Bismah Noor
Batch I FSc
@sochbadlobymak

ALTERNATING CURRENT

alternating current

"current which changes its polarity with time"

Introduction:

Supply of alternating current comes from an alternating current source.

→ **Alternating voltage and voltage source:** A source which produces potential difference of changing polarity with time is called as alternating source". A voltage which changes its polarity at regular interval of time is called an alternating voltage."

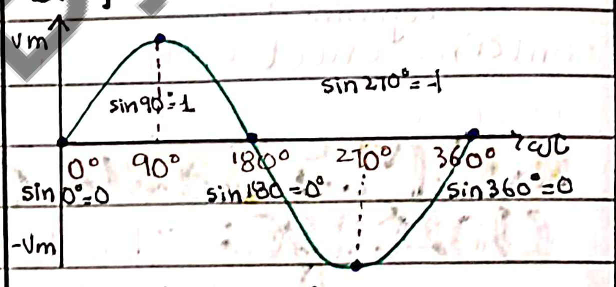
→ **Sinusoidal waveform:** Sinusoidal waveform is obtained from a wave which obeys the range and domain of sine.

→ **Instantaneous alternating voltage:**

$\boxed{V = V_m \sin\omega t}$ 'V' is instantaneous voltage
'Vm' is maximum voltage

"instantaneous voltage is 'sinθ' times of maximum voltage."

Diagram:



▲ Sinusoidal waveform

→ **Trick / important point:** As $\boxed{\sin 0° = 0}$ sinusoidal waveform starts from origin. whereas a waveform obeying cosine function starts from maximum value as $\boxed{\cos 0° = 1}$

AC Terminologies:

→ **Cycle:** Complete set of +ve and -ve values of an alternating quantity is known as a cycle. One cycle corresponds to 360° or 2π radians (consider diagram)

→ **Time period:** Time taken in seconds to complete one cycle. represented by 'T'

→ **Frequency:** Number of cycles occuring in 1 second. Measured in cps or Hz. Frequency of power system in Pakistan is 50Hz. (AC completes 50 cycles in 1 sec)

→ **Instantaneous voltage:** The value of an alternating quantity at any instant is called instantaneous value. Instantaneous values of alternating voltage and current are represented by 'V' and 'I' respectively.

- instantaneous voltage at 0° → 0
- instantaneous voltage at 90° → +Vm
- instantaneous voltage at 270° → -Vm.

→ **Peak value:** The maximum value attained by an AC waveform is called its peak value. V_m and I_m for voltage and current respectively.

→ **Average value:** Average value of a waveform is the average of all its values over a period of time. It's obtained by adding all the values that occur in a specific time interval and dividing the sum by total time.

Average value of AC = Total (net) area under curve for time T ÷ Time T

→ **R.M.S or effective value:** The effective or r.m.s value of an alternating current is that steady current (d.c) which when flowing through a resistor produces the same amount of heat as that produced by the alternating current when flowing through the same resistance for the same time or A single value which contains combined effect of the alternating values of an alternating current.

↳ R.M.S Value of Sinusoidal Current and Voltage:

"It is the r.m.s or effective value which is used to express the magnitude of an alternating voltage or current" Root-Mean-Square

↳ How to devise r.m.s value:

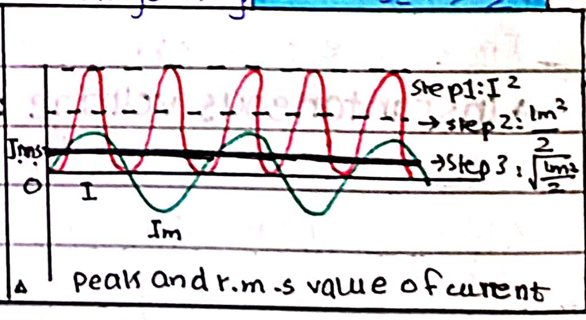
Step 1: Take square → Alternating current has it value in +ve and -ve extremes, to get rid of negative, take square of the given value. x^2

