, then
V=IReq
V_1=IR1
V_2=IR2

V_3= IR3

IReq=IR1+IR2+IR3
Ie; IReq=I(R1+R2+R3)
ie;**Req=R1+R2+R3**

In the same way equivalent resistance for any number of resistance connected in series can be derived.

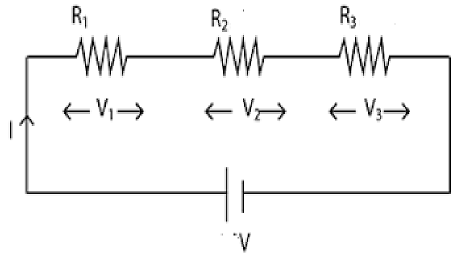
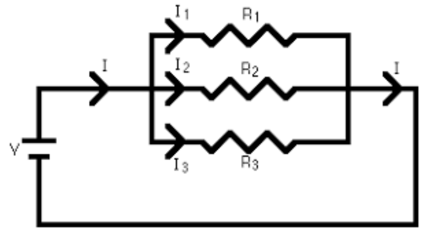
Parallel combination of resistors derivation of equivalent resistance



Consider three resistors R1,R2,R3 connected in parallel to a voltage source V. Let I1,I2,I3 be the current flowing through each resistors and I be the current supplied by the source. Let Req be the equivalent resistance of the combination. We know according to Ohms law I=V/R
In the above circuit we have $I=I_1+I_2+I_3$
I=V/Req
I1=V/R1
I2=V/R2
I3=V/R3
(V/Req)=(V/R1)+(V/R2)+(V/R3)
ie;(1/Req)=(1/R1)+(1/R2)+(1/R3)
By taking the reciprocal of 1/Req, the equivalent resistance can be obtained. Similar method can be adopted for the derivation of any number of resistors connected in parallel.

Problems
Solve problems based on series, parallel, series parallel combinations

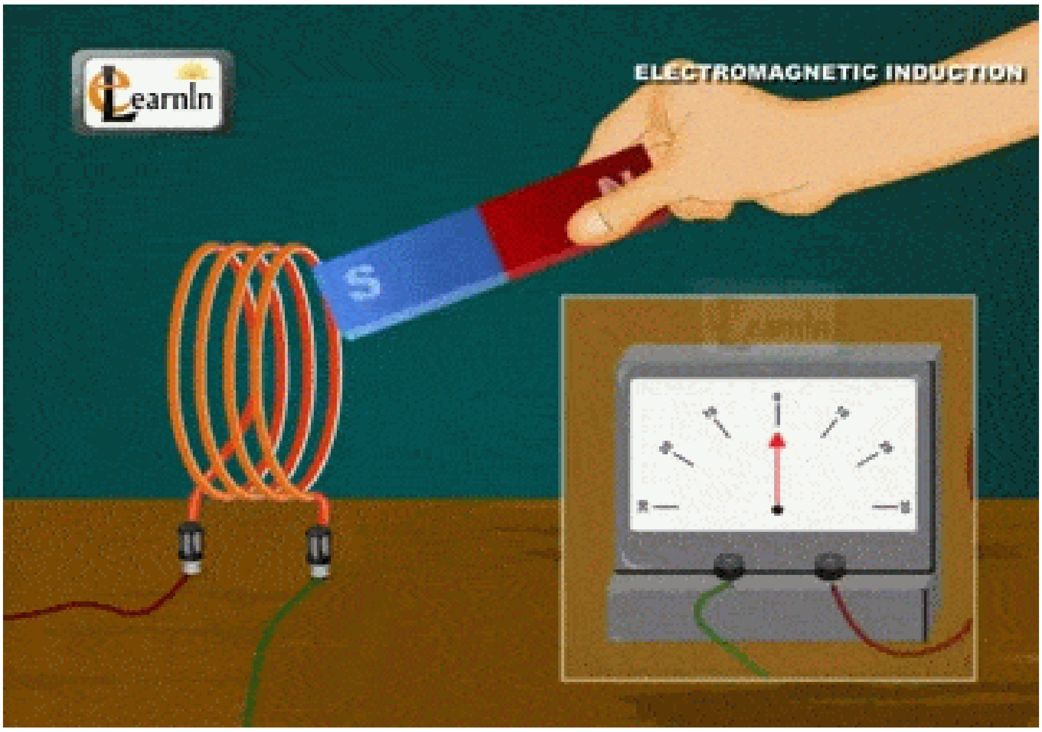
Comparison between series and parallel circuit

