Chapter = 16

Alternating current

Alternating current:

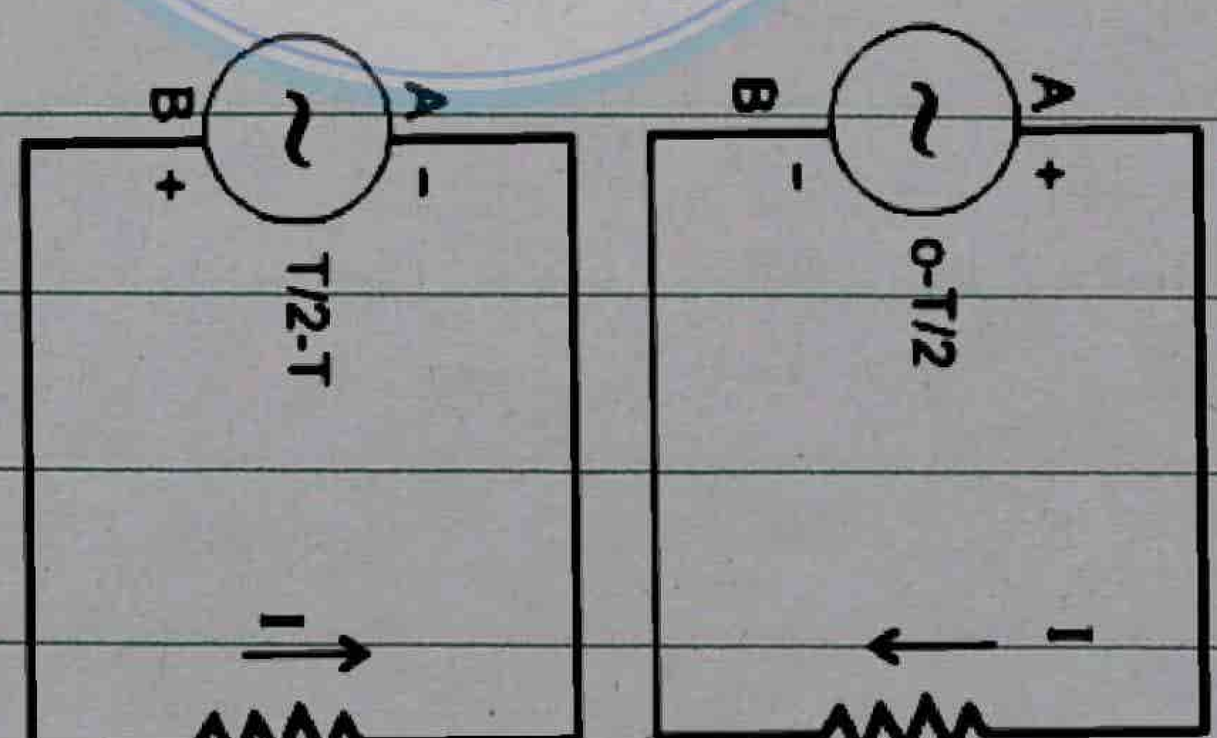
Definition:

"Alternating current (AC) is that is produced by a voltage source whose polarity keeps on reversing with time." Such voltage is called alternating voltage.

If alternating voltage changes according to the change of values of "$\sin\theta$" or "$\cos\theta$". Then such a voltage is called sinusoidal voltage.

Explanation:

Consider the figures (a) and (b)



During time $t = 0$ to $\frac{T}{2}$, terminal "A" of the source is $+Ve$ with respect to termina "B" fig (a).

At $\frac{T}{2}$ the terminols changes their polarity. During time $t = \frac{T}{2}$ to T, terminal "B"

This is one complete cycle of "AC". After that terminal becomes +ve again and the next cycle starts.

i) : During time $0 - \frac{T}{2}$ current flows in one direction.

ii) : During time $\frac{T}{2} - T$ current flows in reverse direction.

Time period:

"The time interval T during which the voltage source changes its polarity once is called time period of alternating current or alternating voltage."

Relation between time peried and frequency is

$$\boxed{T = \frac{1}{f}}$$

Common source of "A.C" or alternating voltage is an "AC" generator.

The formula for the alternating voltage or sinusoidal voltage produced by an "AC" generator is.

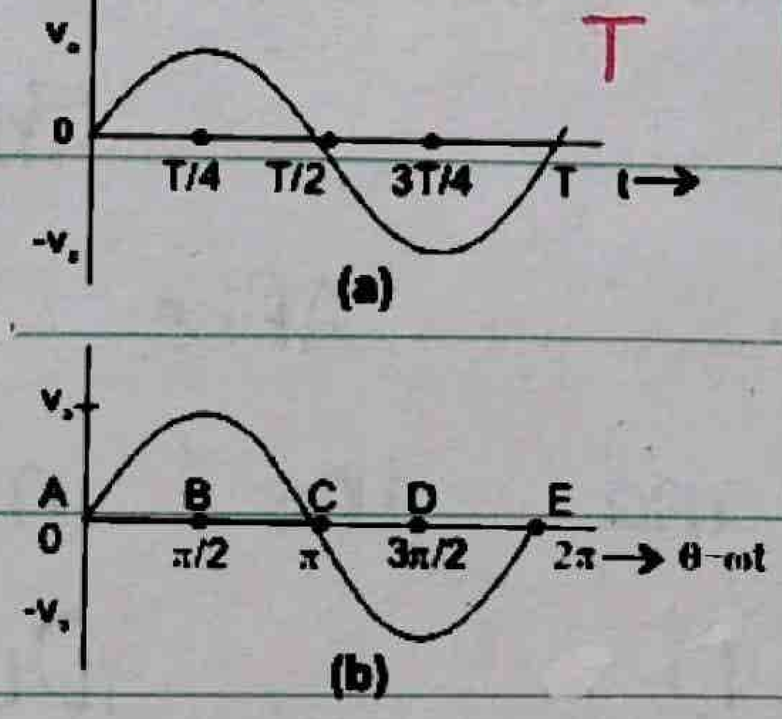
$$V = V_0 \sin\theta = V_0 \sin \omega t$$

$$V = V_0 \sin(2\pi f t)$$

As $\because \omega = 2\pi f$

$$\omega = \frac{\theta}{t}, \quad \theta = \omega t = 2\pi f t \qquad \omega = \frac{2\pi}{T}$$

$$V = V_0 \sin \omega t = V_0 \sin \frac{2\pi}{T} t$$



1- Instantaneous Value:

"The value of voltage or current that exists in a circuit at any instant of time is called instantaneous value of voltage or current." It can have any value between maximum positive (V_0) and maximum negative ($-V_0$) including zero.

$$\boxed{V = V_0 \sin \frac{2\pi}{T} t = V_0 \sin 2\pi f t}$$

2- Peak value:

The highest or maximum possible value of alternating voltage or current is called peak value V_0 / I_0.

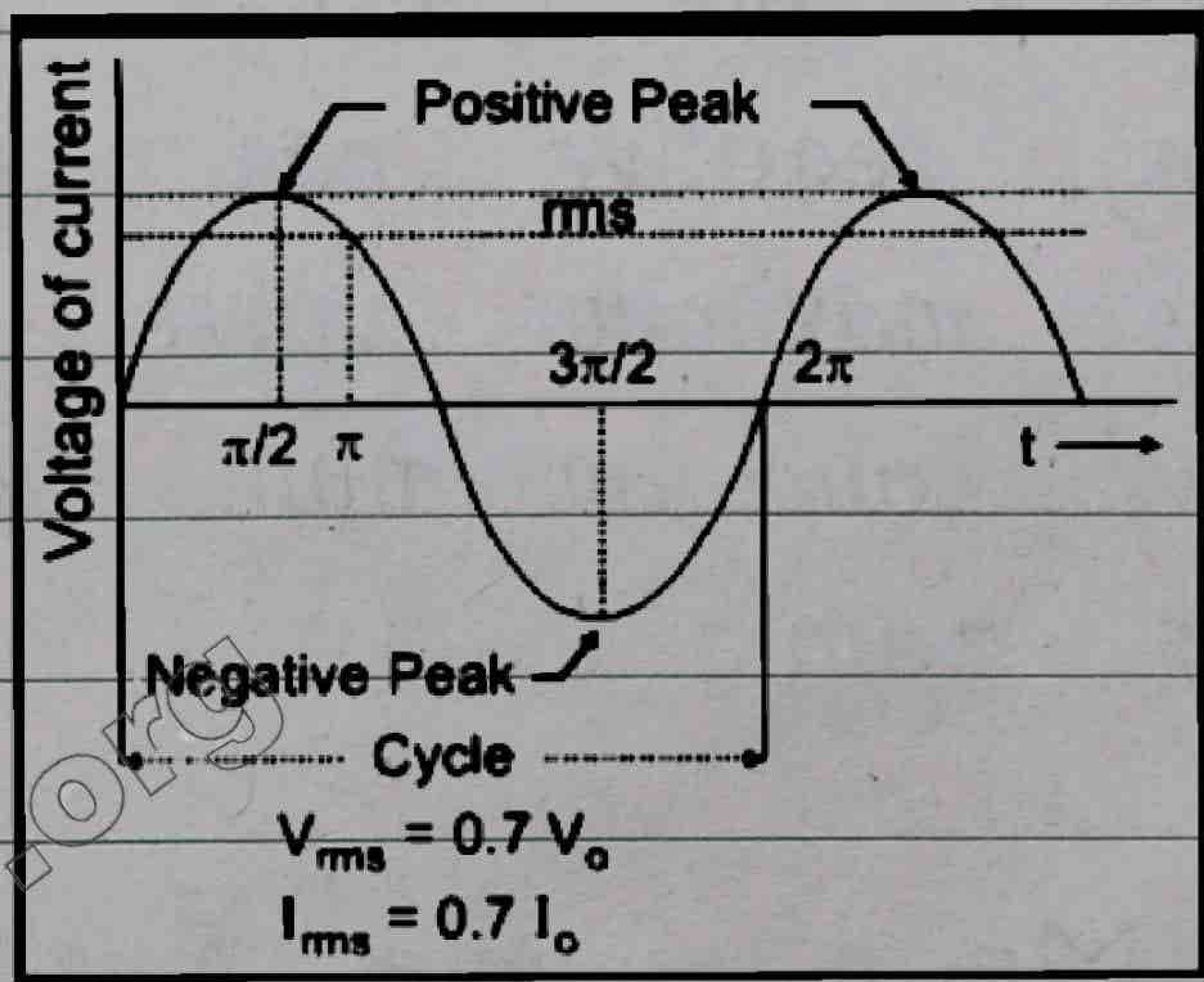
3- Peak to Peak value:

It is the sum of positive and negative peak values of voltages peak to peak value $= V_0 + V_0 = 2V_0$

4- Root mean square value of voltage:

The graph of alternating voltage or alternating current shows that their complete cycle consists of two half cycles. One is called the positive half cycle and the other is called Negative half cycle.

The different values during positive half cycle are same as the corresponding different values in negative half cycle. Hence the sum of all possible positive and negative values during one complete cycle is zero. So the average value of voltage or current for one complete cycle is zero.



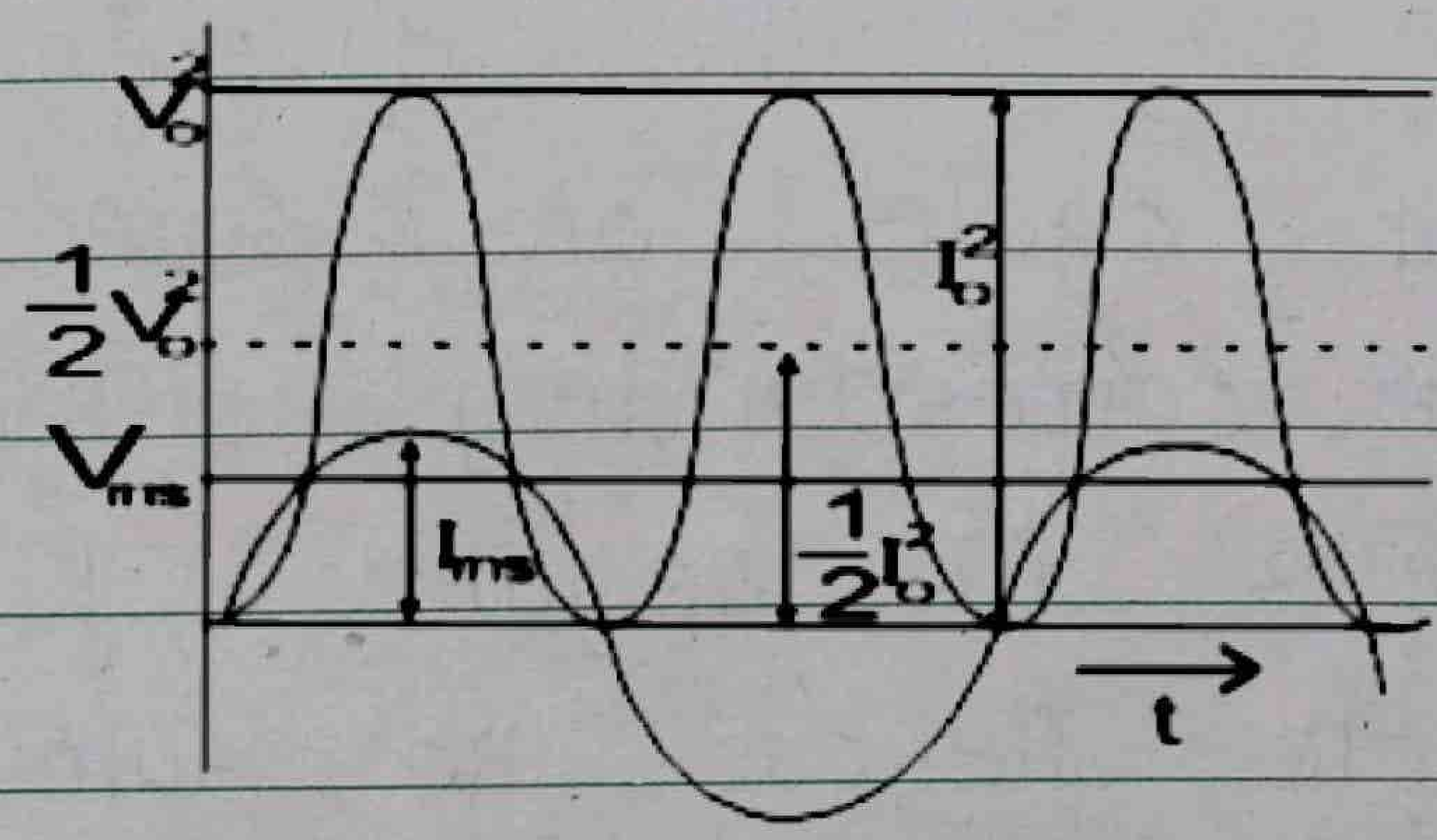
$\left[\frac{+V+(-V)}{2}=0\right]$. But the power delivered in one complete cycle is not zero $P = I^2R$

The average (mean) of the square of all the possible values of voltge or current during one cycle is not zero. Being all +ve values $\frac{+V^2+(-V)^2}{2} \neq 0$.

The square root of mean (average) of square of all possible values of voltage or current during one cycle is called Root mean square value of voltage or current V_{rms} or I_{rms}.

Average value of V^2:

The variation of "V" and "V^2" with time "t" is shown in fig. The values of "V^2" are positive during negative half cycle. Its maximum value is "V_0^2" and minimum value is zero.



Mean square value of voltage

$$V_{rms}^2 = \frac{0 + V_0^2}{2} = \frac{V_0^2}{2}$$

Taking square root

$$V_{rms} = \sqrt{\frac{V_0^2}{2}} = \frac{V_0}{\sqrt{2}}$$

$$\boxed{V_{rms} = 0.707\, V_0}$$

$$\boxed{I_{rms} = 0.707\, I_0}$$

Phase of A.C:

Instantaneous value of voltage is.

$$V = V_o \sin \omega t = V_o \sin \theta t$$

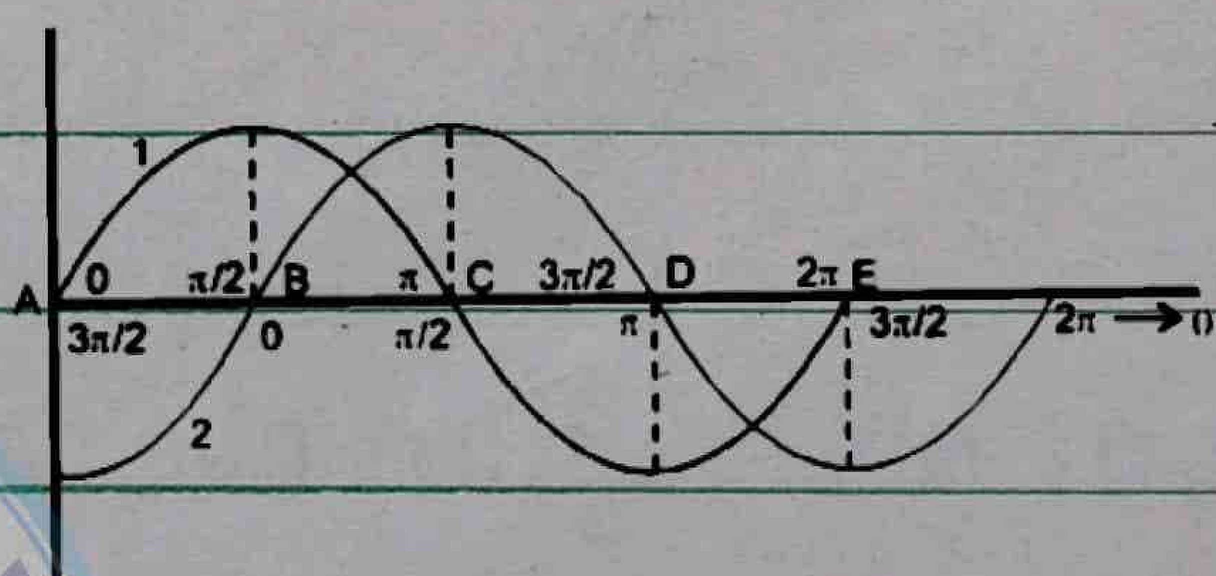
These equation show that value of "V" is specified by the value of the angle "θ".

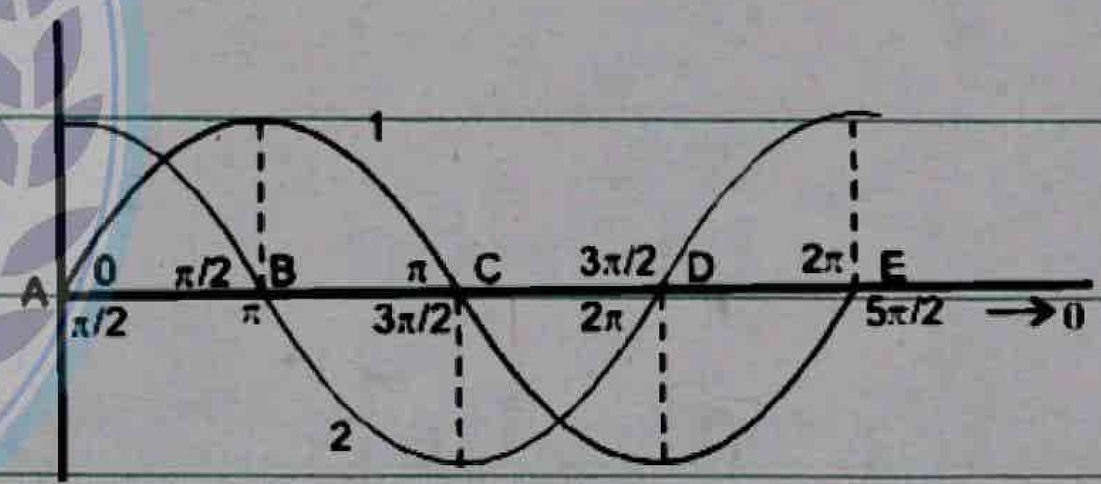
Phase:

"The angle "θ" which specifies the instantaneous value of the alternating voltage or current is called as its phase or phase angle."