Step 2: Take Mean → After squaring value becomes way too great thus we take mean to bring it around the range of actual value. $\frac{x^2}{2}$

Step 3: Take square root → We require the value within $0 \to x$ range thus we take square root. You can calculate r.m.s value of either current or voltage this way $x_{r.m.s} = \sqrt{\frac{x^2}{2}}$

Mathematically $I_{r.m.s} = \sqrt{\frac{(I_m^2)}{2}}$

Important eq for mcqs $I_{r.m.s} = 0.707 I_m$



Peak and r.m.s value of current

↳ Power delivered:

we know that $I = I_m \sin\omega t$

power with respect to current and resistance is given by $P = I^2R$

putting value of I we have $P = (I_m \sin\omega t)^2 R$, $P = I_m^2 \sin^2\omega t \times R$

$\sin\omega t \rightarrow -1 \leq 0 \leq 1$ } range for sin and sin² on calculator

$\sin^2\omega t \rightarrow 0 \rightarrow 1$

since the value of $\sin^2\omega t$ varies b/w 0 and 1, its average value is ½ (in place of $\sin^2\omega t$)

thus average power delivered $P = I_m^2 \left(\frac{1}{2}\right) R$ $\boxed{P = \frac{1}{2} I_m^2 R}$ ①

if $I_{r.m.s}$ is effective value of current then

$\boxed{P = I_{r.m.s}^2 R}$ ②

comparing eq ① and ② $\frac{1}{2} I_m^2 R = I_{r.m.s}^2 R$ [average power equals r.m.s power]

$I_{rms}^2 = \frac{I_m^2}{2}$ (taking underoot b.s)

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

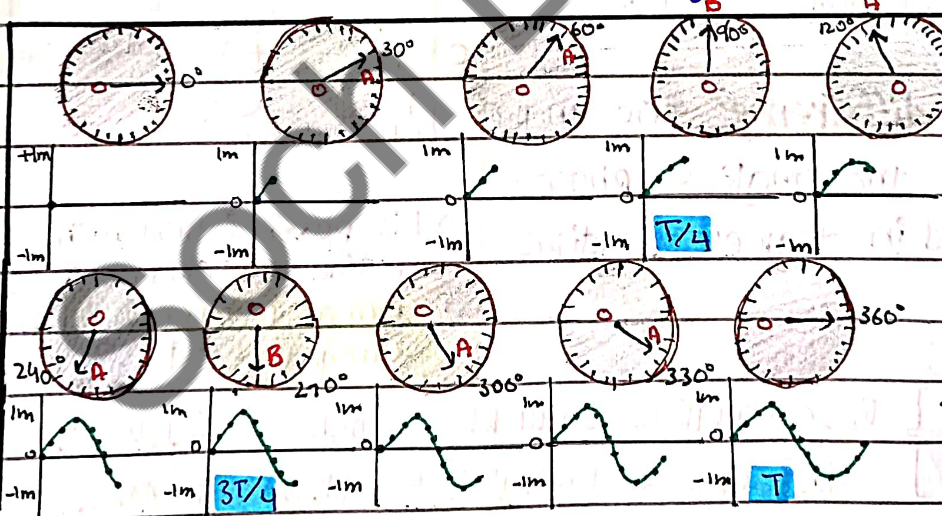
$\boxed{I_{rms} = 0.707 I_m}$

↳ Phase of A.C:

"The angle θ which describes the instantaneous value of alternating current or voltage is called phase. Phase aids us in tracking the path of a wave in the course of certain time T."

→ **What is phasor?** Phasor is short for phase vector. It is a way to represent sine or cosine function graphically. — phasor: phasor is like clock's arm. Its length remains same.