Series circuit	Parallel circuit
	 A figure showing three resistors in parallel

A figure showing three resistors in series is given. Here components are arranged in a line	is shown. Here components are arranged parallel to each other
Same current flows through all resistors I=I1=I2=I3	The total current supplied to the circuit is the sum of current through several branches I=I1+I2+I3
The total voltage is equal to sum of voltage across different resistors in the circuit V=V1+V2+V3	The same supply voltage appears across all elements V=V1=V2=V3
If a component gets disconnected, current through all circuit breaks	Other components will work if any component breaks down
The total resistance is equal to sum of the resistance of individual resistors	The reciprocal of total resistance is equal to the reciprocal of individual resistors

Electro Magnetic Induction

When a magnetic field embracing a conductor moves relative to the conductor, it produces a flow of electrons in the conductor and a potential difference is developed. The electrical potential developed due to changing magnetic field is electro motive force or EMF. This phenomenon where an e.m.f. and hence current (i.e., flow of electrons) is induced in any conductor which is cut by a magnetic field is known as electromagnetic induction.
Discovered by Michael Faraday.



Faraday's laws of electromagnetic induction

Faraday's First Law of Electromagnetic Induction

Whenever the magnetic flux linked with a circuit changes, an emf is induced in it.

Or

Whenever a conductor cuts magnetic field, an emf in induced in the conductor

Faraday's Second Law of Electromagnetic Induction

The magnitude of induced emf is equal to the rate of change of flux linkage.