Phase Lag and Phase Lead:

In fig we see two waveforms of two alternating quantities. At point "B" the phase of waveform 1 is $\frac{\pi}{2}$ and that of waveform 2 is 0. At each point phase of waveform 2 is less than that of waveform 1 by angle $\frac{\pi}{2}$. So.

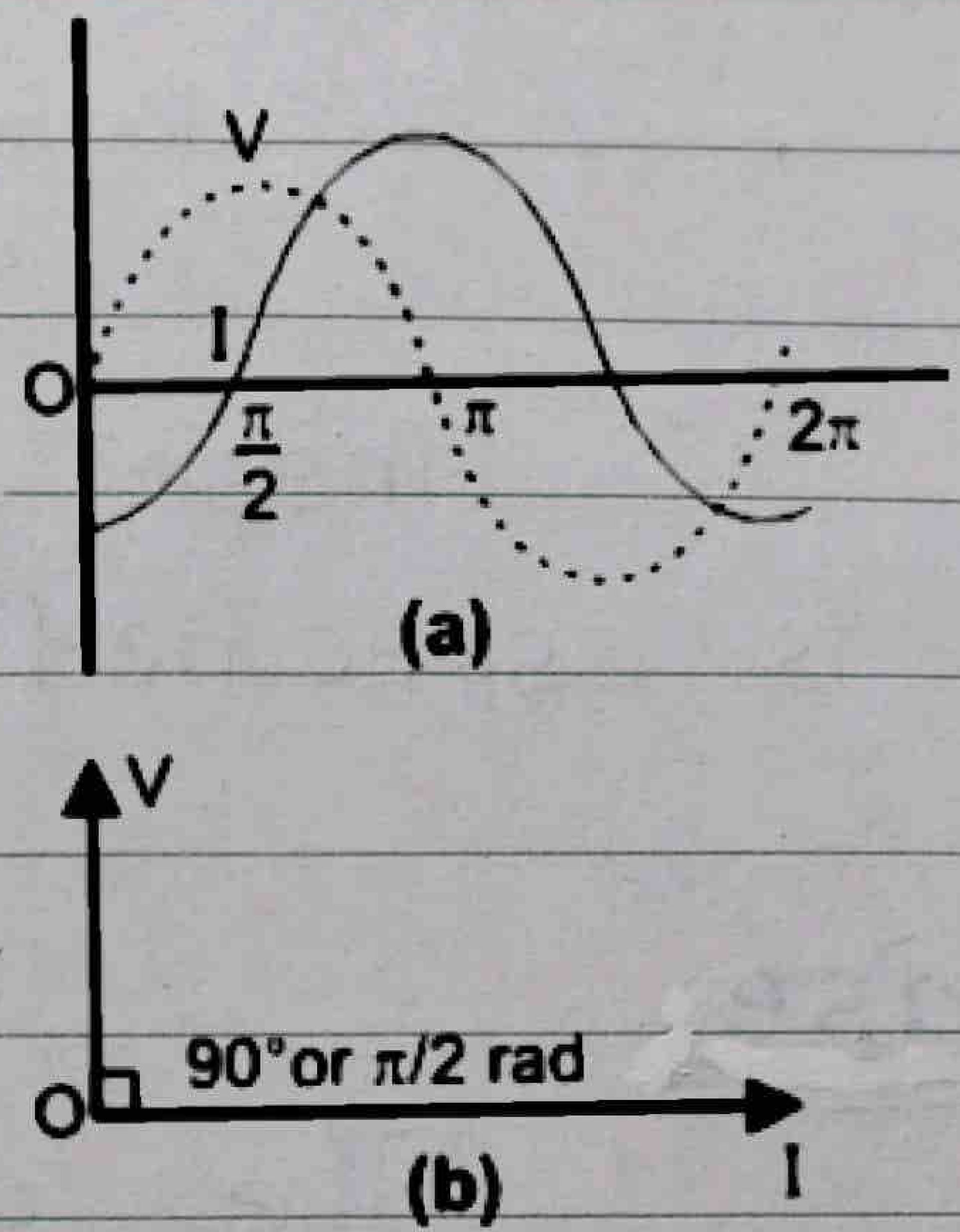




AC _ 2 is lagging behind AC _ 1 by an angle $\frac{\pi}{2}$. Hence the phase of AC _ 2 is less than phase of AC _ 1 by an angle $\frac{\pi}{2}$.

Now consider diagram. In this case the

phase angle of wave form 2 is greater that that of wave form 1 by $\frac{\pi}{2}$.



Hence AC_2 is leading AC_1 by $\frac{\pi}{2}$ (90°) phase lead and phase lag is conventionally represented by representing AC quantities as vectors known as Phasors.

16.2 AC circuits:

The basic component in a D.C circuit is a resister "R". It controls current or voltage by OHM's Law.

$$V = IR$$

In an A.C circuit, current and voltage are controlled by

i) ; Resistor R.
ii) ; Inductor L.
iii) ; Copacitor C.

16.3 AC Through a Resistor

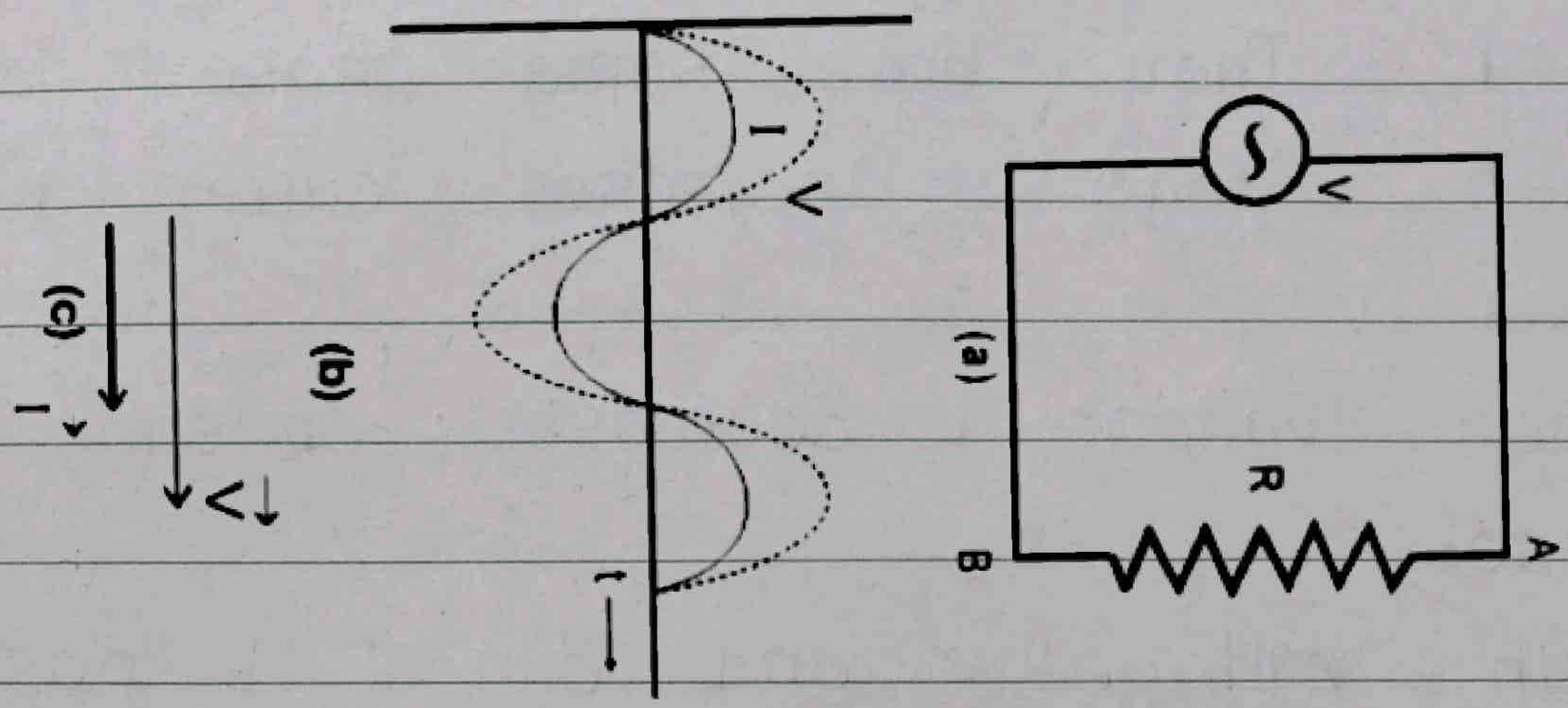


Fig (a) shows a resistor of resistance "R" connected with alternating voltage "V".

$$\boxed{V = V_0 \sin \omega t} \longrightarrow (1)$$

By ohm's Law.

$$I = \frac{V}{R} = \frac{V_0 \sin \omega t}{R} = \frac{V_0}{R} \sin \omega t$$

$$\because \frac{V_0}{R} = I_0$$

$$\boxed{I = I_0 \sin \omega t} \longrightarrow (2)$$

I = Instantaneous value of current.

I_0 = Peak or maximum value of current.

Equations (1) and (2) shows that voltage V and current I both have the same varying factor ($\sin \omega t$). So both voltage and current have the same variation and both has the same phase (ωt). They are in phase fig (b)

We make the following Results.

i) ; There is no phase difference between V and I. They have same phase.

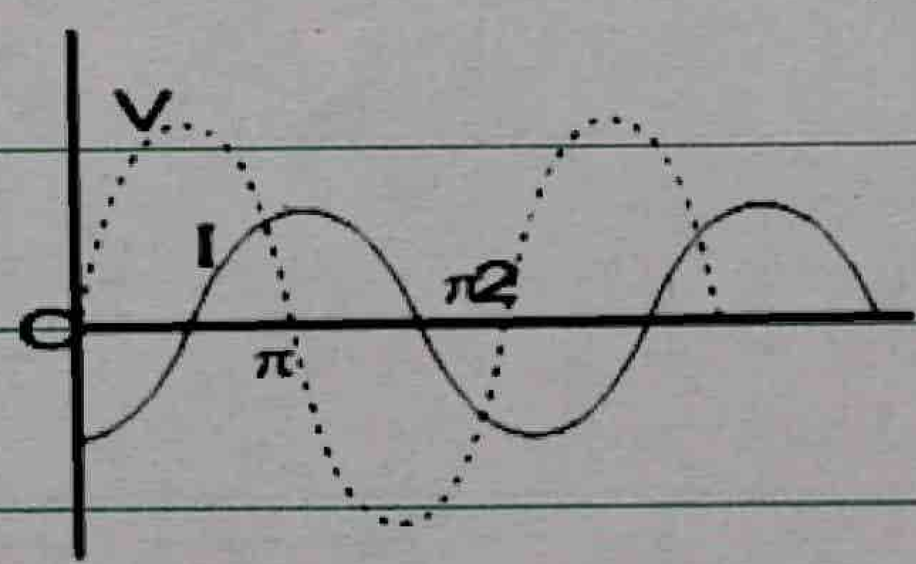
When voltage V increases, curren I also increases.

When voltage V decreases, current I also decreases.

ii) ; Both voltage V and current I pass through the maximum and minimum values at the same time.

iii) ; As phase difference between V and I is zero. so they are shown by vectors in fig (C). They are parallel.

Resistance of the circuit is



$$R = \frac{V}{I} = \frac{V_0 \cancel{\sin \omega t}}{I_0 \cancel{\sin \omega t}}$$

$$\boxed{R = \frac{V_0}{I_0}}$$

Power dissipated in Resistor is

$$P = I^2R = VI = \frac{V^2}{R}$$

or

$$\boxed{P = VI}$$

This relation is only applicable when voltage V and current I are in phase.

The instantaneous power is.

$$P = VI = V_0 \sin \omega t \cdot I_0 \sin \omega t$$

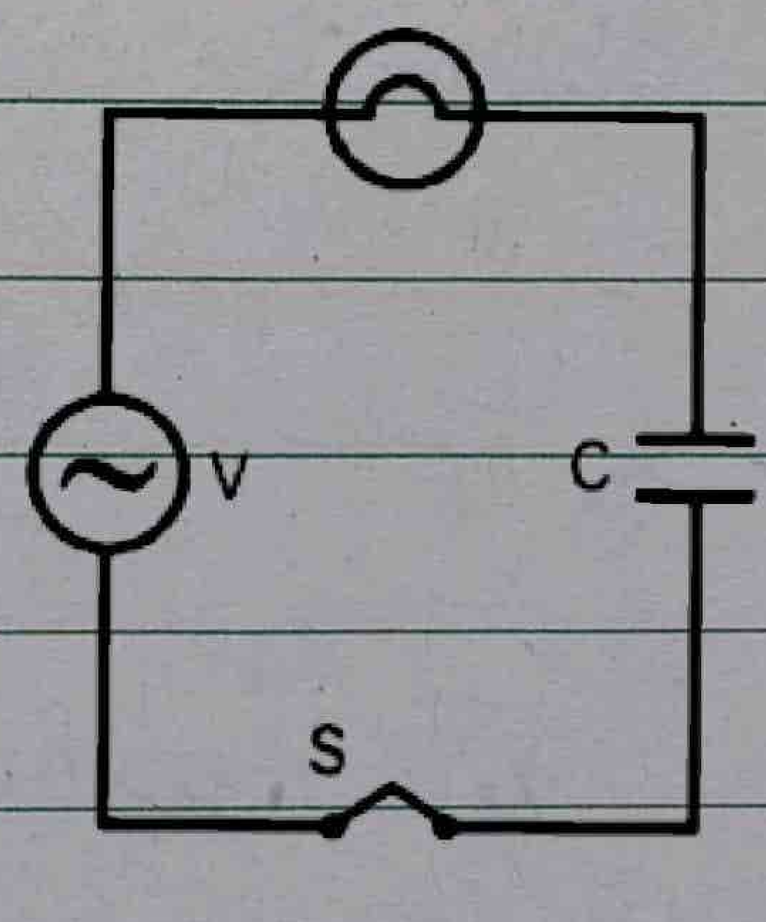
$$P = V_0 I_0 \sin^2 \omega t$$

When and are not in phase.

$$\boxed{P = VI \cos \theta}$$

16.4 AC Through a Capacitor

Fig shows a low power bulb is connected in series with a capacitor "C" and alternating voltage "V". The bulb lights up when the switch is closed. Direct current (DC) cannot pass through a capacitor because there is an insulator between the plates.

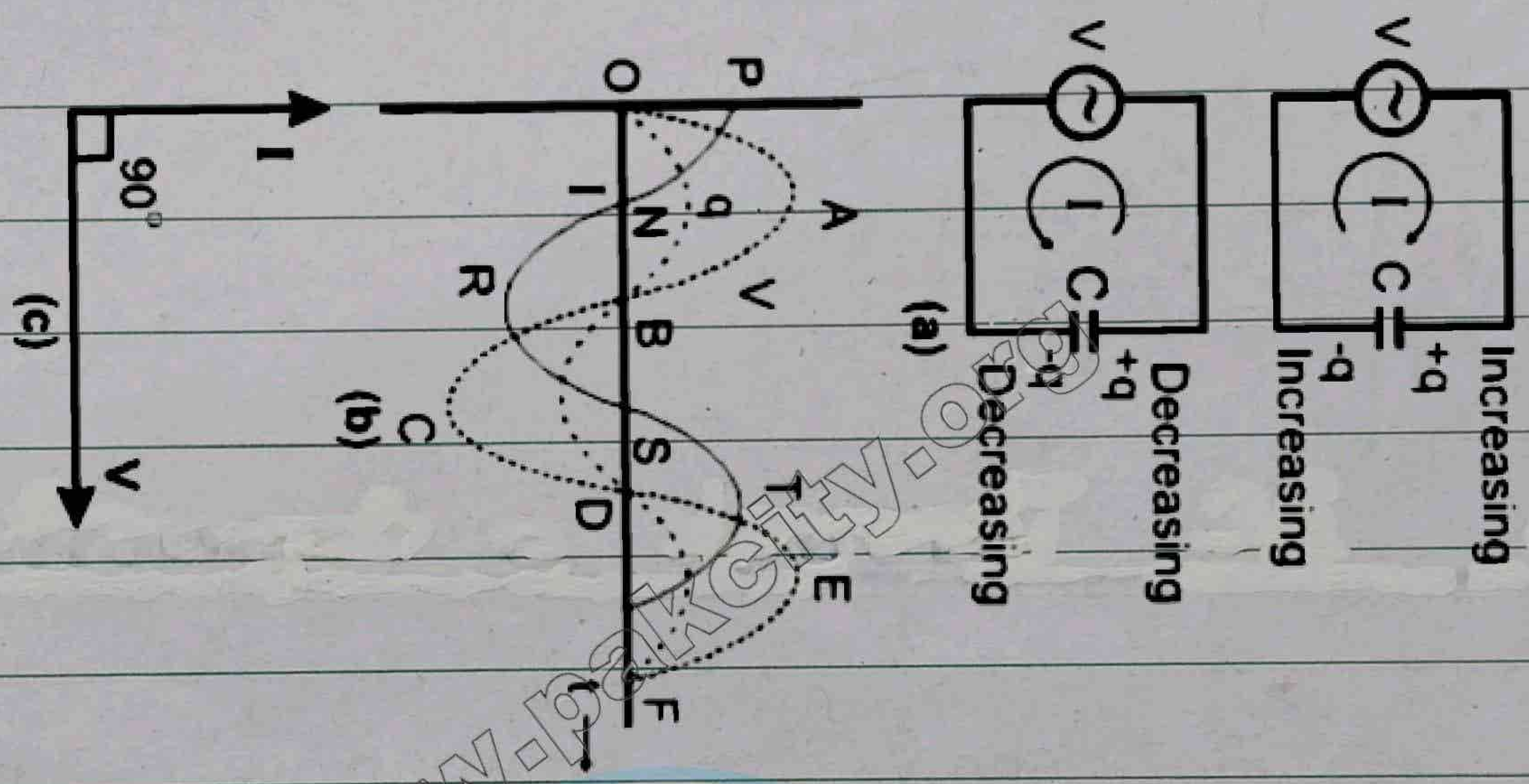


AC can pass through a capacitor. It is due to the reason that capacitor is continuously being charged and discharged and then recharged the other way round.

The charge q on the capacitor at any instant is

$$\boxed{q = CV = CV_0 \sin \omega t} \qquad \because V = V_0 \sin \omega t$$

q varies as V varies. so both q and V are in phase in a capacitor.