↳ Drawing a wave

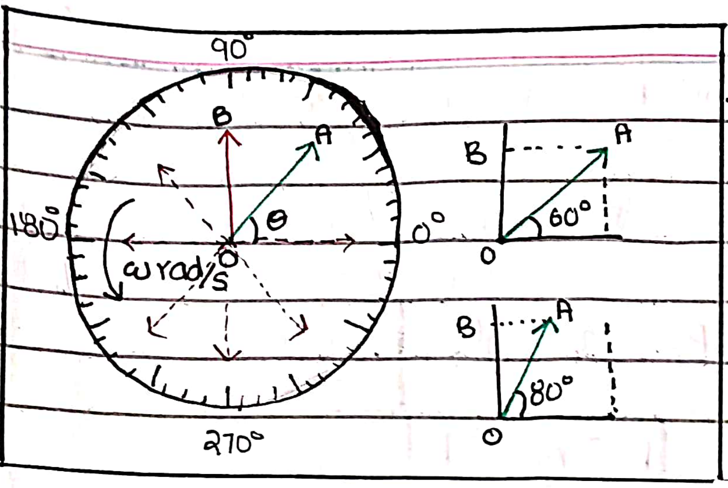


→ **OA:** Phasor rotating about point O with angular ω rad/s.

→ **OB:** Projection of phasor OA on Y axis. It gives instantaneous value of wave

$\boxed{OB = OA\sin\theta}$, $\boxed{I = I_m \sin\omega t}$

→ **When phasor goes past 90°:** wave's direction reverses i.e it declines from peak, after 180° it becomes negative.



→ considering OA's length constant through out the rotation, lets name it 'I_m'.

→ As θ increases from 60° → 80°, the distance of OA or I_m from base increases. Thus the distance from OA to base is instantaneous I as it varies with θ.

→ Projection of OA on y axis is it's distance from base. This projection is OB. representing instantaneos value of I.

Mathematically: $\sin\theta = \frac{perp}{hyp}$, $\sin\theta = \frac{OB}{OA}$ or $\sin\theta = \frac{I}{I_m}$

thus $\boxed{OB = OA\sin\theta}$ or $\boxed{I = I_m \sin\theta}$

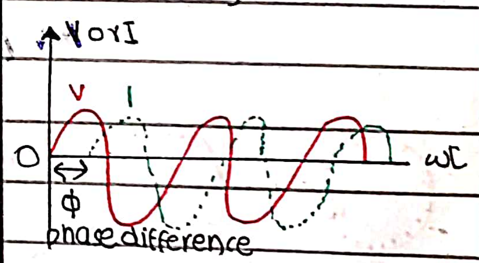
↳ Phase Difference:

→ **What is meant by lead and lag?** When alternating quantities of the same frequency have different zero point they are said to have a phase difference. This phase differece causes one quantity to lead and other to lag.

→ The quantity which passes through its zero point earlier is said to be leading while other is lagging.

→ **How to measure phase difference?** The angle between the zero points is the angle of phase differce and is measured in degrees or radians.

Phasor Diagram:



→ 'V' is passing through the zero line earlier than 'I'

→ current I lags behind Voltage V by φ.

Mathematically
(consider the diagram)

$\boxed{V = V_m \sin\omega t}$
$\boxed{I = I_m \sin(\omega t - \phi)}$ } These equations clearly tell us which quantity leads, which lags and what is the phase difference.

→ For eq ① $\theta = \omega t$ whereas for eq ② $\theta = \omega t - \phi$ which shows θ is less than that for 'V' thus V leads, I lags and φ is phase difference.

↳ A.C Through Resistor:

↳ Background: When alternating voltage is applied in a circuit containing resistance R, alternating current flows through the resistor. Both current and voltage flow through the resistor 'in-phase' i.e, there is no phase difference. This means that starting point of both waveforms will be same. The reason behind both 'V' and 'I' being inphase through the resistor is that resistor doesn't store any current.