$e=N\frac{d\Phi}{dt}$

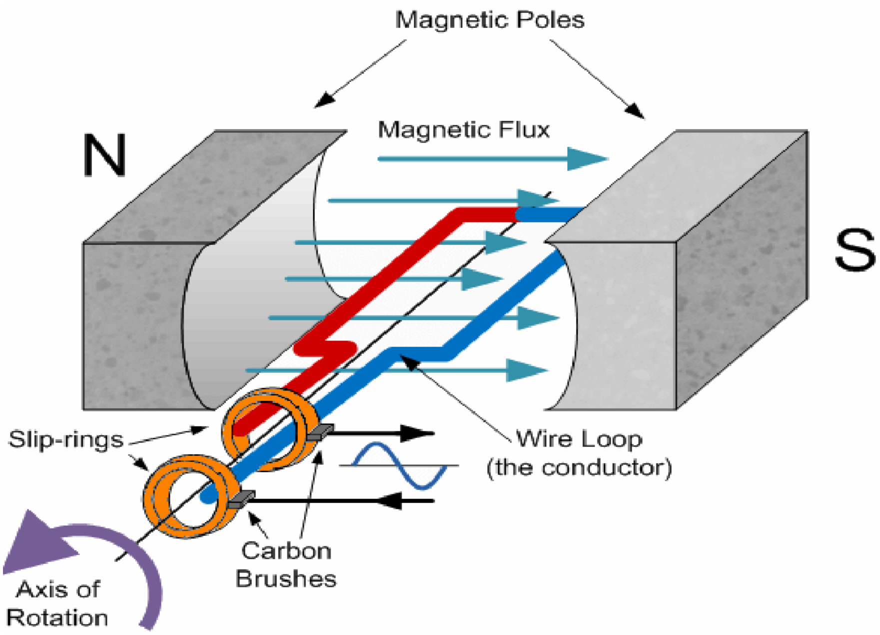
N is the number of turns of the coil

Φ is the flux linked with the coil

T is the time

Generation of ac voltage

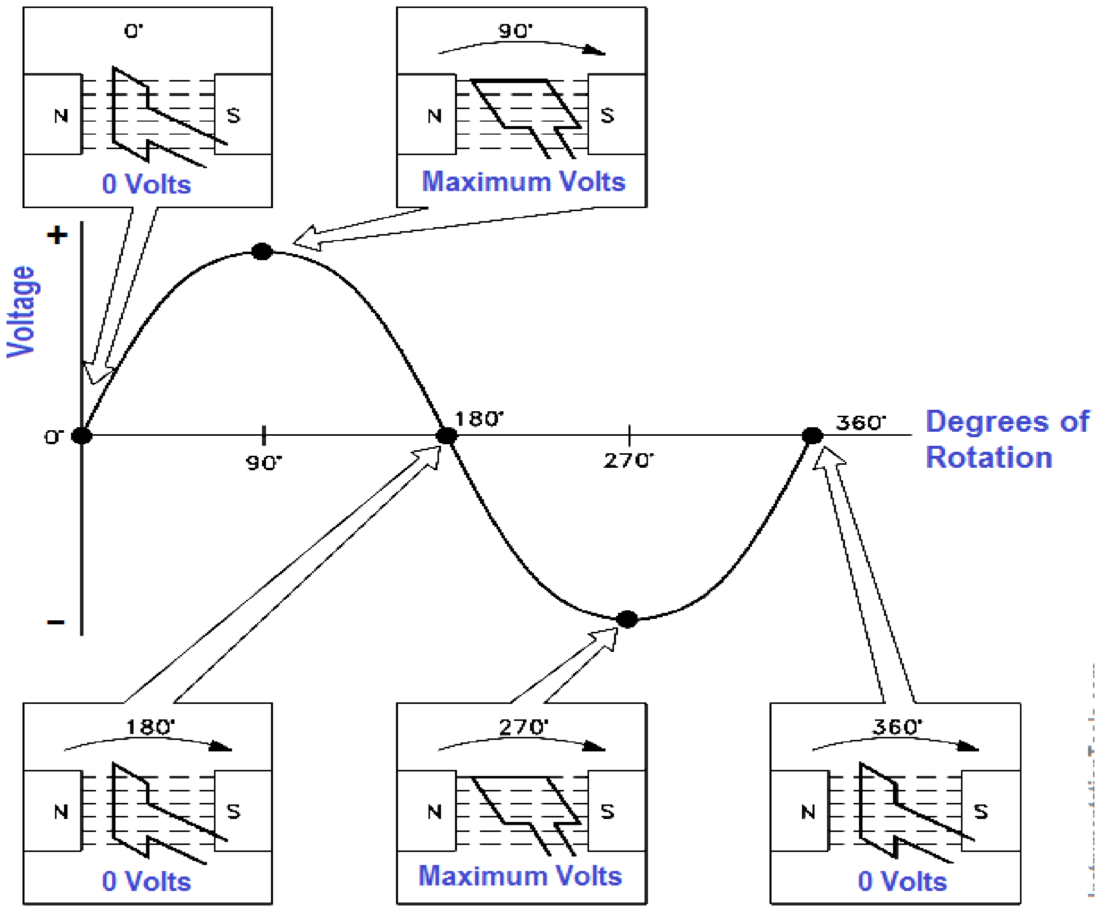
AC voltage is generated by rotating a coil in a magnetic field.



- Consider a single loop generator as shown in figure . A rotating coil is placed in magnetic field. Each conductor in the coil is connected to a slip ring and carbon brushes are placed in contact with slip rings to collect the generated current. The coil is rotated with the help of a prime mover. The slip rings also rotate along with the coil.
- The shape of induced emf for each degree of rotation is shown in figure below.

- Start from the condition when the plane of coil is perpendicular to the magnetic field (0^{o}) .At this condition the magnitude of induced emf is zero because the conductors of coil do not cut any magnetic flux lines.
- As the coil continues to rotate, the coil sides begin to cut magnetic flux lines and induced emf increases. At 90^{o} , when the plane of coil is parallel to plane of magnetic flux,the induced emf is maximum since coil sides cut maximum flux lines.
- Again as the coil rotates the induced emf reduces and becomes zero when the plane of the coil becomes perpendicular to the plane of magnetic field at 180^{o}.
- As the coil rotates from 180^{o} to 270^{o}, the induced emf gain increases but in opposite direction since the coil sides interchanged their position.

- At 270° the induced emf is maximum but in the opposite direction. From 270° to 360° (0°), the induced emf again reduces. As shown in figure, the shape of generated emf is sine wave.



The magnitude of emf induced depends on

(i) Speed: The speed at which coil rotates inside the magnetic field.

(ii) Strength: The strength of the magnetic field.

(iii) Length: The length of the conductor passing through the field.

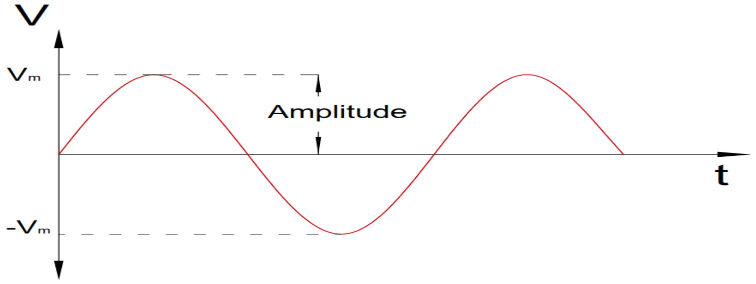
Basic terms in ac system

Instantaneous value

The value of an AC quantity at any instant of time is called instantaneous value.