To study the variation of current in the above circuit, We use the equation.

$$\boxed{I = \frac{\Delta q}{\Delta t}} \qquad \because \frac{\Delta q}{\Delta t} = \text{slop}$$

i) ; At point O, when $q = 0$, the slope of the $q - t$ graph is maximum i.e, current is maximum.

ii) ; At point A, when $q =$ maximum, the slope of the $q - t$ graph is zero, so value of current is zero.

iii) ; From point A to B the slope of the graph is negative, so current becomes negative (from N to R).

The curve PNRS gives the variation of current.

Hence in a capacitor, the current I leads the voltage V by $\frac{\pi}{2}$ (90°). And voltage V lags current I by $\frac{\pi}{2}$ 90°.

Reactance X_c:

"The opposition offered by a capacitor to the flow of AC is called the reactance of the capacitor."

$$\boxed{X_c = \frac{\text{voltage}}{\text{current}} = \frac{V}{I}}$$

Unit:

Unit of reactance is OHM.

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

This formula shows that $X_c \propto \frac{1}{f}$.

i) ; Rectance X_c of the capacitor is large for small frequency f of AC.

ii) ; Rectance X_c of the capacitor is small for large frequencey f of AC.

iii) : Also reactance is inversely proportional to the capacitance of the capacitor.

$$\boxed{X_c \propto \frac{1}{C}}$$

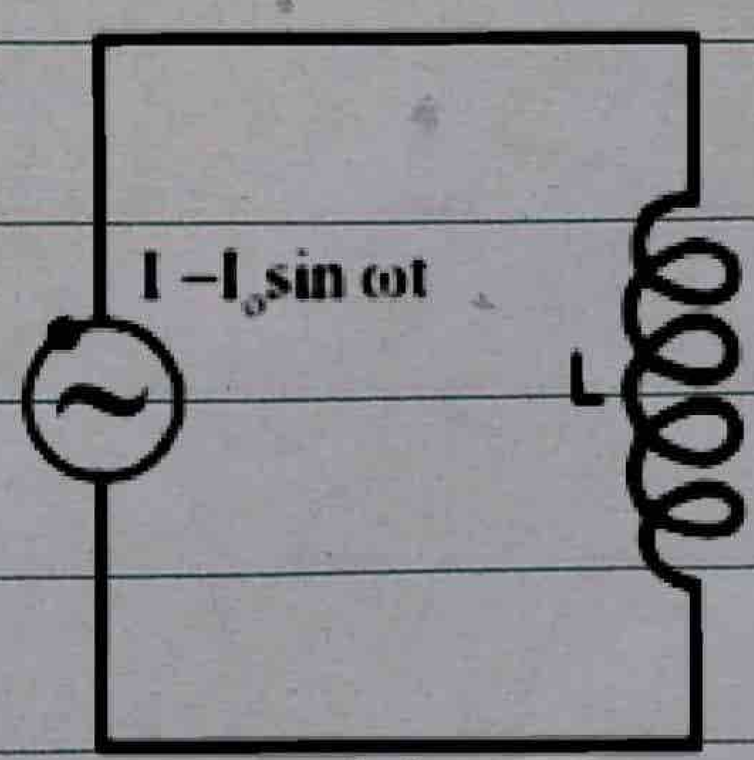
16.5 AC Through Inductor

Inductor

An inductor is usually in the form of a coil or a solenoid wound from a thick wire, so that it has a large value of self inductance L and a neglible resistance (R = 0).

Explanation:

When a sinusoidial or alternating voltage is applied across an inductor, then due to alternating current passing through the circuit induced emf is automatically produced in it. By Lenz's Law this induced emf opposes the cause which produces it. Hence an inductor offers opposition to the flow of current which is due to source voltage.



(a)

Suppose that the DC resistance of

the inductor is very small, so that the induced emf or back emf is equal to the applied voltage.

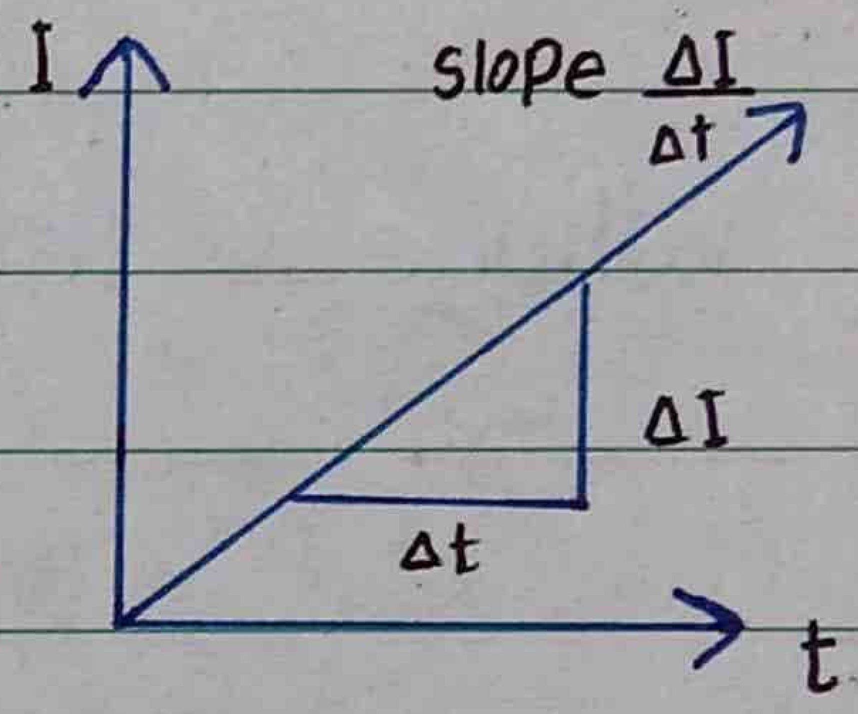
The induced emf is

$$\varepsilon_L = L \frac{\Delta I}{\Delta t}$$

$$V = L \frac{\Delta I}{\Delta t}$$

$\because L = \text{constant}$

$$V = \text{constant} \frac{\Delta I}{\Delta t}$$



$$\boxed{V \propto \frac{\Delta I}{\Delta t}}$$

But,

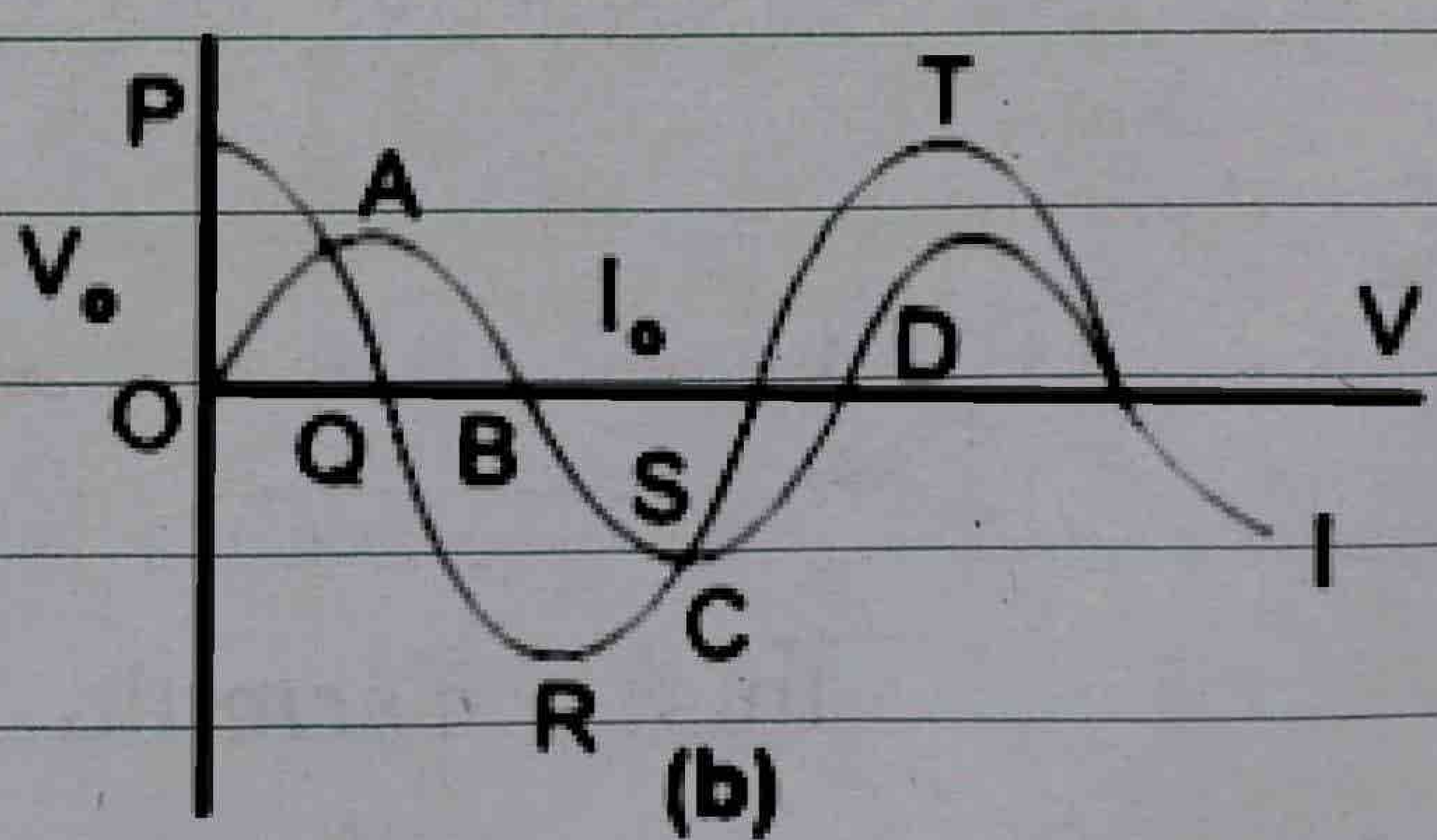
$$\frac{\Delta I}{\Delta t} = \text{slope of the } I — t \text{ graph}$$

Variation of current with time:

i) ; The slope is maximum at point O, so V is maximum at O and it is equal to V_o.

ii) ; From O to A slope is decreasing, slope is zero at A. So $V=0$ at A. Hence voltage decreases from V_o to 0.

iii) ; From A to B slope of I — t graph is negative so the voltage has



negative value.

iv) : Curve "OABCD" represent the curren I.

v) : Curve "PQRST" represent the voltage V.

vi) : Phase of current is always less then the phase of voltage V by $\frac{\pi}{2}$ (90°).

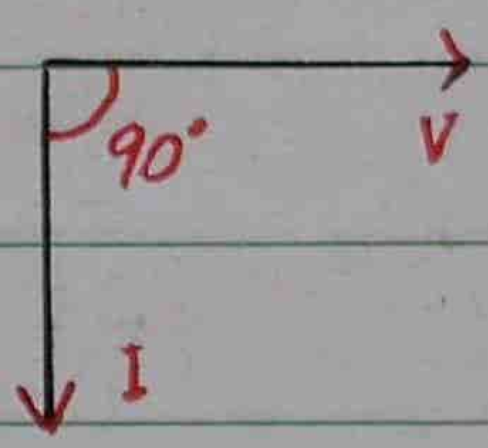
So, inar inductor

Current I lags behind voltage V by $\frac{\pi}{2}$ (= 90°).

or

Voltage leads the current by $\frac{\pi}{2}$.

This is shown in fig.



Inductive reactance X_L :

"It is the measure of opposition offered by the inductance coil to the flow of AC."

$$X_L = \frac{V}{I} \qquad \because R = \frac{V}{I}$$

$$\boxed{X_L = \omega L = 2\pi f L}$$

This formula shows that X_L depends upon frequency f and inductance L.

$X_L \propto f$, $X_L \propto L$

i) : X_L is large for large value of frequency f of AC.

ii) : X_L is small for small value of frequency f of AC.

Unit:

Unit of X_L is OHM.

X_L is expressed in ohm, when L is expressed in Henry and f in Hz.

Pure Inductor:

Consider the fig (b) again.

i) : In the first quarter of AC cycle, V and I are both +Ve. So $P = VI = +Ve$. Hence energy is supplied to the inductor.

ii) : In the second quarter of AC cycle is +ve and $P = -V.+I = -VI = -ve$ value so energy is returned by the inductor.

iii) : In the 3rd quarter inductor receives energy but in the 4th quarter it returns the same amount of energy.

iv) ; So, there is no net change of energy in a complete AC cycle.

Result:

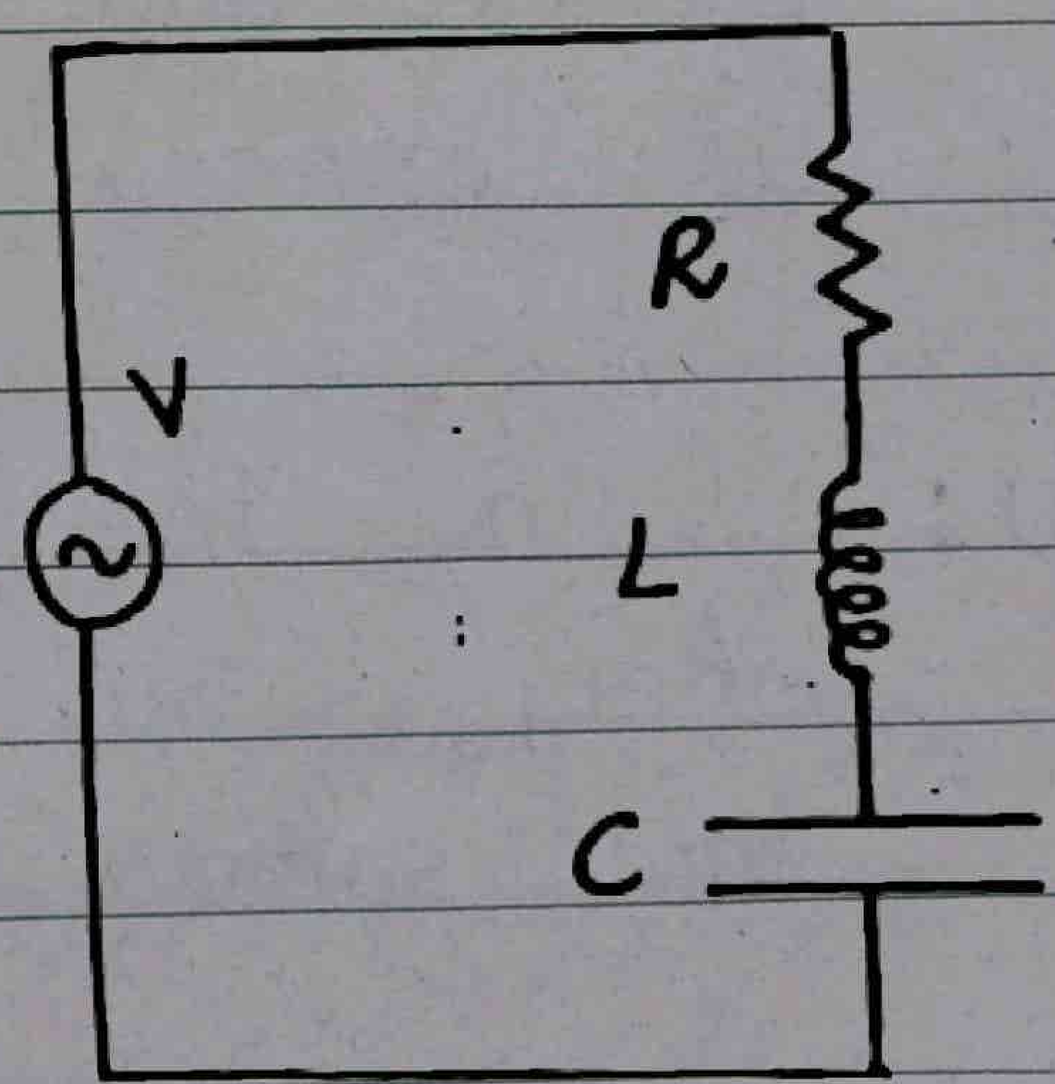
An ideal inductor coil (having zero DC resistance) does not consume energy. No power is dissipated.

Choke:

Hence inductor is a device which controls current in the circuit with consuming energy. Such an inductance coil is called a choke.

16.6 Impedence

An AC circuit consisting of an inductor, capacitor and resistor shows a resultant opposition to the flow of current AC. This resultant opposition due to all the different components of the circuit is known as impedance of the circuit. It is denoted "Z".



$$\boxed{Z = \frac{V}{I}}$$

Impedence = Ratio of rms values of voltage and current.

Opposition offered by the individual capacitor or individual inductor to AC is called reactance X_C or X_L. Resultant of X_C, X_L, R is called impedance.

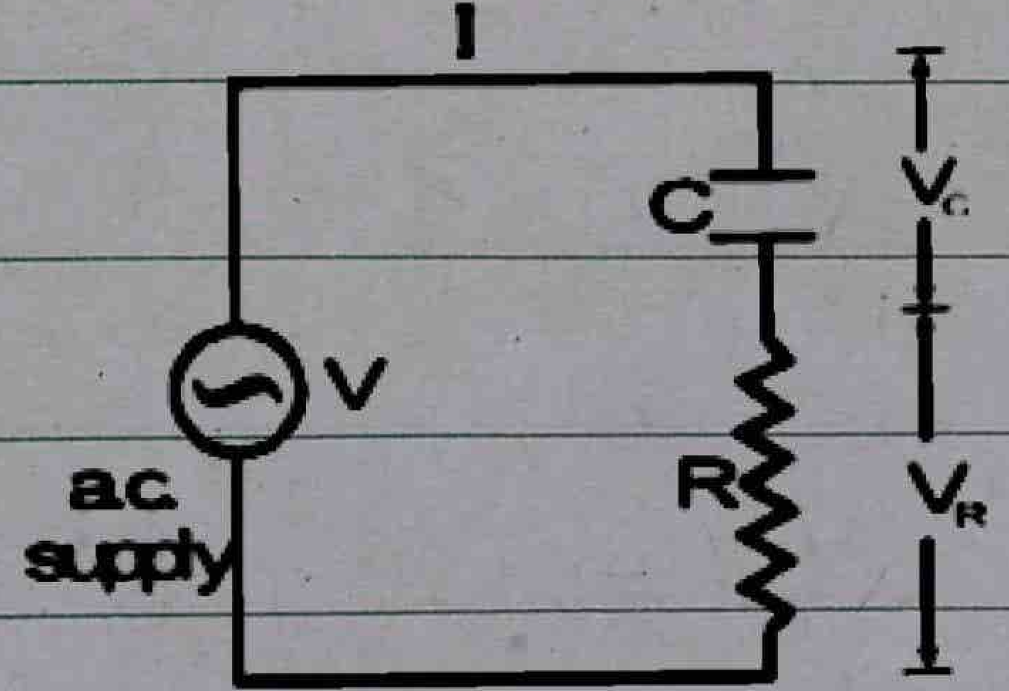
Unit:

The unit of Z is OHM.