Mathematically By Ohm's law $V = IR$ and $I_m = \frac{V_m}{R}$

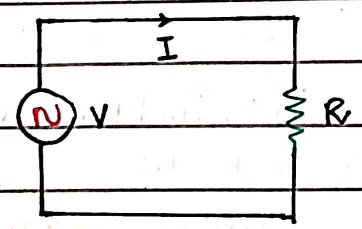
$\boxed{V = V_m \sin\omega t}$ and $\boxed{I = I_m \sin\omega t}$ thus

when ωt $V_m \sin\omega t = I_m \sin\omega t \times R$ the repeating factor '$\sin\omega t$' in both V and I values shows that they are inphase

If $\sin\omega t = 1$ then $V_m = I_m \times R$

for rms values, $\frac{V_m}{\sqrt{2}} = \frac{I_m R}{\sqrt{2}} \Rightarrow V_{rms} = I_{rms} R$

Circuit Diagram:



↳ Power loss: Power loss in an AC circuit through a resistor happens as the electricity is constantly converted into heat

Mathematically:

Average power dissipated over 1 cycle: $P = \langle VI \rangle$

$P = \langle V_m \sin\omega t \times I_m \sin\omega t \rangle = V_m I_m \langle \sin^2\omega t \rangle$

$\sin^2\omega t = \frac{1}{2}$ thus $\boxed{P_{av} = \frac{V_m I_m}{2}}$

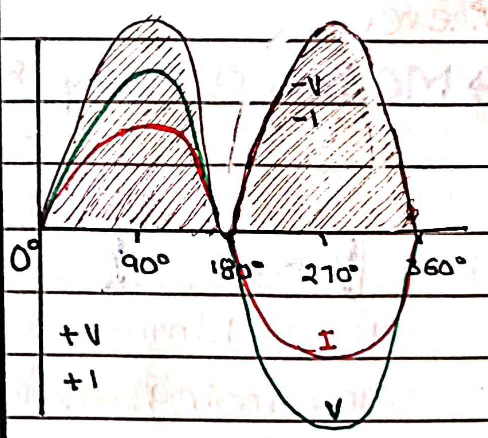
Rms power dissipated:

we know $\sqrt{2} \times \sqrt{2} = 2$ thus eq ① can be written as

$\boxed{P_{av} = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}}}$ but $\frac{V_m}{\sqrt{2}} = V_{rms}$ and $\frac{I_m}{\sqrt{2}} = I_{rms}$

thus $\boxed{P = V_{rms} I_{rms}}$

Power curve:

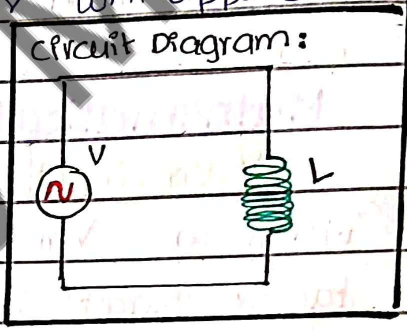


Thus we can conclude: Average power loss equals rms power loss.

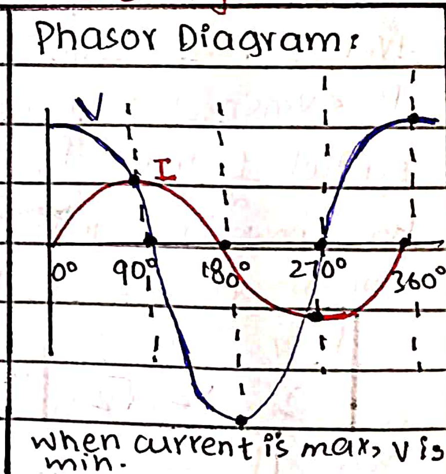
AC Through Inductor:

→ What is inductor: Inductor is just like a coil with high number of turns and the wire of inductor is thick so as to offer less resistance to current flowing through it $\boxed{R \propto 1/A}$

→ Role of inductor: Inductor opposes changes in alternating current thus tries to keep current constant by varying the voltage applied across it. The back emf induced in inductor will oppose the change in current.



Procedure:
Initially, there is no current stored in form of magnetic field across inductor thus current starts from origin point in graph but voltage is at max. When current across inductor is increasing, inductor will oppose this current. Inductor will act as a load and decrease applied voltage across it in an attempt to reduce current. When current across inductor is decreasing it will try to increase current by increasing applied voltage across it. Here it wont act as a load but as a source by using energy saved in it. In graph we can see when current rises, voltage falls and vice versa.