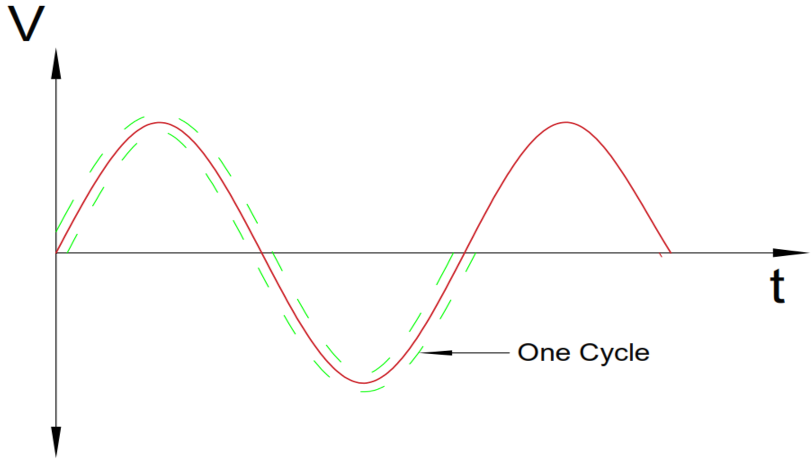
Maximum value/ Amplitude

The peak value, positive or negative of an AC quantity is called its amplitude or maximum value.



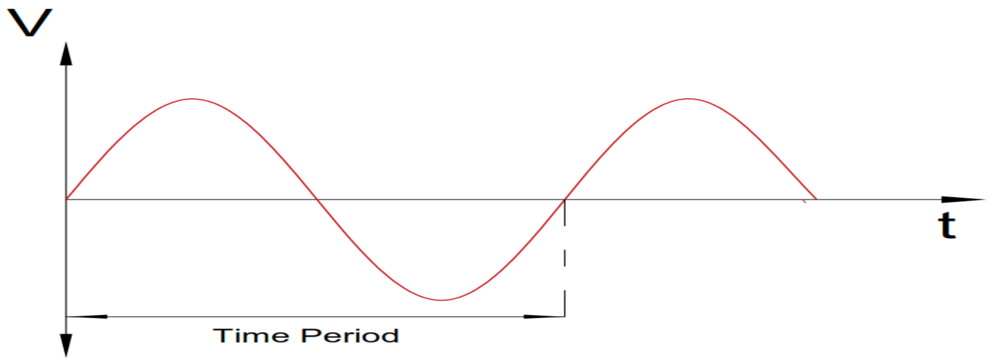
Cycle

One complete set of positive and negative values of an ac quantity is called a cycle. One complete cycle is 360° or 2π radians



Time Period

The time taken by an alternating quantity to complete one cycle is called its time period T.
For eg., a 50 Hz alternating current has a time period of 1/50 second.



Frequency

The number of cycles per second of an alternating quantity is called frequency. Its unit is Hertz(Hz)

Angular frequency

The valueof an AC quantity varies with time at a rate given by the numerical value of ω which is called the angular frequency of the quantity. It is expressed in radians per second

$\omega=2\pi f$, where f is the frequency.

Root Mean Square value (RMS Value)

RMS value of an alternating current is given by that steady(dc) current which when flowing through a given circuit for a given time produces the same heat as produced by the alternating current when flowing through the circuit for the same time.

$V_{rms}=V_m/\sqrt{2}$

Where Vm is the maximum value or amplitude.

Equation for AC voltage
A sinusoidal ac voltage is given by the equation
$v=V_m \sin \omega t$
Or
$v=V_m \sin 2\pi ft$

Where V_m is the maximum value
ω is the angular frequency
f is the frequency
t is time

Similarly sinusoidal current is given by the equation
$i=I_m \sin \omega t$
Or
$i=I_m \sin 2\pi ft$

Problems
Eg: Calculate (a) Amplitude, (b) Frequency and (c) Time period of the following expression.
$V = 25 \sin 628t$

Ans: General expression of ac voltage is

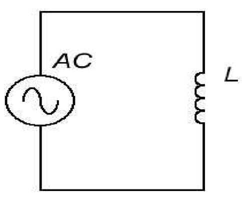
$v=V_m \sin 2\pi ft$

Comparing with above equation
a) Amplitude V_m =25V

   $2\pi f=628$
   $f=628/2\pi$
b) f=100Hz
c) T=1/f=1/100=0.01s

Electrical Reactance
Reactance is defined as the opposition to the flow of current from a circuit element due to its inductance or capacitance.
When an electric current passes through inductance or capacitance, its amplitude and phase changes. Reactance is the parameter used to compute this change in the current or voltage waveform.