16.7 RC and RL series circuit

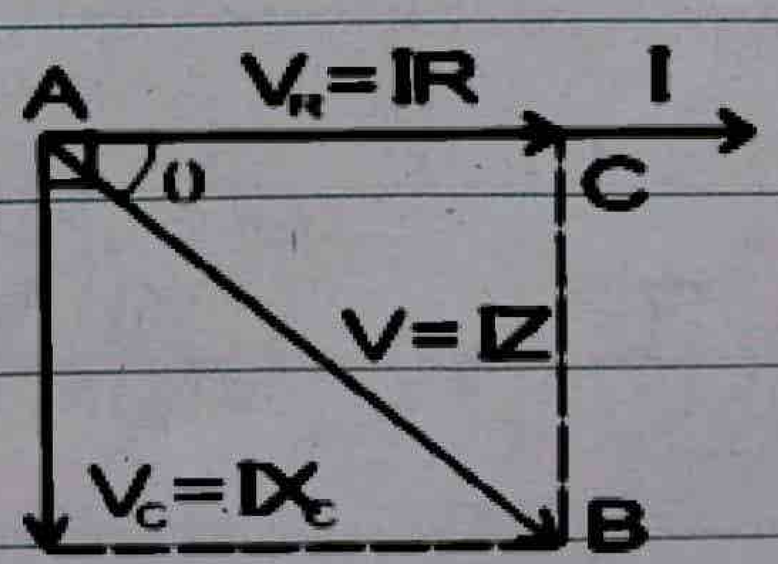
R-C series circuit:

R-C series circut is shown in fig, where R and C are connected in series with the alternating voltage V.



The potential difference V_R across R is given by ohm's Law.

$$V_R = IR$$



In resistance V and I are in phase.

The potential difference V_c across the capacitor C is

$$V_c = IX_c = I \times \frac{1}{\omega C}$$

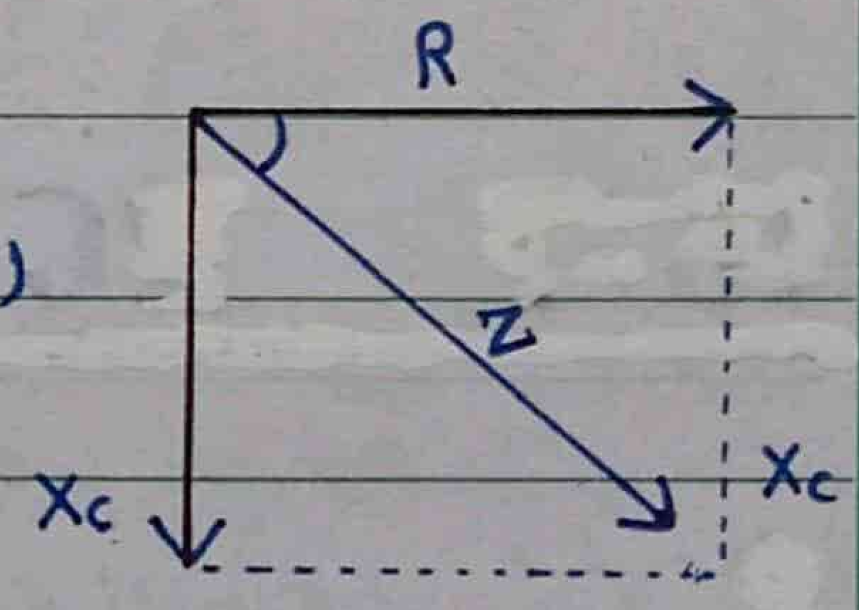
$$\boxed{V_c = \frac{I}{\omega C}}$$

Voltage V_c lays behind the current I by $\frac{\pi}{2}$ (90°). V_c is perpendicular to current or V_R as shown in Fig.

The applied voltage V ($V = IZ$) is.

$$V^2 = V_R^2 + V_c^2$$

Fig(c)



$$V = \sqrt{(IR)^2 + \left(\frac{I}{\omega C}\right)^2}$$

$$V = \sqrt{I^2\left(R^2 + \frac{1}{(\omega C)^2}\right)}$$

Impedance diagram.

$$V = I\sqrt{R^2 + X_c^2}$$

$\because X_c^2 = \frac{1}{(\omega C)^2}$

$$\frac{V}{I} = \sqrt{R^2 + X_c^2}$$

$\because V = IZ$

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

$$\boxed{Z = \sqrt{R^2 + X_c^2}} \longrightarrow (1)$$

Fig (b) shows that V and I are not in phase current I leads the voltage V by an an angle θ.

$$\theta = \tan^{-1}\left(\frac{V_c}{V_R}\right) = \tan^{-1}\left(\frac{IX_c}{IR}\right) = \tan^{-1}\left(\frac{X_c}{R}\right)$$

$$\theta = \tan^{-1}\left(\frac{X_c}{R}\right)$$

$\because X_c = \frac{1}{\omega C}$

$$\boxed{\theta = \tan^{-1}\left(\frac{1}{\omega CR}\right)}$$

Equation (1) shows that Z can be found by the vector summation of R and X_c as shown in fig (C) impedance diagram.

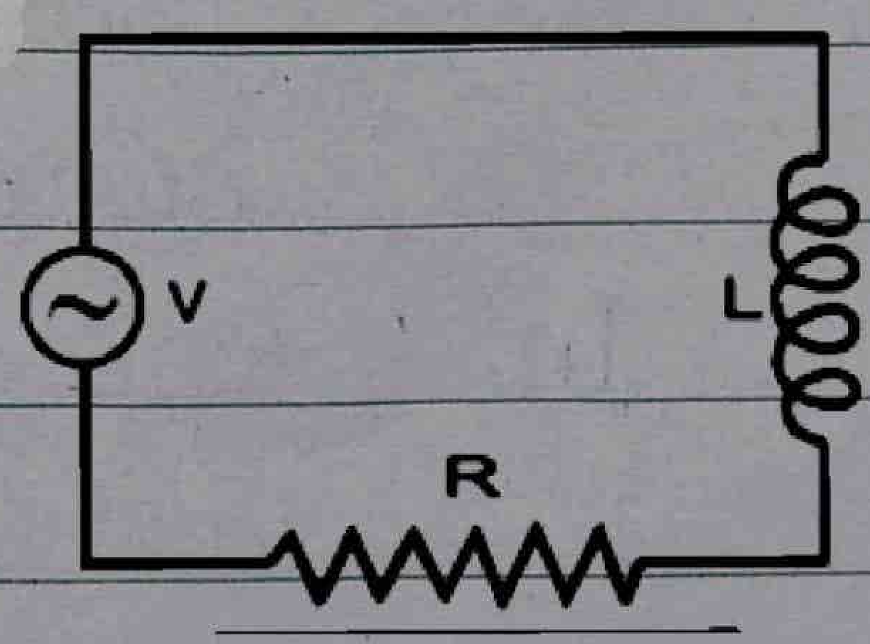
In R_C series circuit curren I leads voltage V by

$$\theta = \tan^{-1} \frac{X_c}{R}$$

$$\boxed{\theta = \tan^{-1} \frac{1}{\omega CR}}$$

R_L series circuit:

Fig (a) shows an R_L series circuit. In fig (b) current line is taken as reference line. R_ line lies on the current



line because IR is in phase with the applied voltage.

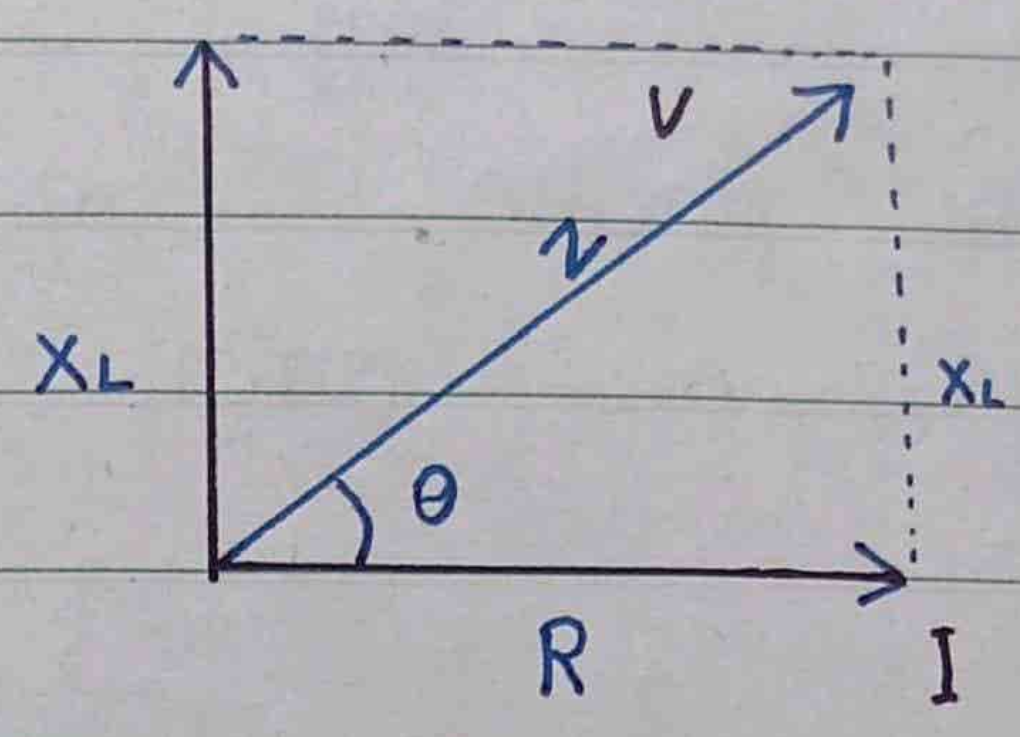


Fig (b)

As $V_L = IX_L$ lead the current I by $\frac{\pi}{2}$ in an inductor so, X_L leads the current line or (R_line) by 90° Fig (b).

Impedence Z of RL circuit is

$$Z^2 = R^2 + X_L^2$$

$$Z = \sqrt{R^2 + X_L^2}$$

$\because V_L = IX_L$

$V_L = I\omega L$

$$\boxed{Z = \sqrt{R^2 + (\omega L)^2}}$$

The angle which Z_line makes with the reference line (current line) by θ.

$$\boxed{\theta = \tan^{-1} \frac{X_L}{R}}$$

$\because X_L = \omega L$

θ = phase difference betwee voltage and current.

In RL_series circuit V lead by

$\theta = \tan^{-1} \frac{\omega L}{R}$.

16.8 Power in AC circuits

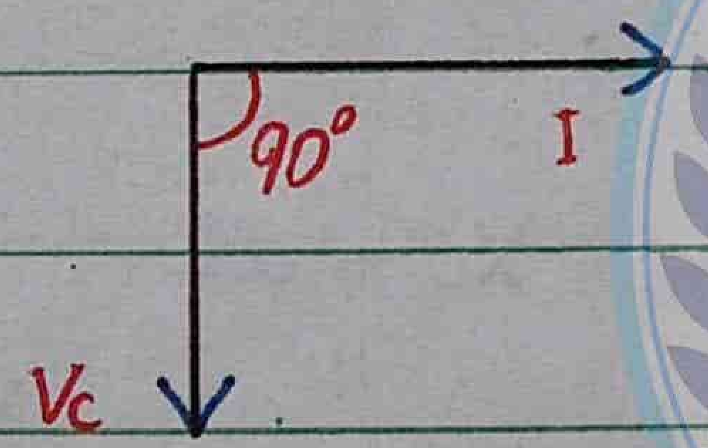
Power = Voltage x current

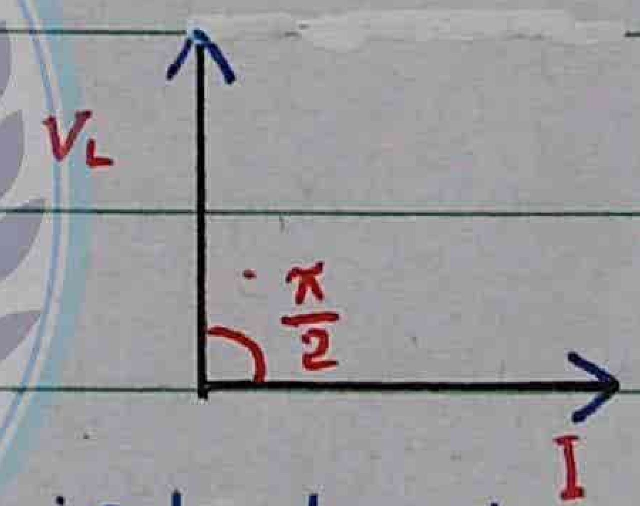
$$\boxed{P = VI}$$

This formula is only applicable in AC circuits when V and I are in phase such as in pure resistance.

The power dissipation in a pure capacitance and in pure inductance is zero. This is due to the phase difference between V and I which is $\frac{\pi}{2}$ (90°).

The component of applied voltage vector along the direction of current is zero, as shown in fig.





Pure capacitor C Pure inductor L

In an AC circuit let θ is the phase difference between the applied voltage V and current I.

So,

$V\cos\theta$ = component of V vector parallel to I vecotor.

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$V\cos\theta$ is in phase with I
Now the power dissipation is not zero.

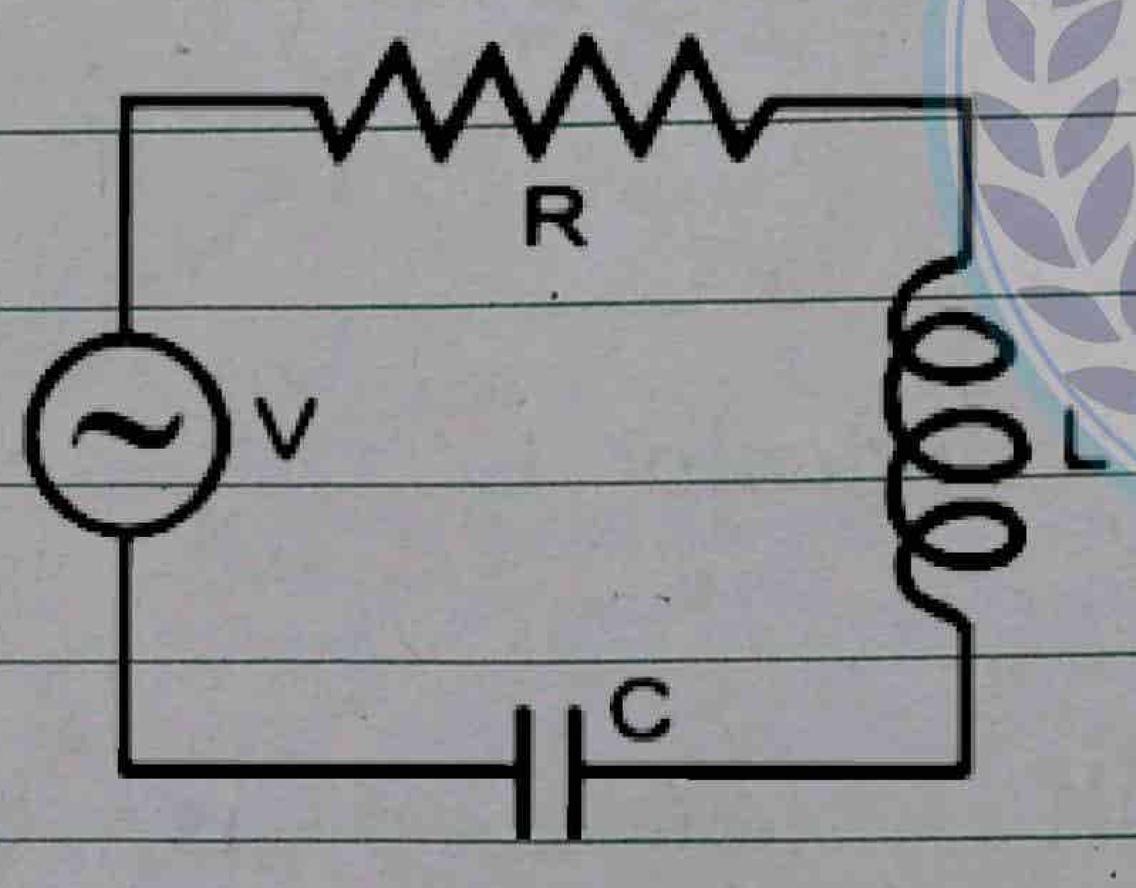
$$P = V\cos\theta \times I$$

$$\boxed{P = VI\cos\theta}$$

In this formula $\cos\theta$ is called power factor.

16.9 Seres resonance circuit

Fig (a) shows RLC series circuit in which alternating voltage V is applied fig_b shows impedence diagram.



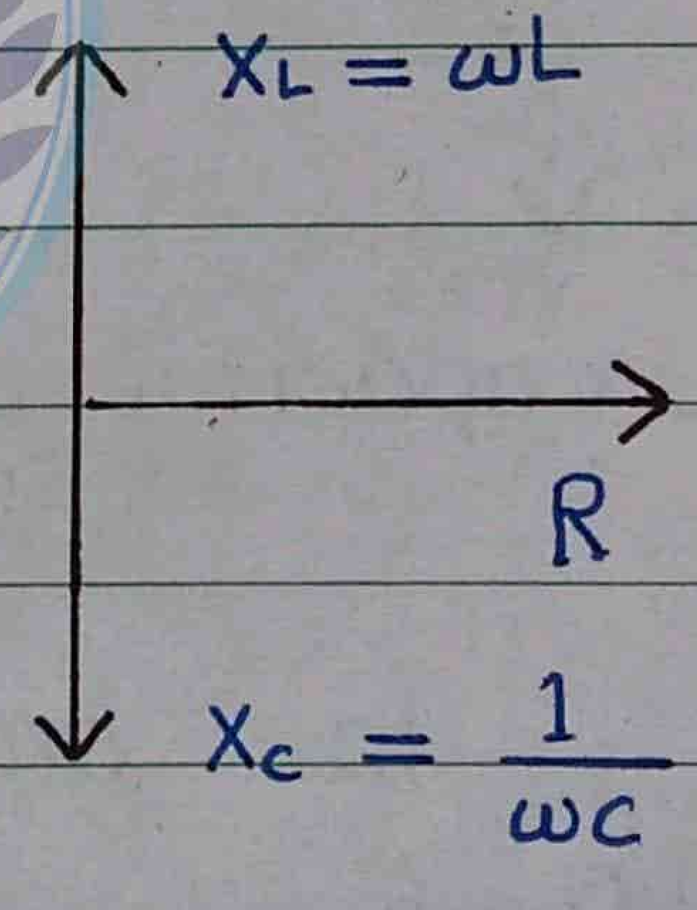


fig (a) Fig. (b)

Reactances X_c and X_L are represented by vectors in opposite direction.

As,

$$X_C = \frac{1}{\omega C} \quad , \quad X_L = \omega L$$

$$\boxed{X_C = \frac{1}{2\pi f C}} \quad , \quad \boxed{X_L = 2\pi f L}$$

i: At low frequency f:

X_L is small , X_C is large

So,

i: Circuit behaves like R-C series circuit.

ii: Capacitance dominates inductance.

ii: At high frequency f:

X_L is large , X_C is small

So,

i: Circuit behaves like R-L series circuit.

ii: Inductance dominates capacitance.

At a particular frequency

f_r = Resonance frequency

$X_L = X_C$ $\quad \because \omega_r = 2\pi f_r$

Reactance of inductor = Reactance of capacitance

This condition is called Resonance.