→ Mathematically Back emf is given by

$\mathcal{E} = L\Delta I/\Delta t$ or $V = L\left(\frac{\Delta I_m \sin\omega t}{\Delta t}\right)$

$V = L I_m \left(\frac{\Delta \sin\omega t}{\Delta t}\right)$, $V = L I_m \omega \cos\omega t$ ①

but $\boxed{V = V_m \cos\omega t}$ ② By ① and ② we can say $V_m = L I_m \omega$

Transforming cos into sin in eq ②

$V = V_m \sin(\omega t + 90°)$

$\boxed{V = V_m \sin(\omega t + \pi/2)}$ ③ whereas $\boxed{I = I_m \sin\omega t}$ ④

→ lead & lag: considering eq 3 and 4, voltage leads current by $\pi/2$ radians. Inductors opposition to change in current is responsible for current lagging behind applied voltage.

→ **Inductive Reactance:** The opposition offered by an inductor to the flow of A.C is called inductive reactance X_L.

Mathematically: By ohm's law; $V_m = I_m X_L$ but we know $V_m = L I_m \omega$; thus $L \cancel{I_m} \omega = \cancel{I_m} X_L$ $\boxed{X_L = \omega L}$

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

→ At higher frequency : X_L increases as $X_L \propto f$.

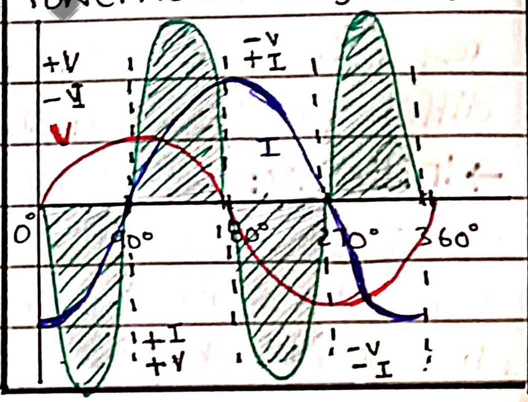
→ In case of DC : X_L will be zero as for DC, $f = 0$.

Thus inductor offers no resistance to direct current.

Power Loss:

consider the graph

Powerwave Diagram:



→ During 0° → 90° : V is +ve whereas I is -ve

thus $P = (+V)(-I)$; Power (-ve)

→ During 90° → 180°: V is +ve and so is I thus $P = (+V)(+I)$; Power (+ve)

→ During 180° → 270°: V(-ve) and I (+ve) thus $P = (-V)(+I)$ and Power (-ve)

→ During 270° → 360°: Both V and I -ve thus $P = (-V)(-I)$; Power (+ve)

→ As during 1 cycle, +ve power loss equals -ve power loss, inductor consumes zero power.

Mathematically.

Average power loss

$P = \langle VI \rangle$

$\boxed{P = \langle V_m \cos\omega t \rangle \langle I_m \sin\omega t \rangle}$

$P = V_m I_m \langle \sin\omega t \rangle \langle \cos\omega t \rangle$

$\boxed{P = 0}$ $\because \langle \sin\omega t \rangle \langle \cos\omega t \rangle = 0$

Important points:

→ -ve power loss : means power is supplied from coil to source

→ +ve power loss: means power supplied from source to coil

↳ A.C through Capacitor:

→ **What happens if capacitor is joined in a circuit with DC?** For a very breif time current will flow through the circuit after which the potential difference of plates will start opposing current thus no current will be able to flow across the circuit. Capacitor in a circuit with DC is just like an open circuit!

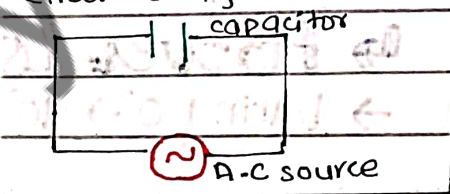
→ **Why is AC required when capacitor is in the circuit?** AC changes its polarity and as the current changes its polarity the plates of capacitor do aswell which allows AC to flow through the circuit. As DC lacks this property, it can't flow across circuit in this case.