Inductive Reactance
Reactance offered by an inductor to electric current is called **inductive reactance.** It is represented by X_L. its unit is ohm(Ω). The magnitude of inductive reactance is given by the equation $\mathbf{X_L = \omega L = 2\pi f L}$
Where ω is the angular frequency, f is the frequency in hertz(Hz) and L is the inductance in henry(H).

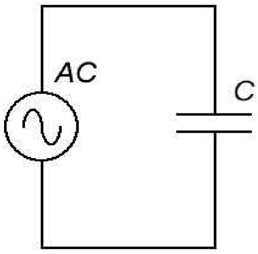


$$X_L = \omega L$$
$$= 2\pi f L$$

Capacitive Reactance

Reactance offered by a capacitor to electric current is called capacitive reactance.It is represented by X_C. its unit is ohm(Ω). The magnitude of inductive reactance is given by the equation $\mathbf{X_C} = \frac{1}{\omega C} = \frac{1}{2\pi f C}$

Where ω is the angular frequency, f is the frequency in hertz(Hz) and C is the capacitance in farad(F).

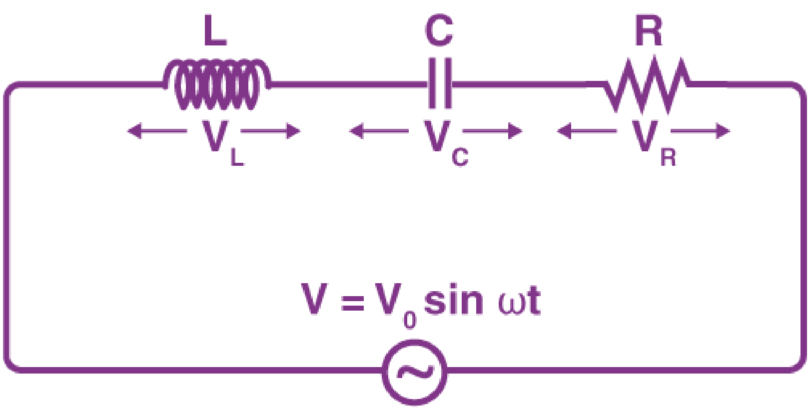


$$X_C = \frac{1}{\omega C}$$
$$= \frac{1}{2\pi f C}$$

Impedance

- The net opposition to current flow in an electric circuit is called impedance
- It is represented by the symbol Z
- Its unit is ohm(Ω)
- In a DC circuit, since the opposition to current is offered by only resistance, impedance is equal to the resistance of the circuit
- In an AC circuit, opposition to current flow is offered by both resistance and reactance
- In both cases, impedance is represented by the equation Z=V/I Ω

In a series circuit consisting of resistor, inductor and capacitor



The impedance, Z is given by the equation

$$|Z| = \sqrt{R^2 + (X_L - X_C)^2} \text{ ohms}$$

Where R is the resistance

$X_L$is the inductive ractance $X_L = \omega L = 2\pi f L$

X_C is the capacitive reactance $\mathbf{X_C} = \frac{1}{\omega C} = \frac{1}{2\pi f C}$

Qn: Find the inductive reactance offered by an inductance of 50mH when connected in a 230V, 50 Hz supply.

Ans:

Given f= 50 Hz

$L=50x10^{-3}$ H

X_L =2πfL=2πx50x50x10^{-3} =15.7 Ω

Qn:

A resistor having resistance 250Ω , Inductor having inductance 650mH, capacitor having capacitance 1.5μF are connected in series across 120V, 60Hz supply. Calculate a) capacitive reactance, b) Inductive reactance c) Net impedance of the circuit

Ans:

Given R=250Ω, L=250mH, C=1.5μF, V=120V, f=60Hz

a) X_c=1/(2πfC)=1/(2πx60x1.5x10^{-6})= 1769Ω

b) X_L=2πfL=2πx60x650x10^{-3}=245Ω

c) Impedance , $Z = \sqrt{R^2 + (X_L - X_C)^2}$
   (substitute and solve)

   Substituting, Z=1.544kΩ