In impedence diagram X_L and X_C are equal and opposite, so they cancel each other. Only vector re

$\overrightarrow{R}$

$$X_L = X_C$$

$$\omega L = \frac{1}{\omega C}$$

$$\omega_r L = \frac{1}{\omega_r C}$$

$$\omega_r^2 = \frac{1}{LC}$$

$$\omega_r = \frac{1}{\sqrt{LC}}$$

$\because \omega = 2\pi f$

$\because \omega_r = 2\pi f_r$

$$2\pi f_r = \frac{1}{\sqrt{LC}}$$

$$\boxed{f_r = \frac{1}{2\pi\sqrt{LC}}}$$

$\because f_r \propto \frac{1}{\sqrt{L}}$, $f_r \propto \frac{1}{\sqrt{C}}$

This is the formula for resonance frequency f_r.

Properties of series resonance circuit:

i): Impedence of the circuit is minimum

ii): Current and voltage are in phase so power factor is 1.

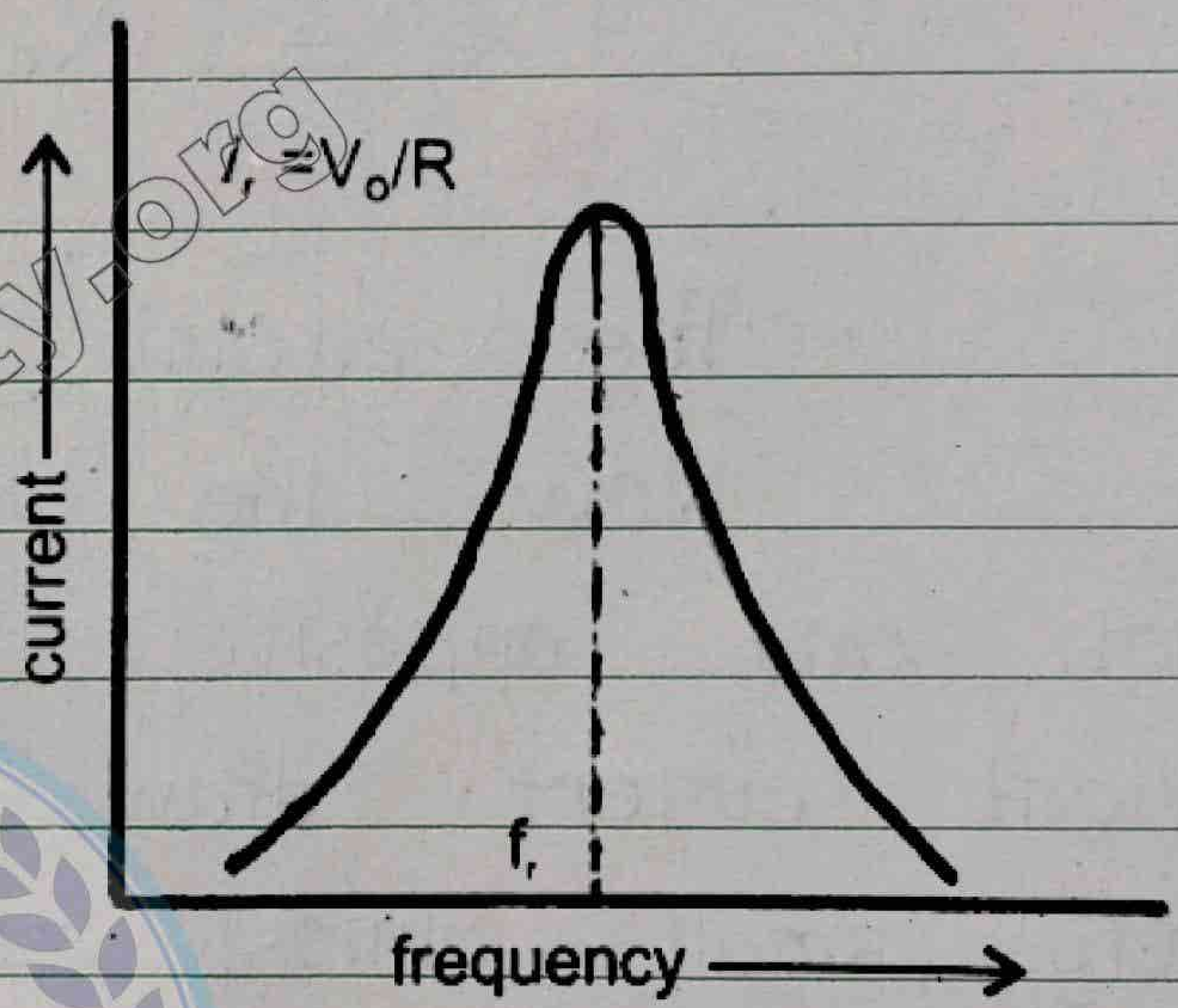
iii) : Since impedence is minimum, current is maximum I_0

$$\boxed{I_0 = \frac{V_0}{Z} = \frac{V_0}{R}}$$

V_0 = Peak value of applied voltage

iv) : Variation of current with frequency is shown in fig.

v) : At resonance voltage drop V_L across the inductance and V_C across the capacitance may be mach large than the source voltage V.



16-10 Parallel Resonance Circuit

Fig (a) shown RLC paraller circuit in

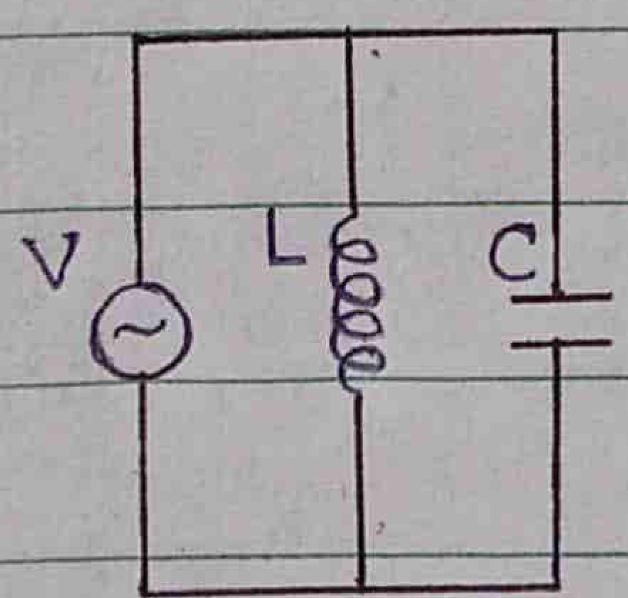


Fig (a)

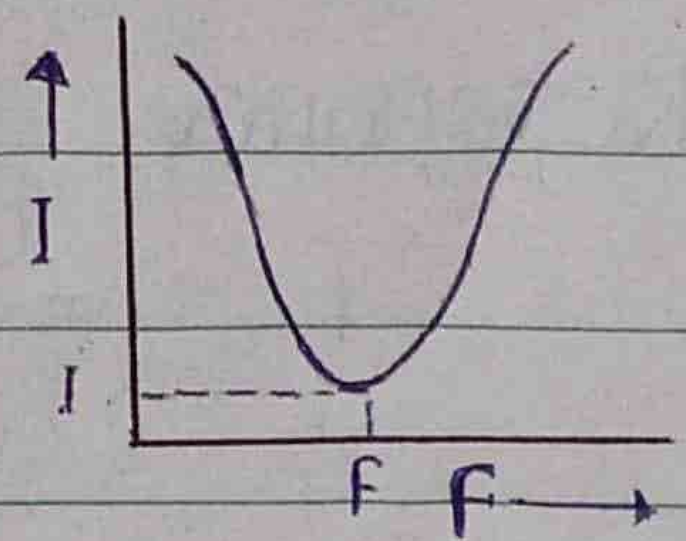
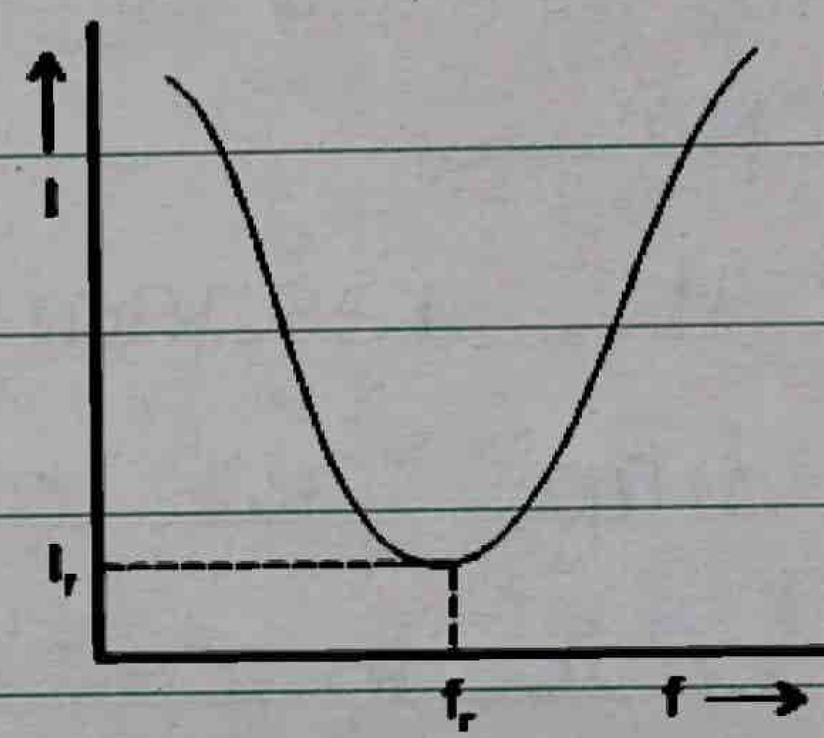


Fig (b)

An alternating source of voltage V is applied whose frequency can be changed.

Resistance of the inductance coil is very small almost zero. The capacitor draws a leading current, whereas the inductor draws a lagging current.

At resonance frequency $\omega = \omega_r$



$$\boxed{X_L = X_C}$$

The circuit resonates.

Now the two braned currents are equal and opposite thy cancel out, so the resultant current draw from the source becomes very small almost zero.

Practically current is not zero but it has minimum value due to small resistance R of the coil (inductance).

Properties of parallel resonance circuit:

i) : Resonance frequency is

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

ii) : The circuit impedence is maximum. Ite

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value is. $\left(\frac{L}{CR}\right)$.

$$\boxed{Z_{max} = \frac{L}{CR}}$$ unit of $\frac{L}{CR}$ is ohm.

iii) ; The current I is minimum and it is in phase with the applied voltage V.
So, power factor, is 1. $(\cos\theta = \cos 0^\circ = 1)$

iv) ; The variation of currents with frequency is shown in fig (b).

V) ; The branch currents I_L and I_c may each be larger than the source current I_r.

16.11 Three Phase AC suppy

One phase A.C supply:

In one phase A.C generator there is a coil with a pair of slip rings. An alternating voltage is generated across the slip rings when the coil is rotated in a magnetic field.

Three phase A.C supply:

Principle:

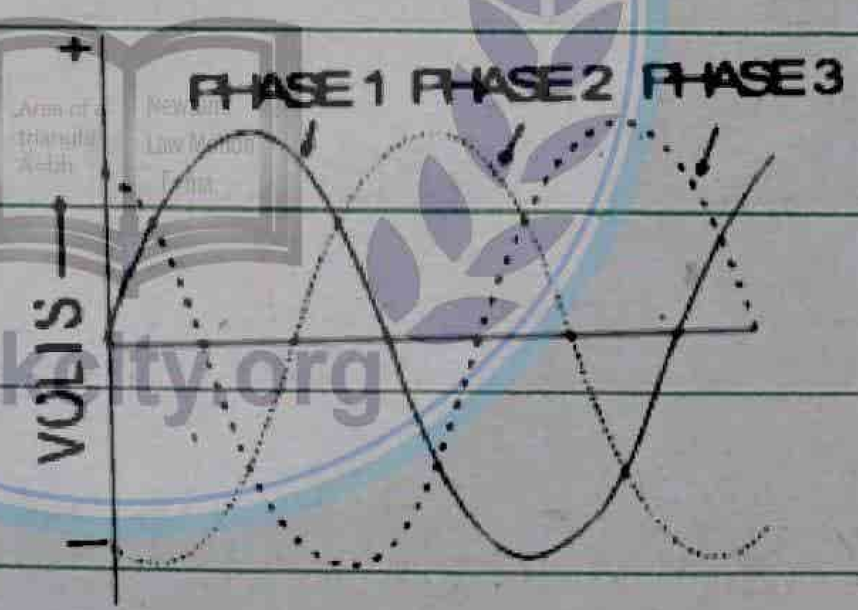
When the coils rotate in the magnetic field, an alternating voltage is produced across the slip rings.

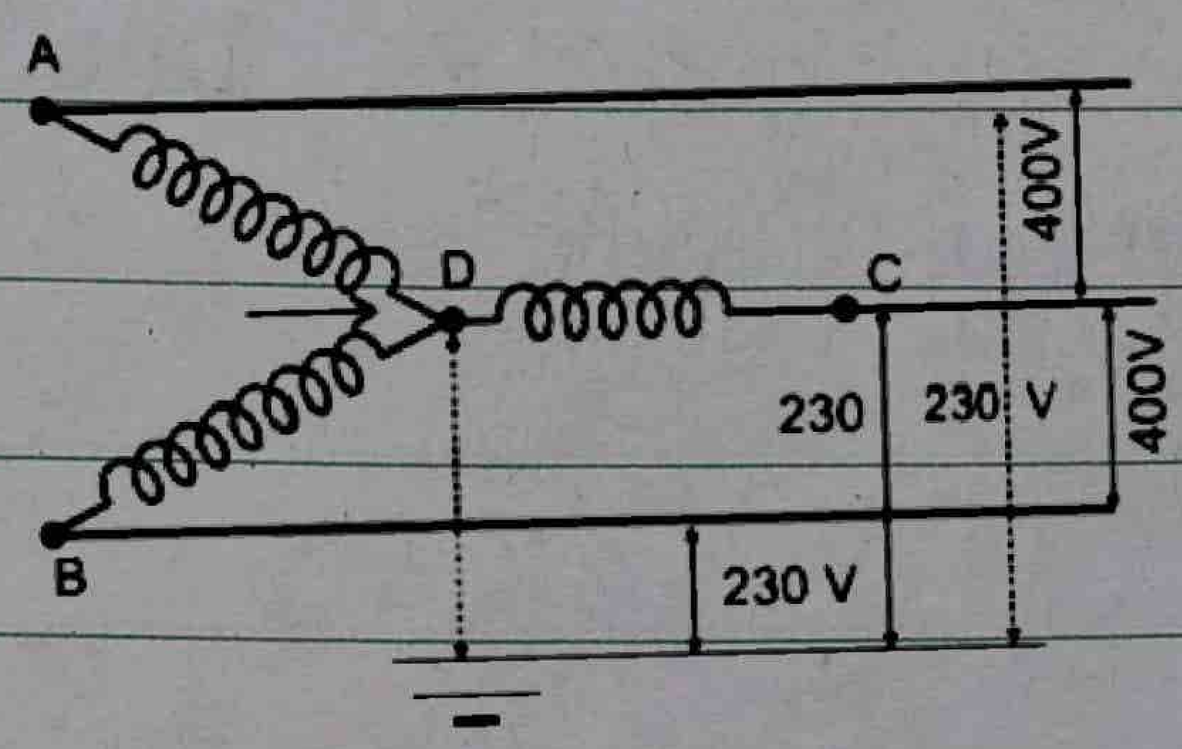
Constrction:

In the case of one phase A.C generator, there is a single coil. But in three phase generator instead of one coil, there are three coils, inclined at 120° to each other. each coil connected to its own pair of slip rings.

Working:

When the combination of three coils rotate in the magnetic field, three alternating voltages are produced across its own pair of slip rings.





The phase different between these

voltage is 120°. It means that when potential difference or voltage across the slip ring is zero having a phase of 0, the voltage across the second coil is not zero and also it has phase difference = 120°. phase difference for the voltage develped across the third coil = 240°. This is shown in fig (a)

The three phase generator has six slip rings and it should have six terminals. But instead, there are only four terminals. It is explained as follows.

The winding of the three coils start from a common terminal, which is usually earthed. It is called common terminal "D". There are other three terminals A, B, C which are the end points of the three seperate coils. Their connections are shown in the fig (b).

The voltage between A, B, C and neutral line is 230 V. Due to phase shift of 120° the potential difference between "AB", "BC", "CA" is 400 V.

Use:

i) : The main advantage of a three phase supply is that the total load is divided in three parts, so that no line is overloaded. If heavy load (consisting of a number of air conditioners and motors etc.) is supplied power from a single phase supply, its voltage is expected to drop at full load.

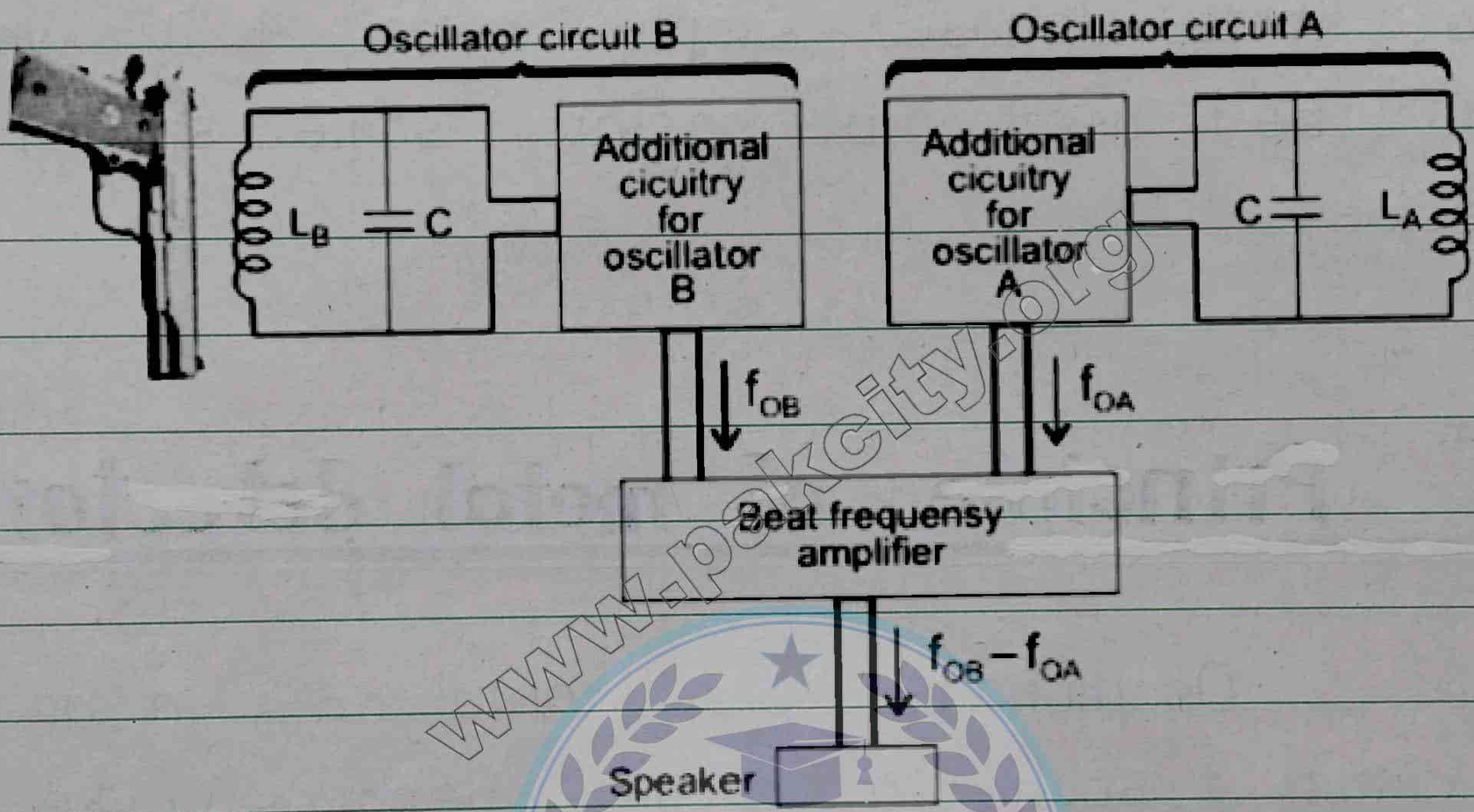
ii) ; The three phase supply gives 400V which can be used to operate some special devices.