↳ Mechanism:

Consider Phasor Diagrams

We have to study the relation between the current responsible for charging capacitor and the potential difference between the plates of the capacitor.

Circuit Diagram:



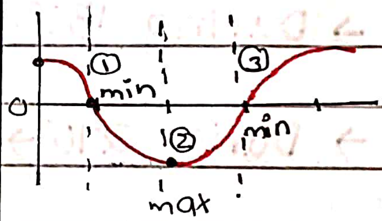
→ **Initially:** In the very begining the AC provided by source is maximum and the charge on capacitor plates is zero and so is the potential Difference between the plates. This can be seen in phasor diagram.

→ **Gradually:** With the flow of current charges start depositing on plates of capacitor and potential difference also starts developing b/w the plates.

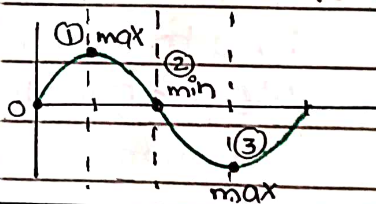
→ **When plates are max charged:** When plates are max charged after quarter cycle, the potential difference between plates will also be maximum. This potential difference will oppose incoming current and current I becomes minimum. This can be seen in graph.

Phasor Diagrams:

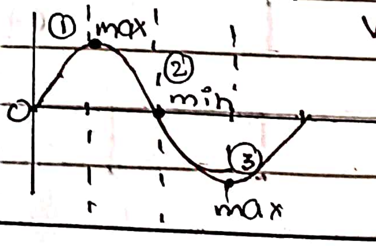
Alternating current, I



Charge on plates: Q



Potential diff b/w plates: V



→ **Current changes its polarity:** After becoming zero, current will change its polarity, direction of current becomes reversed in circuit. Capacitor plates ~~be~~ start getting charged in opposite direction. When capacitor plates are changing their polarity, a time comes when plates become neutral which means min Q and min V thus max current flows through circuit as shown in graph. ②

→ **When plates become fully charged in opposite direction:** When this happens, max potential difference opposes current once again and it ~~is~~ (current I) becomes zero or minimum. ③

Mathematically charge on capacitor $q = CV$

where $\boxed{V = V_m \sin\omega t}$ ① thus $q = CV_m \sin\omega t$ we know $I = \Delta q / \Delta t$

thus $I = \dfrac{\Delta(CV_m \sin\omega t)}{\Delta t} = \dfrac{CV_m(\Delta \sin\omega t)}{\Delta t}$ using math formula

$I = CV_m \omega \cos\omega t = CV_m \omega \sin(\omega t + \pi/2)$

$\boxed{I = CV_m \omega \sin(\omega t + \pi/2)}$ ② here $\boxed{CV_m \omega = I_m}$

→ **What leads & what lags:** From eq ① and ② it's evident that voltage lags behind current by $\pi/2$ radians or $90°$. This is because voltage across capacitor plates is dependent on flow of current.

→ **Capacitive Reactance XC :** It is the opposition offered by the capacitor to the flow of AC.

Mathematically $I_m = \omega V_m C$, $\dfrac{V_m}{I_m} = \dfrac{1}{C\omega}$

or $\dfrac{V_m}{I_m} = X_C$ or $X_C = 1/C\omega$ or $\boxed{X_C = \dfrac{1}{2\pi f C}}$

→ This eq shows higher the frequency of AC, lesser will be opposition offered to it and vice versa

→ **In Case of DC:** For DC we know $f = 0$ thus eq becomes $X_C = 1 \div 2\pi(0)C$ or $X_C = \dfrac{1}{0}$ or $\boxed{X_C = \infty}$ which means where very high opposition thus capacitor does allow DC flow.