16.12 Principle of metal detector

Oscillations are produced in an L_C circuit. Such a circuit behaves like an oscillating "mass spring system". The energy oscillates between capacitor "C" and inductor "L" and the charge oscillates in the circuit. Such a circuit is called "Electrical oscillator circuit."

Metal detectors consist of two electrical oscillating circuits as shown in fig. Both the oscillating circuits are identical and have same frequency of oscillations of electric charge. Inductor "B" is called search coil. When this coil is brought near a metal, then its inductance decreases and the corresponding frequency of oscillating charge increases.

$$\boxed{f = \frac{1}{2\pi\sqrt{LC}}} \quad ; \quad f \propto \frac{1}{\sqrt{L}}$$



Due to small difference of small frequencies of two oscillatory circuits "beats" are produced. Due to which "beat note" is heard in the speakers of the metal detectors.

Use:

Metal detectors are used for security purpose as well as for the search of buried metal objects.

16.13 Choke

A coil of thick copper wire, which is wound with large number of turns on soft iron laminated core is called choke coil. The value of self-inductance "L" of such a coil is very large. The d.c resistance "R" of the coil is kept very small. so that the power loss (I^2R) is very small (negligible).

Use

The chock coils are used to control electric current in "AC" circuits with consming small amount of energy as compared to a pure resistor "R".

16.14 Electromagnetic waves

Definition:

"The electromagnetic waves consist of electric and magnetic fields which oscillate with the same frequency and their amplitudes of oscillations are perpendicular to each other."

The electromagnetic waves require no medium for their propagation. They can travel in vacuum. Their speed is very large.

They can rapidly propagate all around.

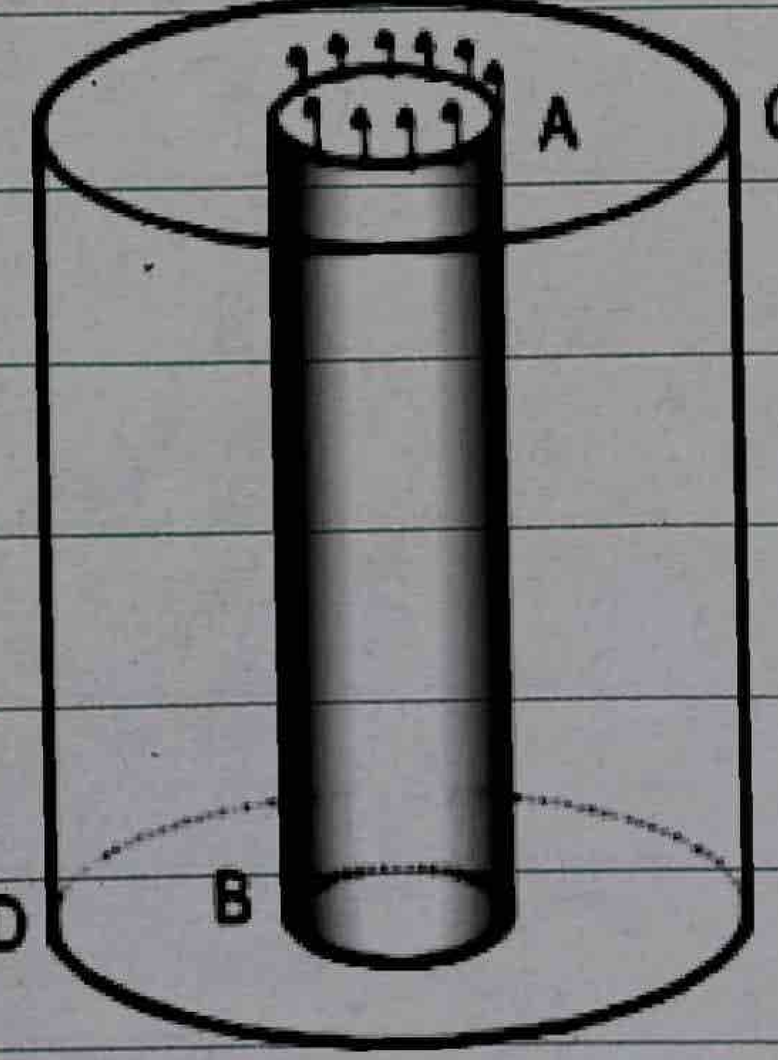
In 1864 British physicist James clark Maxwell formulated a set of equations known as Maxwell's equations which explained the electromagnetic phenomena.

Explanation:

According to Maxwell's equations a changing magnetic flux creates an electric field, and changing electric field produces magnetic field.

Consider a region of space "AB" in which magnetic field is changing. Due to which changing electric field is generated in the surrounding regin "CD". This changing electric field produces magnetic field surrounding "D.C."

Thus each field generates the other and the whole package of electric and magnetic fields will move along propelling it self through space. Such moving electric and magnetic fields are known as



Electromagnetic waves. The electric field, magnetic field and the direction of their propagation are mutually perpendicular to each other as shown in fig.

The electromagnetic waves are periodic waves because they repeat them selves after a fixed interval. They move with the speed of light "C".

$$\boxed{C = f\lambda}$$

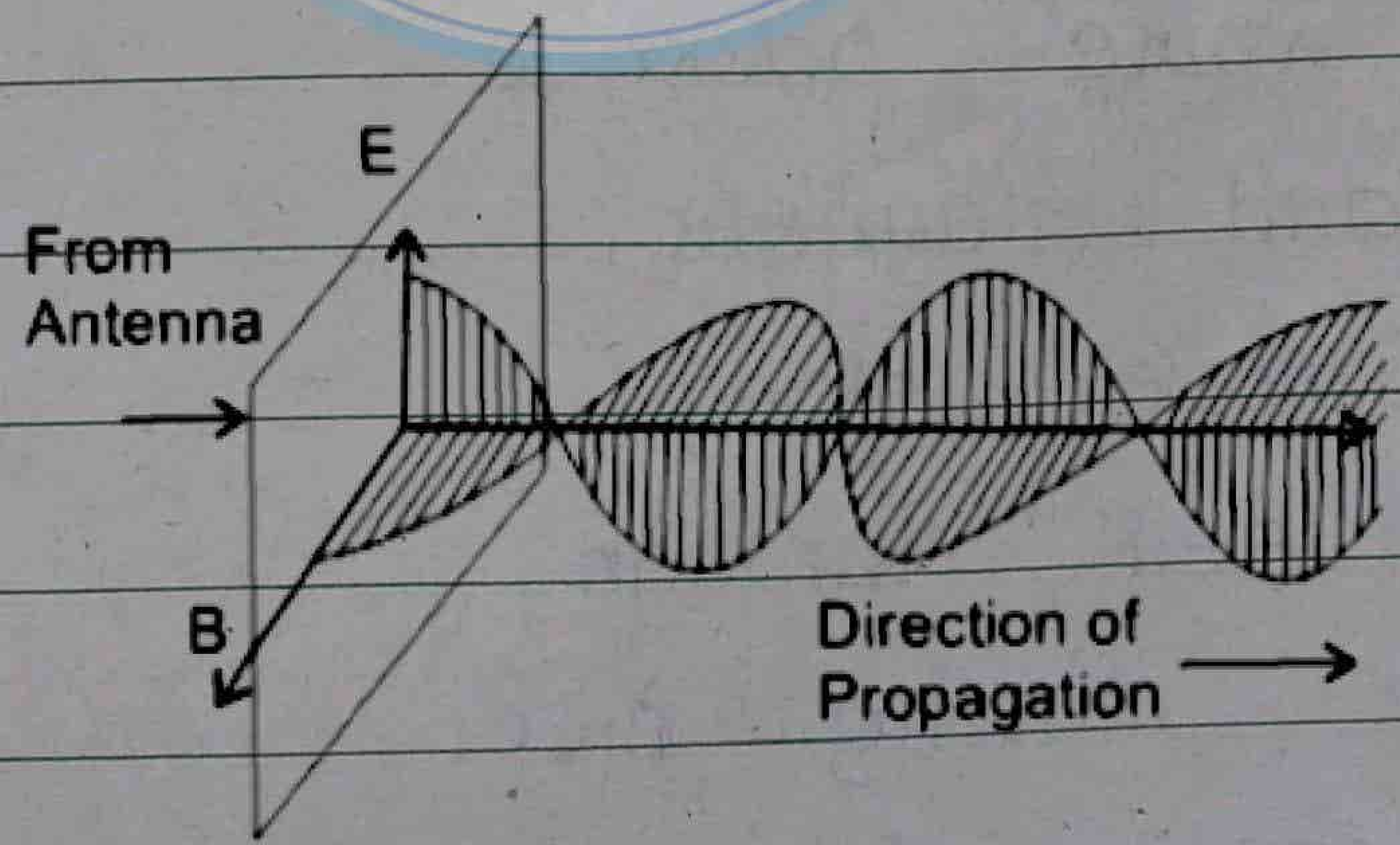
$\because$ $C = 3 \times 10^{8}\, ms^{-1}$

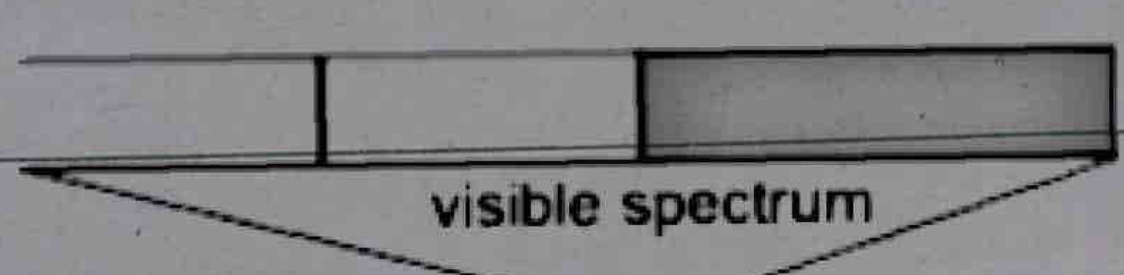
λ = wavelength

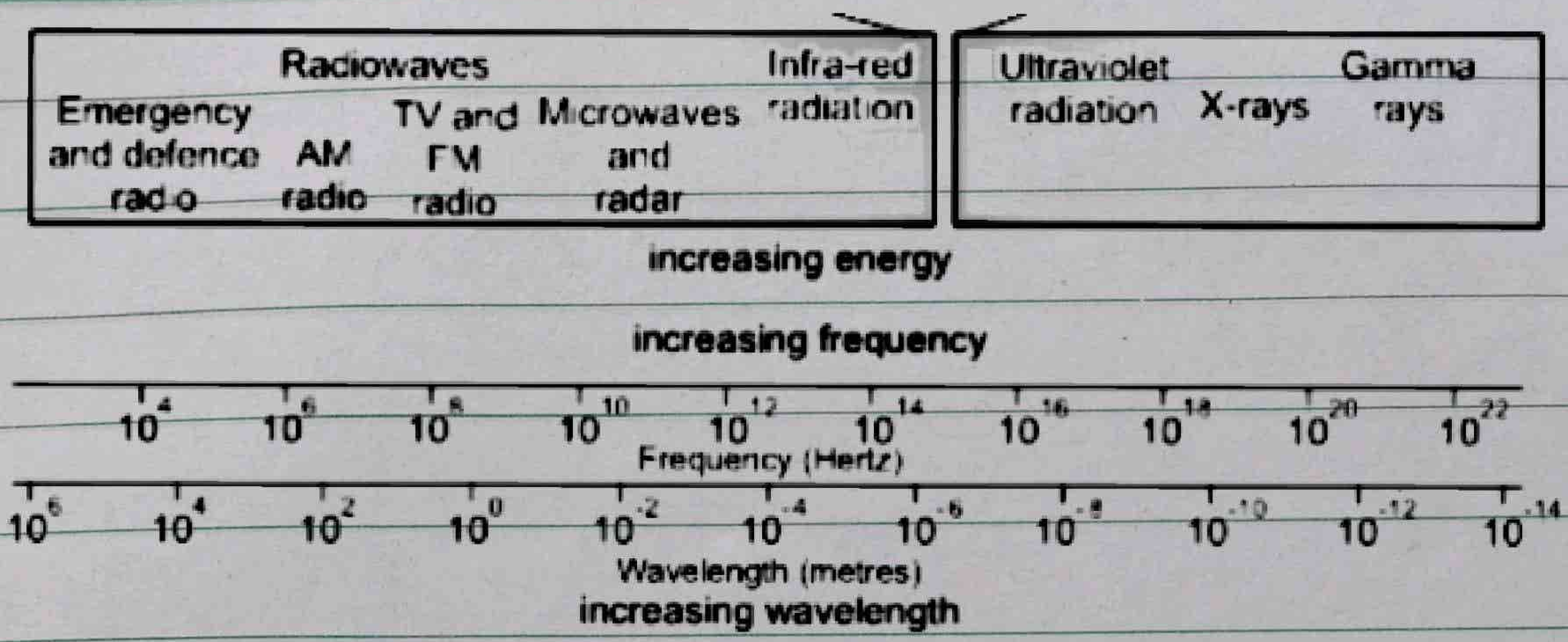
f = frequency

According to the different ranges of frequency, the electromagnetic waves are named differently. The full spectrum of electromagnetic waves is shown in fig.

The spectrum consists of radio waves to high frequency gamma rays.







16.15 Principle of generation, transmission and reception of electromagnetic waves.

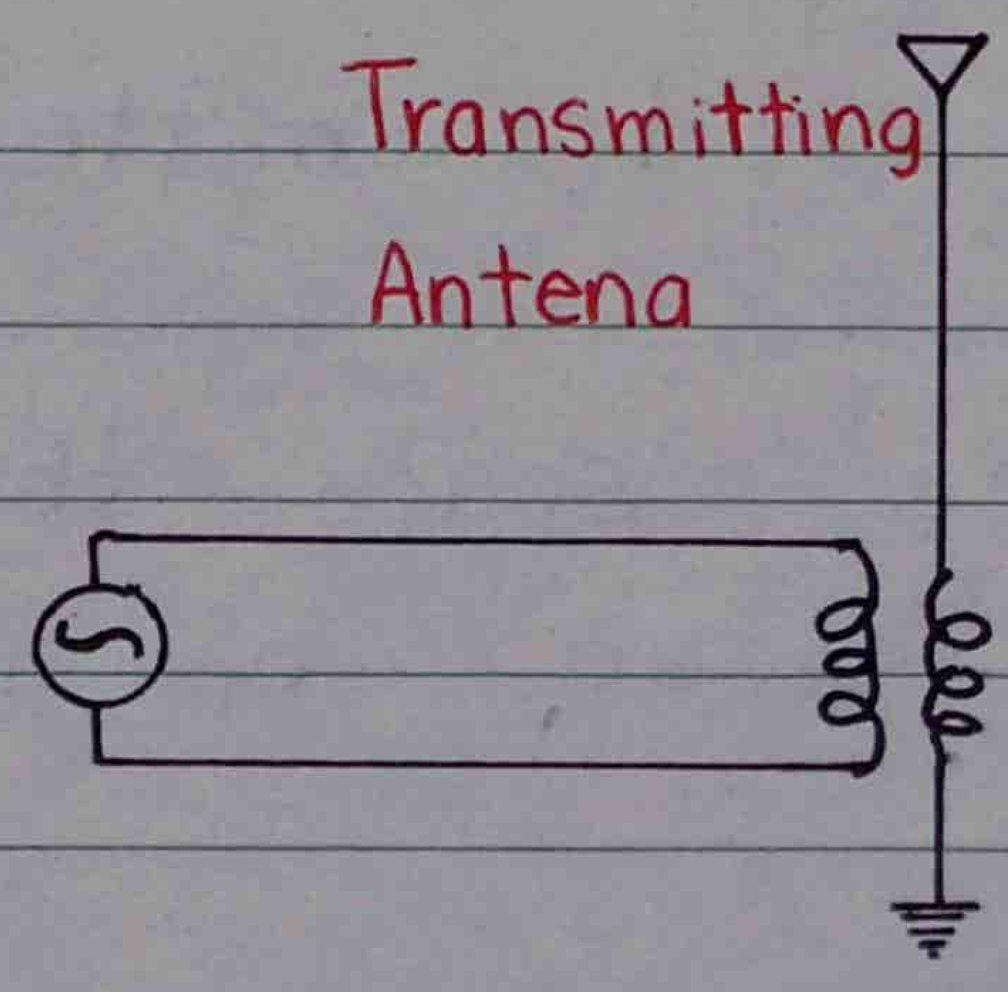
Generation of radio waves:

Electromagnetic wave are generated in a region of space where electric and magnetic fields are changing.

1- An electric charge at rest gives constant electric field around it. There is no change of electric flux, there fore constant electric field around it. This is the reason that charge at rest do not radiate energy in the form of electromagnetic waves.

2_ But when the electric charge moves with constant velocity, it is equivalent to a constant current flowing. This generates constant magnetic field in the region of space around it.
Due to steady current, the magnetic field produced by it is also constant, so no change of magnetic flux takes place.
No electric field is produced.
Hence electromagnetic waves are produced.

3_ So, in order to produce electric waves, we must have oscillating charge or accelerating charge.
A radio transmitting antenna is a good example of generating electromagnetic waves.
A piece of wire or wire loop along which the changes are made to accelerate are known as Transmitting Antena.
See Fig.



The wire loop is charged by the help alternating source of electric potential of particular

Frequency F and time period T.

As the charging potential oscillates, the charge on the antena also constantly reverses.

For example if the top has +q charges at any instant, then after a time $\frac{T}{2}$ the charge on it will be -q.

Such regular reversal of charges on the antenna given rise to an electric flux that constantly charges with frequency F.

This changing electric flux produces an electromagnetic wave which propagate out in space away from the antenna.

The frequency with which the fields alternate is always equal to the frequency of the source producing them.

These electromagnetic waves which are propagated out in space from antenna of a transmitter are known as Radio waves.

In free space these waves travel with the speed of light.