Power Loss: consider graph

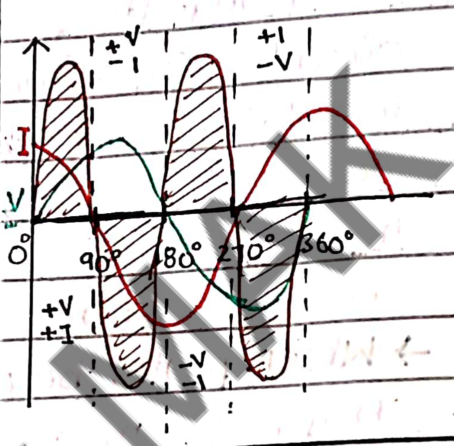
→ **During 0° to 90°:** Both V and I are positive
thus $P = VI$; Power loss +ve

→ **During 90° to 180°:** Voltage is +ve but I is -ve thus $P = -IV$; Power loss -ve

→ **During 180° to 270°:** Both V and I are -ve
thus $P = (-I)(-V)$; Power loss +ve

→ **During 270° to 360°:** Voltage is -ve but I is +ve thus $P = -VI$; Power loss -ve

Powerwave Diagram:



→ As during whole cycle +ve power loss equals -ve power loss thus there is no power loss through capacitor.

Mathematically

$P = \langle VI \rangle = \langle V_m \sin \omega t \rangle \langle I_m \cos \omega t \rangle$

$= V_m I_m \langle \sin \omega t \rangle \langle \cos \omega t \rangle$

$\boxed{P = 0}$

→ Important points:
+ve power loss means circuit is giving energy to capacitor whereas -ve power loss means capacitor is returning energy to circuit.

R.L Series A.C Circuit:

We have to study how AC behaves when Resistor R and Inductor L are joined in series

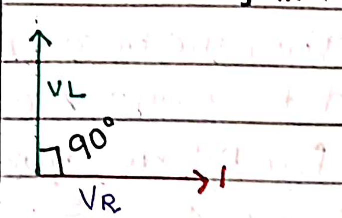
→ **For Resistor:** Voltage and Current (V & I) are inphase

→ **For Inductor:** Current lags behind voltage by 90°.

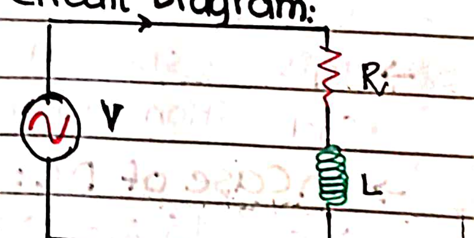
Now we have two voltages VR and VL thus for this circuit we will have to find the resultant and that will be the applied voltage.

- Consider the phasor diagram. VL and I being perpendicular indicates 90° phase difference
- VR and I are labelled for a single vector, this means that phase difference between VR and I is zero.

Phasor Diagram:

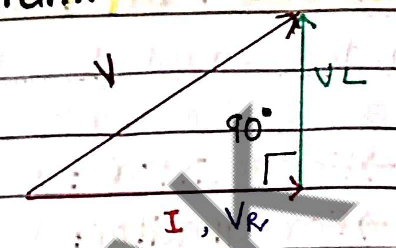


Circuit Diagram:



- Through head and tail rule of vector addition we shall find the resultant voltage for the R-L series circuit.

Diagram:



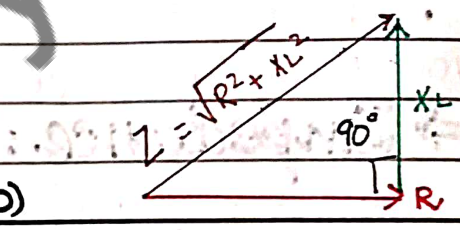
(a)

- **Very Important point:** Notice that the resultant voltage V is leading current but NOT by an angle of 90° as for pure inductor. Thus in a circuit having both inductor and resistor in series, voltage leads current by an angle $0° < \phi < 90°$ (greater than zero, smaller than 90).

↳ Impedance of circuit:

Combined opposition due to inductor and resistor in the circuit will be impedance of circuit.