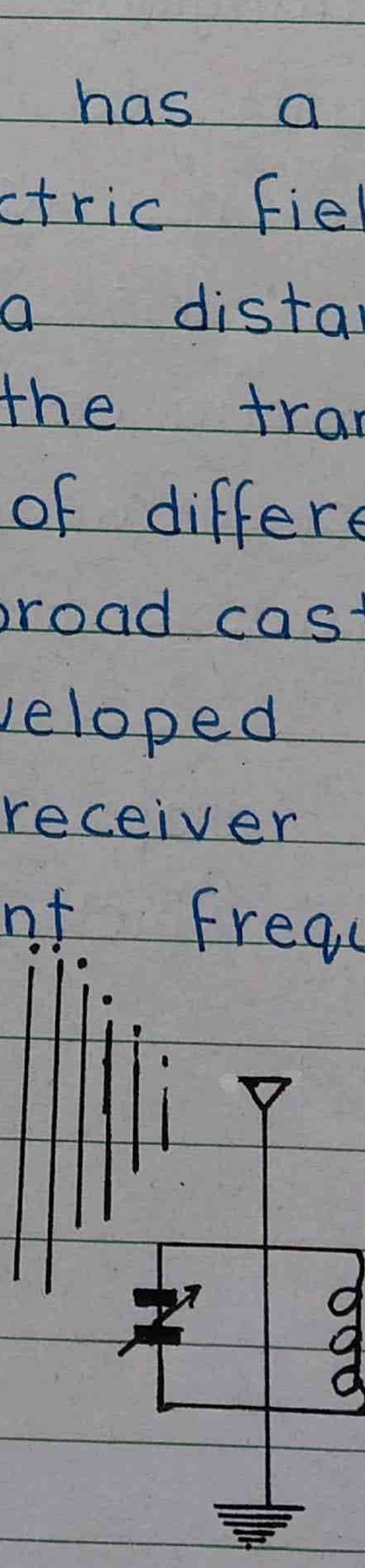
Reception of radio waves:

Suppose the radio waves falls on the antenna of radio-receiver the free electrons in the receiving antenna start oscillating with the same frequency as the frequency of transmitted electromagnetic waves from transmission antenna. This gives rise to alternating voltage across the antenna of radio receiver. This alternatting voltage has the same frequency as the frequency of radio waves falling on the antenna of radio receiver.

This alternating voltage has a very small value because the electric field of the wave is very weak at a distance of many kilometers from the transmitter

Due to a number of different radio stations of different broad casting frequencies, the voltage developed in the antenna of the radio-receiver is alternating voltage of different frequencies.

The alternating voltage of one frequency can be picked up (from the mixture of different frequencies) a circuit consisting of an inductor L and a



variable capacitor C in parallel, is connected at one end of the receiving antenna, as shown in fig.

The LC - circuit is oscillator circuit which produces oscillations of charges.

The frequency of oscillation is given by

$$\boxed{f = \frac{1}{2\pi\sqrt{LC}}}$$

By changing C we can set the value of f equal to the frequency of a particular transmission waves of a particular radiation.

This matching of frequencies produces resonance to give large responce to a particular frequency. This is called Tuning of radio frequency.

Due to resonance the voltage drop across L and C becomes very Large which is amplified and detected.

16.16 Modulation

Modulation:

It is a process of combining the low frequency signal with a high frequency radio wave. The resultant wave is called modulated carrier wave.

Explanation:

Speach and music are transmitted hundreds of kilometers away by a radio transmitter. The picture taken by TV-camera is sent many kilometers away to viewers.

In all these cases, the carrier of speech or picture is a high frequency radio wave. The information is superposed on the radio wave and is carried along with it to the destination.

Carrier wave:

The high frequency radio wave in modulation is called carrier wave.

Modulating Signal:

The low frequency signal in modulation is called modulating signal.

Types of modulation:

Modulation is achieved by changing Amplitude or frequency of the carrier wave in accordance with the modulating signal.

There are two types of modulation.

1- Amplitude modulation (AM)

2- Frequency modulation (FM)

1- Amplitude modulation: (AM)

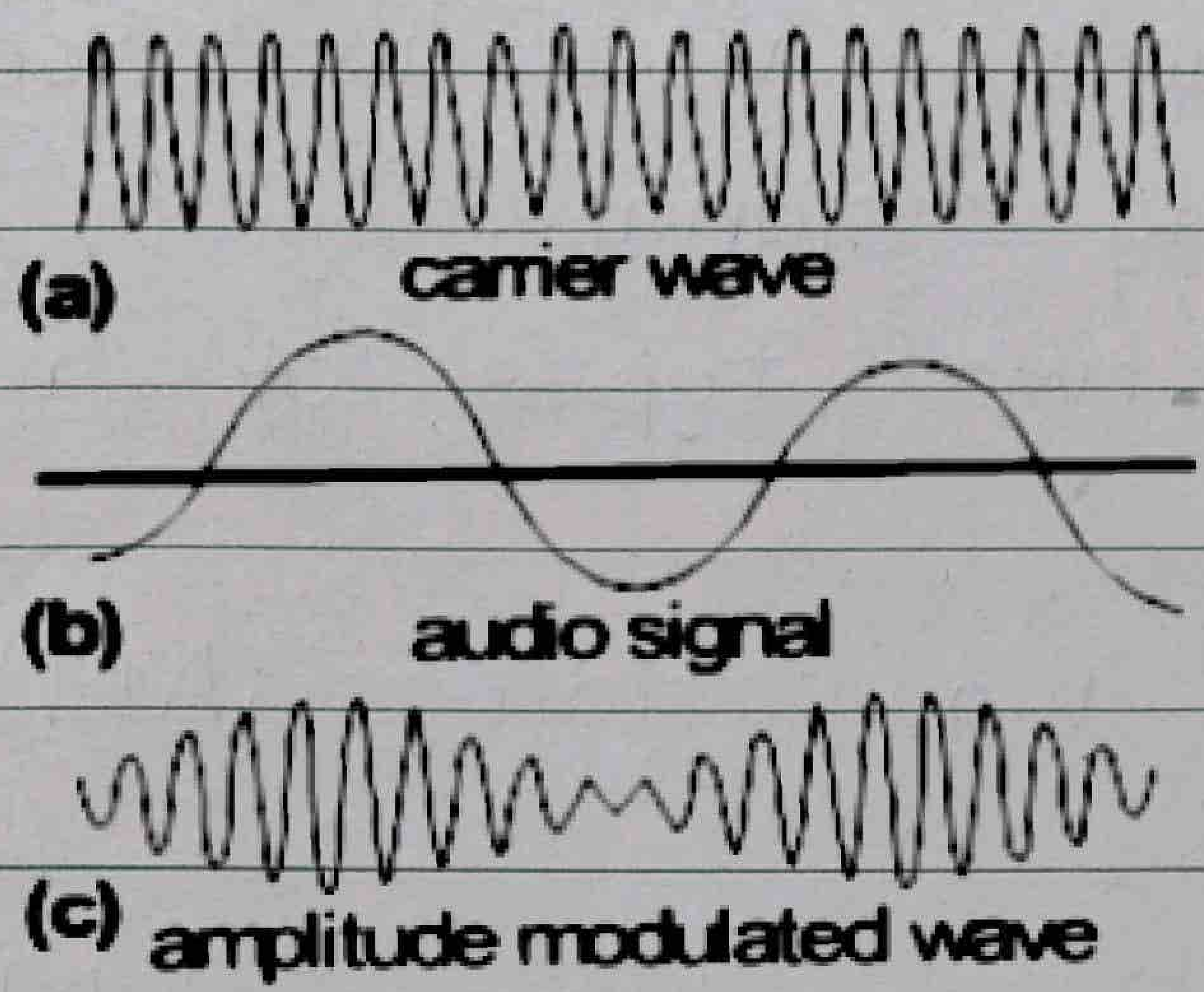
In this type of modulation the amplitude of the carrier wave is increased or decreased as the amplitude of the super posing modulating signal increases or decreases.

Fig (a) represents the high frequency carrier wave of constant amplitude and frequency

Fig (b) represents a Low frequency or audio frequency signal of a sine wave form.

Fig (c) shows the result obtained

by modulating the carrier waves with the modulating waves.



Range:

The AM transmission frequencies range from $\boxed{540\,kHz \text{ to } 1600\,kHz}$.

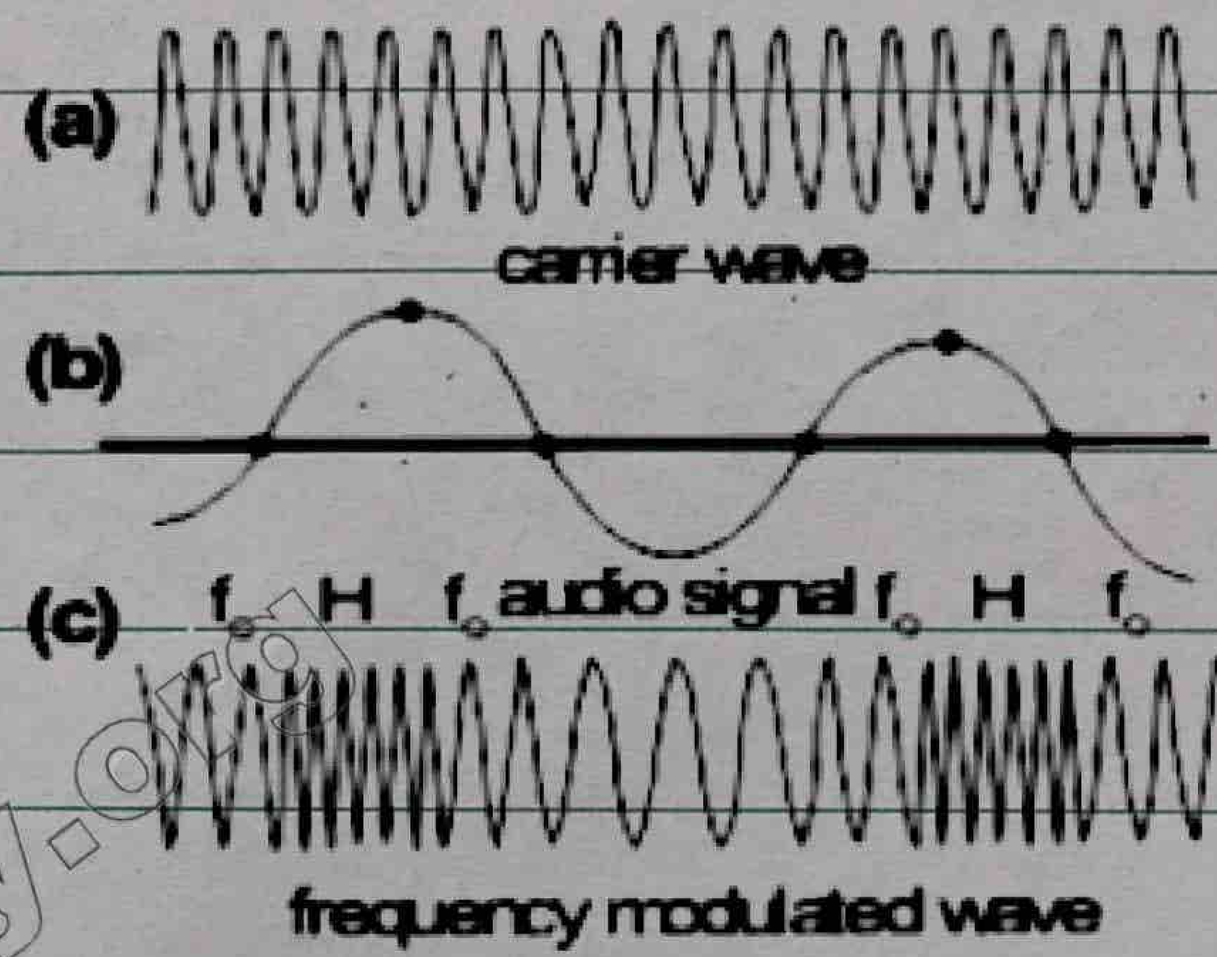
2- Frequency modulation:

In this type of modulation the frequency of the carrier wave is increased or decreased as the modulating signal amplitude increases or decreases but the carrier wave amplitude remains constant.

Fig shows frequency modulation.

1- The frequency of the modulated carrier wave is highest (at point H) when the signal amplitude is at its maximum positive value.

2- The frequency of the modulated carrier wave is lowest amplitude (point L) when the signal amplitude has negative value.



3- When the signal amplitude is zero, the carrier frequency is at its normal value f_o.

Range:

The range of FM transmission frequency is from.

88 MHz to 108

Advantages:

FM radio waves are affected less by electrical interference than AM waves. They provide a higher quality transmission of sound.

Diadvantages:

They are less able to travel around obstacles such as hills or large buildings.

Chapter = 16

Questions

Question 16.1

Answer:

$I_{rms} = 10A$

$I_o = ?$

$I_{rms} = \frac{I_o}{\sqrt{2}}$

$I_o = \sqrt{2}\ I_{rms}$

$I_o = \sqrt{2} \times 10\ A$

$I_o = 1.414 \times 10A$

$I_o = 14.14\ A$

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Question 16.2

Answer:

(a) Inductor
(b) Capacitor

Question 16.3

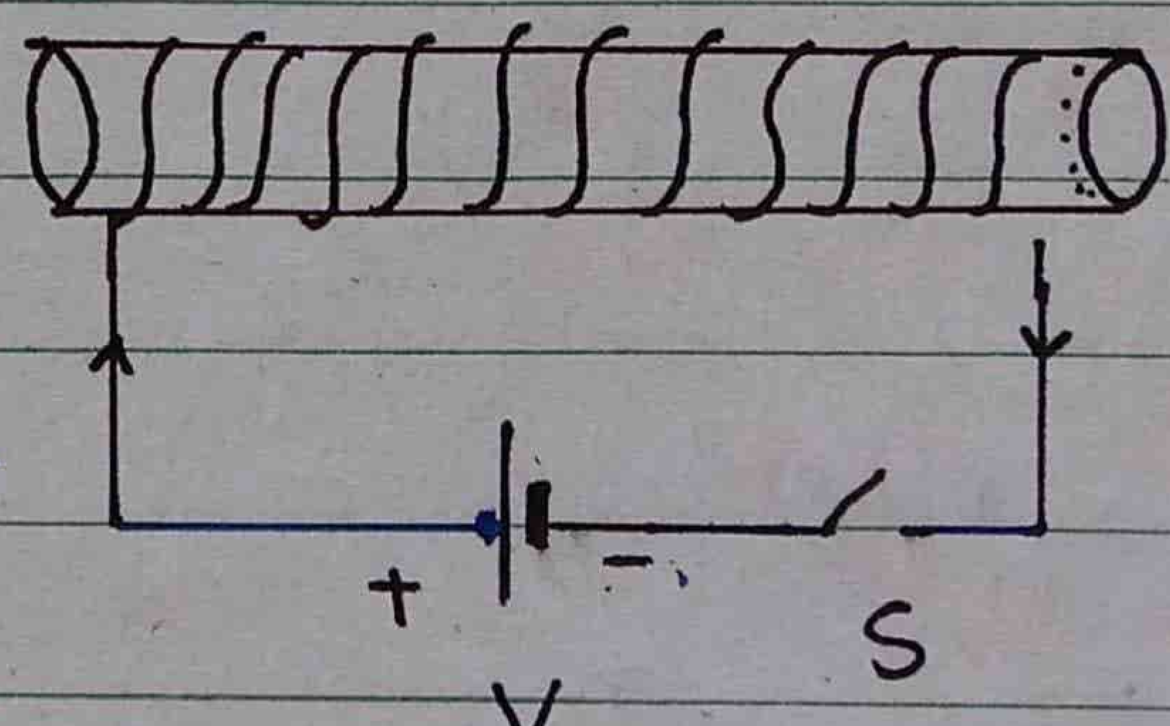
Answer:

$f = 50\,Hz$. In one AC cycle, the current becomes maximum twice.
At $+I_0$; at $-I_0$ (peak values).
In one second brillance is maximum twice the frequency of $AC = 2f = 2\times50 = 100$ time /sec

Question 16.4

Answer:

When the switch S is closed, current grows from zero to maximum value. This changing current produces change in the magnetic flux due to which an emf is induced in the coil. This induced emf becomes zero when current becomes steady. When the switch is reopened, again induced



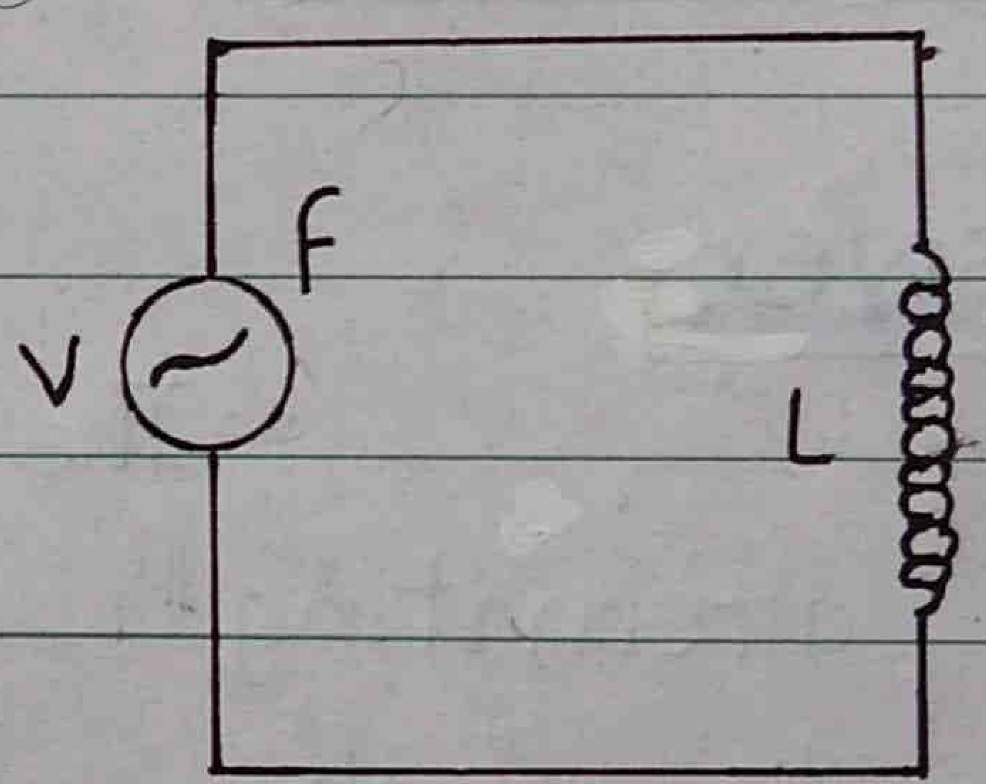
emf (back emf) is developed across the inductor (coil). When this back emf has a sufficiently Large value, it is produces a spark at the ends of the switch contacts.

Question 16.5

Answer:

(a) Rectance X_L of inductor is

$$X_L = \omega L$$



$$X_L = 2\pi f L$$

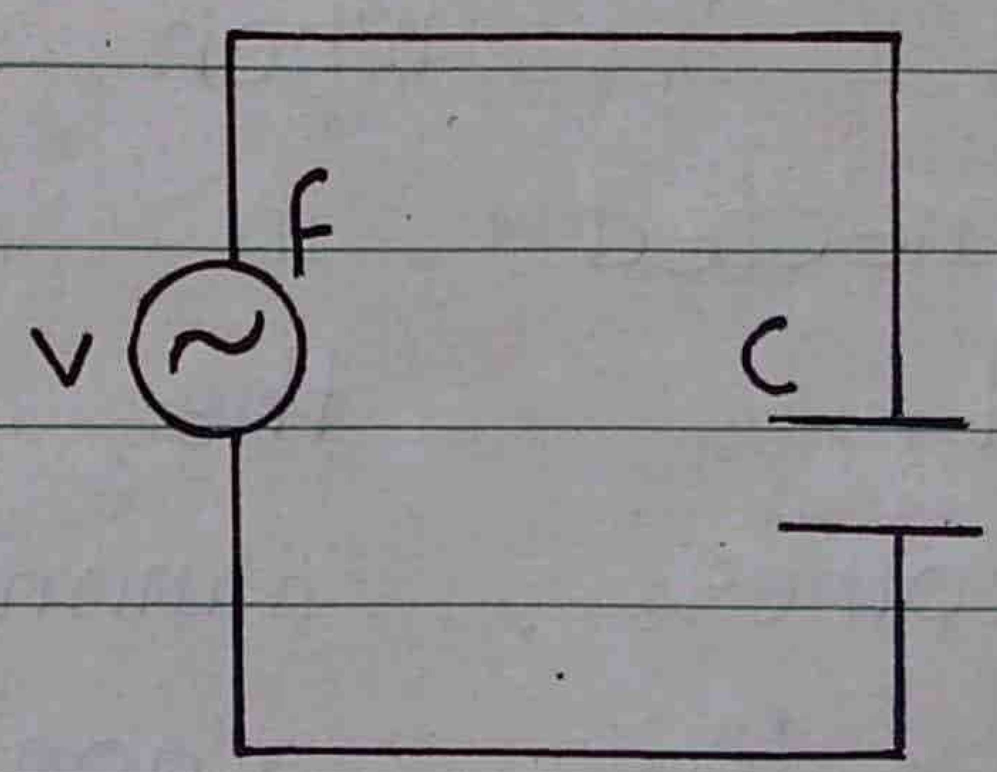
or,

$$X_L \propto f$$

If frequency f is doubled X_L is also doubled

(b) Rectance X_c of a capacitor is

$$X_L = \frac{1}{\omega C}$$



$$X_L = \frac{1}{2\pi f C}$$

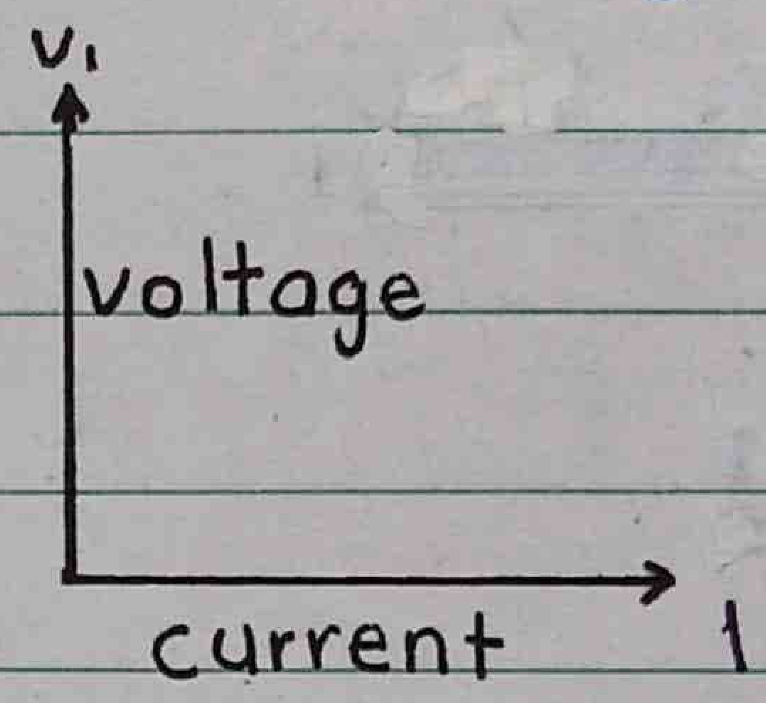
or $$X_c \propto \frac{1}{f}$$

If frequency f is doubled X_c becomes half

Question 16.6

Answer:

In a R-L- series circut current I lags behind voltage V by $\theta = \tan^{-1}\left(\frac{X_L}{R}\right)$ OR $\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$ as shown in Fig.



Question 16.7

Answer:

The lamp becomes dim because the alternating choke coils offers Reactance X_L to the Flow of alternating current.

So, current passing through the lamp decreases and the lamp becomes dim.

When a variable capacitor is also connected in series with the choke coil, the impedence of the circuit becomes minimum at a certain value of the capacitance C at resonance condition.

At resonance;

$$X_L = X_C$$

As X_L and X_C are equal but opposite in direction. so they cancel the effect of each other. The impedence Z of the circuit becomes mini-umand current becomes maximum.

So. the lamp glows with normal brilliance.

Question 16.8

Answer:

Electromagnetic waves are produced by charges i,e, electrons are made to vibrate in an antena the vibrations of electrons creat changing magnetic field. which in turn produce changing electric field.

So, electromagnetic waves are generated.

Question 16.9

Answer:

Electromagnetic waves from the radio station make the electrons vibrates in the receiving antena of the radio.

This antena is connected to the L_C circuit. A particle radio station is tuned by changing the capcitance C of the circuit. When frequency of the electromagnetic waves become equal to the frequency of the L_C circuit.

Resonance is acheived maximum current gives the maximum signal which is amplified and detected.

As

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Question 16.10

Answer:

Amplitude modulation: (AM)

A type of modulation in which amplitude of the carrier wave is increased or decreased as the amplitude of the superposing signal increases and decreases.

Frequency modulation: (FM)

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A type of modulation in which frequency of the carrier wave is increased or decreased as the modulating signal amplitude increases or decreases but the carrier wave amplitude remains constant.

Chapter = 16

Examples

Example 16·1

Solution:

$$V_{rms} = 250V$$

$$V_o = ?$$

$$V = ?$$ Instantaneous value

$$f = 50Hz$$

$$V_{rms} = \frac{V_o}{\sqrt{2}}$$

$$V_o = \sqrt{2}\, V_{rms}$$

$$V_o = 1.414 \times 250$$

$$V_o = 353.5V$$

$$\omega = 2\pi f$$ (Angular frequency)

$$\omega = 100\pi \ HZ$$

$$V = V_o \sin\omega t$$

$$\boxed{V = 353.5 \sin(100\pi t)}$$

Example 16.2

Solution:

$$C = 100 \mu F$$

$$C = 100 \times 10^{-6} F$$

$$V = V_{rms} = 24V$$

$$F = 50Hz$$ $$\omega = 2\pi f$$

(a) $X_c = ?$

(b) $I = I_{rms} = ?$

(a) $$X_c = \frac{1}{\omega C}$$

$$X_c = \frac{1}{2\pi f C}$$

$$X_c = \frac{1}{2 \times 3.14 \times 50 \times 100 \times 10^{-6}}$$

$$X_c = 31.8\ \Omega\ (\text{ohm})$$

$$V = I X_c$$

(b) $V_{rms} = I_{rms} X_c$ $(V = IR)$

$$I = I_{rms} = \frac{V_{rms}}{X_c}$$

$$I = I_{rms} = \frac{24}{31.8}$$

$$\boxed{I = I_{rms} = 0.75\,A}$$

Example 16. 3

Solution:

$$V = V_{rms} = 10V$$

$$I = I_{rms} = 100\ mA$$

$$I = I_{rms} = 100 \times 10^{-3}\ A$$

$$I = I_{rms} = 0.1A$$

$$Z = ?$$

$$V = IZ$$

$$V_{rms} = I_{rms} Z \qquad (V = IR)$$

$$Z = \frac{V_{rms}}{I_{rms}}$$

$$Z = \frac{10}{0.1}$$

$$\boxed{Z = 100\,\Omega}$$

Example 16.4

Solution:

$$L = 1.0\,H$$

$$X_L = 500\,\Omega$$

$$f = ?$$

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

$$f = \frac{X_L}{2\pi L}$$

$$f = \frac{500}{2 \times (3.14) \times 1.0} \quad , \quad \boxed{f = 80\,Hz}$$

Example 16.5

Solution :

$L = 2H$

$R_2 = 50\ \Omega$

$R = 450\ \Omega$

$V = V_{rms} = 100V$

$f = 50Hz$

(i) $I = I_{rms} = ?$

(ii) $\theta = ?$

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

$X_L = 2 \times 3.14 \times 50 \times 2$

$X_L = 628\ \Omega$

$Z = \sqrt{R^2 + X^2{}_L}$

$Z = \sqrt{R^2 + (\omega L)^2}$

$$Z = (500)^2 + (628)^2$$

$$Z = 803\ \Omega$$

$$V = IZ$$

$$V_{rms} = I_{rms} Z$$

$$I_{rms} = \frac{V}{Z}$$

$$I_{rms} = \frac{100}{803}$$

$$I_{rms} = 0.01245 A$$

$$I = I_{rms} = 12.45 \times 10^{-3} A$$

$$I = I_{rms} = 12.45 \mu A$$

$$\theta = tain^{-1}\left(\frac{X_L}{R}\right)$$

$$\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$$

$$\theta = \tan^{-1}\left(\frac{628}{500}\right)$$

$$\boxed{\theta = 51.5}$$

Example 16.6

Solution:

$$C = 2\mu F$$

$$C = 2 \times 10^{-6} F$$

$$R = 1000\,\Omega$$

$$f = 50 Hz$$

$$V = V_{rms} = 12$$

(i) $I = I_{rms} = ?$

(ii) $P = ?$

$$X_c = \frac{1}{\omega C}$$

$$X_c = \frac{1}{2\pi f C}$$

$$X_c = \frac{1}{2 \times 3.14 \times 50 \times 2 \times 10^{-6}}$$

$$X_c = 1592\,\Omega$$

$$Z = \sqrt{R^2 + X_c^2}$$

$$Z = (1000)^2 + (1592)^2$$

$$Z = 1880\ \Omega$$

$$V_{rms} = I_{rms} Z \qquad V = IR$$

$$I_{rms} = \frac{V_{rms}}{Z}$$

$$I_{rms} = \frac{12}{1880} = 6.4 \times 10^{-3}\ A$$

$$I_{rms} = 6.4\ mA$$

$$\theta = \tan^{-1}\left(\frac{X_c}{R}\right)$$

$$\theta = \tan^{-1}\left(\frac{1592}{1000}\right)$$

$$\theta = 57.87^\circ$$

$$P = Vi\cos\theta$$

$$P = V_{rms} I_{rms} \cos\theta$$

$$P = 12 \times 6.4 \times 10^{-3} \times \cos 57.87^\circ$$

$$\boxed{P = 0.04\ W}$$

Example 16.7

Solution:

$$f_r = 1000k\ Hz$$

$$f_r = 1000 \times 10^3\ Hz$$

$$f_r = 1 \times 10^6\ HZ$$

$$L = 5\ mH$$

$$L = 5 \times 10^{-3}\ H$$

$$C = ?$$

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$f_r^2 = \frac{1}{4\pi LC}$$

$$C = \frac{1}{4\pi^2 f_r^2 L}$$

$$C = \frac{1}{4 \times (3.14)^2 \times (1 \times 10^6)^2 \times 5 \times 10^{-3}}$$

$$C = 5.09 \times 10^{-12}\ F$$

$$\boxed{C = 5.09\ pF}$$

Chapter = 16

Problems

Problem 16.1

Solution:

$$I = 20 \sin 100\pi t \longrightarrow (1)$$

$$f = ?$$

$$I_o = ? \text{ (maximum current)}$$

$$I_{rms} = ? \text{ (rms Value)}$$

standard eq is

$$I = I_o \sin 2\pi ft \longrightarrow (2)$$

comparin equ 1 and 2

$$I_o = 20A$$

$$2\cancel{\pi} f \cancel{t} = 100 \cancel{\pi} \cancel{t}$$

$$2f = 100$$

$$f = \frac{100}{2}$$

$$f = 50Hz$$

$$I_{rms} = \frac{I_o}{\sqrt{2}}$$

$$I_{rms} = \frac{20}{\sqrt{2}}$$

$$I_{rms} = \frac{20}{1.414}$$

$$\boxed{I_{rms} = 14.14}$$

Problem 16.2

Solution:

$$I_o = 15A$$

$$I_{rms} = ?$$

$$I = ?$$

$$t = \frac{1}{300} s$$

$$I_{rms} = \frac{I_o}{\sqrt{2}}$$

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$$I_{rms} = \frac{15}{\sqrt{2}}$$

$$I_{rms} = \frac{15}{1.414}$$

$$I_{rms} = 10.6\ A$$

$$I = I_o \sin(2\pi f t)$$

$$I = 15 \sin\left(2\pi \times 50 \times \frac{1}{300}\right)$$

$$I = 15 \sin\left(\frac{\pi}{3}\right)$$

$$I = 15 \sin\left(\frac{180^\circ}{3}\right)$$

$$I = 15 \sin 60^\circ$$

$$I = 15 \times 0.866$$

$$I = 12.9 A$$

$$\boxed{I = 13\ A}$$

$\because (\pi\, rad = 180^\circ)$

Problem 16.3

Solution:

$I = I_{rms} = ?$

$V = V = 220V$

$X_L = ?$

$f = 50Hz$

$L = 10H$

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

$X_L = 2 \times (3.14) \times 50 \times 10$

$X_L = 3141\ \Omega$

$$I_{rms} = \frac{V_{rms}}{X_L}$$

$$I = I_{rms} \quad \frac{220}{3141}$$

$$\boxed{I = I_{rms} = 0.07\ A}$$

Problem 16.4

Solution:

$L = \frac{1}{\pi}\ H$

$R = 1000\ \Omega$

$f = 50\ Hz$

$X_L = ?$ (Reactance)

$Z = ?$ (Ipedence)

$X_L = \omega L$

$X_L = 2\pi f L$

$X_L = 2 \times \cancel{\pi} \times 50 \times \frac{1}{\cancel{\pi}}$

$\boxed{X_L = 100\ \Omega}$

$Z = \sqrt{R^2 + X_L^2}$

$Z = \sqrt{(2000)^2 + (100)^2}$

$\boxed{Z = 2002.5\ \Omega}$

Problem 16.5

Solution:

$$L = \frac{3}{\pi} H$$

$$R = 40 \Omega$$

(i) $I_o = ?$

(ii) $I_{rms} = ?$

(iii) $\theta = ?$

$$V = 350 \sin(100\pi t)$$

AS $V = V_o \sin(2\pi f t)$

Comparing $V_o = 350V$

$$2\cancel{\pi} f \cancel{t} = 100 \cancel{\pi} \cancel{t}$$

$$2f = 100$$

$$f = \frac{100}{2}$$

$$f = 50 \text{ Hz}$$

$$\boxed{\begin{aligned} X_L &= \omega L \\ &= 2\pi f L \\ X_L &= 2\pi \times 50 \times \frac{3}{\pi} \\ X_L &= 300 \Omega \end{aligned}}$$

(i) $I_o = \frac{V_o}{Z}$

$$Z = \sqrt{R^2 + X_L^2}$$

$$Z = \sqrt{40^2 + 300^2}$$

$$= 302.6\ \Omega$$

$$I_o = \frac{V_o}{Z}$$

$$I_o = \frac{350}{302}$$

$$\boxed{I_o = 1.16\ A}$$

(ii) $$I_{rms} = \frac{I_o}{\sqrt{2}}$$

$$I_{rms} = \frac{1.16}{\sqrt{2}}$$

$$I_{rms} = \frac{1.16}{1.414}$$

$$\boxed{I_{rms} = 0.82\ A}$$

(iii) $$\theta = \tan^{-1}\left(\frac{X_L}{R}\right)$$

$$\theta = \tan^{-1}\left(\frac{300}{40}\right)$$

$$\boxed{\theta = 82.4^\circ}$$

Problem 16.6

Solution :

$L = 10 mH$

$R = 20 \Omega$

$L = 10 \times 10^{-3} H$

$V_{rms} = 240 V$

$f = \frac{180}{\pi} Hz$

$P = ?$

$X_L = \omega L$

$X_L = 2\pi f L$

$X_L = 2\pi \times \frac{180}{\pi} \times 10 \times 10^{-3}$

$X_L = 3.6 \Omega$

$Z = \sqrt{R^2 + X^2 L}$

$Z = \sqrt{20^2 + (3.6)^2}$

$$Z = 20.3\ \Omega$$

$$V = I \times Z$$

$$V_{rms} = I_{rms} Z \qquad (V = IR)$$

$$I_{rms} = \frac{V_{rms}}{Z}$$

$$I = I_{rms}$$

$$I = \frac{240}{20.3}$$

$$I = 11.81\ A$$

$$\text{Power} = P = I_{rms}^2 Z$$

$$P = (11.81)^2 \times 20.3$$

$$\boxed{P = 2837\ \text{watt}}$$

Problem 16.7

Solution :

$$I_{rms} = ?$$

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$$C = 0.5\,\mu F$$

$$C = 0.5 \times 10^{-6}\,F$$

$$V_{rms} = 150\,V$$

$$f = 50\,Hz$$

$$X_c = \frac{1}{\omega C}$$

$$X_c = \frac{1}{2\pi f C}$$

$$X_c = \frac{1}{2 \times 3.14 \times 50 \times 0.5 \times 10^{-6}}$$

$$X_c = 6366.2\,\Omega$$

$$I_{rms} = \frac{V_{rms}}{X_c}$$

$$I_{rms} = \frac{150}{6366.2}$$

$$I_{rms} = 0.0235\,A$$

$$\boxed{I_{rms} = 0.024\,A.}$$

Problem 16.8

Solution :

$V_{rms} = 12V$

$f = 50HZ$

$C = 3\mu F$

$C = 3 \times 10^{-6} F$

$R = 1k\Omega = 100\Omega$

$\theta = ?$

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

$X_c = \frac{1}{2\pi f C}$

$X_c = \frac{1}{2 \times 3.14 \times 50 \times 3 \times 10^{-6}}$

$X_c = 1061\ \Omega$

$\theta = \tan^{-1}\left(\frac{X_c}{R}\right)$

$\theta = \tan^{-1}\left(\frac{1061}{1000}\right)$

$$\theta = 46.69$$

$$\boxed{\theta = 47.7^\circ}$$

Problem 16.9

Solution:

$$f_r = ?$$

$$L = 2.5\,H$$

$$C = 40\,\mu F$$

$$C = 40 \times 10^{-6}\,F$$

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$f_r = \frac{1}{2 \times 3.14 \times \sqrt{2.5 \times 40 \times 10^{-6}}}$$

$$\boxed{f_r = 15.9\,Hz}$$

Problem 16.10

Solution:

$L = 150\mu H$

$L = 150\times10^{-6}\ H$

$C = 500pf$ to $20pF$

$f_r = ?$

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

For $C = 500\mu F$

$C = 500\times10^{-12}\ F$

$$f_r = \frac{1}{2\times3.14\times\sqrt{150\times10^{-6}\times500\times10^{-12}}}$$

$f_r = 0.58\times10^{6}\ Hz$

$f_r = 0.58\ MHz$ (minimum value)

For $C = 20pF$

$C = 20\times10^{-12}\ F$

$$f_r = \frac{1}{2\times 3.14\times\sqrt{150\times 10^{-6}\times 20\times 10^{-12}}}$$

$$f_r = 2.91\times 10^{6}\ Hz$$

$$\boxed{f_r = 2.91\,MHz}$$