Impedance triangle:



(b)

Applying pythagorus theorem (diagram a)

$V^2 = V_R^2 + V_L^2$ where $V_R = IR$ and $V_L = IX_L$

$V = \sqrt{(IR)^2 + (IX_L)^2}$

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

$V = IZ$

The quantity $\sqrt{R^2 + X_L^2}$ is called impedance 'Z'

→ **Impedance triangle:** From diagram (b) we can clearly see, The triangle that is created when adding resistance R (of resistor) to the reactance X_L is known as the impedance triangle.

→ **Phase angle:** Value of phase angle ϕ can be determined from the phasor diagram. $\tan\phi = V_L / V_R = \frac{IX_L}{IR} = \frac{X_L}{R}$ $\boxed{\tan\phi = \frac{X_L}{R}}$

→ **lead and lag:** applied voltage $\boxed{V = V_m \sin\omega t}$ then as current is lagging $\boxed{I = I_m \sin(\omega t - \phi)}$ factor $(\omega t - \phi)$ shows current is lagging by ϕ which is less than 90°.

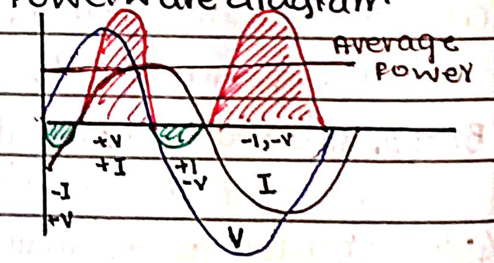
↳ Power:

- For purely resistive circuit power factor is $\cos 0° = 1$.
- For purely inductive power factor is $\cos 90° = 0$

Average power $= P = \frac{V_m I_m}{2}\cos\phi = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}} \times \cos\phi$

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

Power wave diagram



The graph shows net power dissipation over one cycle is positive.

green area: Inductance of circuit returns power to source
Red area: Power dissipation by R

↳ RC Series AC Circuit:

In this circuit, Resistor and capacitor are connected in series.

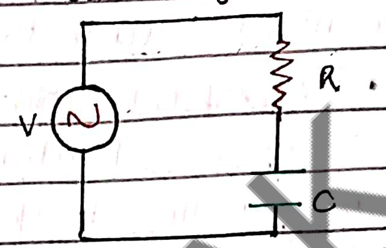
→ For resistor : V and I are in phase

→ For capacitor: V_c lags behind I by 90°

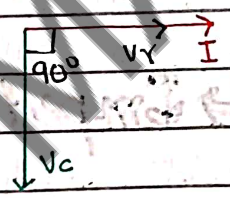
→ Resultant Voltage: We will have to find resultant of V_R and V_C to find the applied voltage.

- $V_R = IR$, $V_C = IX_C$ or $-IX_C$ as it's in -ve Y-axis
- Important Point: Current leads applied voltage by an angle ϕ i.e, $I = I_m \sin(\omega t + \phi)$.

Circuit Diagram:



Phasor Diagram:
(VR and I are in phase)



→ **Impedance:** "Combined opposition offered by capacitor and resistor."

Mathematically: Applying pythagoras theorem (diagram a)

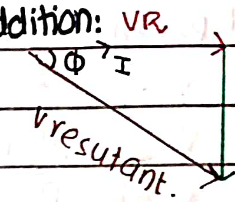
$$V_R^2 + V_C^2 = V^2$$

$$V = \sqrt{(IR)^2 + (-IX_C)^2} = I\sqrt{R^2 + X_C^2}$$

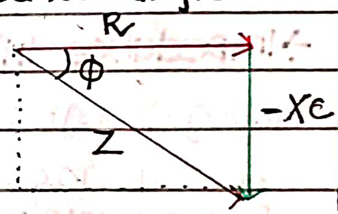
or $I = \dfrac{V}{\sqrt{R^2+X_C^2}}$ By applying pythagoras theorem on triangle (b), we get $Z = \sqrt{R^2+X_C^2}$

thus $\boxed{I = V/Z}$ where $Z = \sqrt{R^2+X_C^2}$ which is impedance of circuit.

Vector Addition:



Impedance triangle:



→ Phase value of phase can be determined by $\boxed{\tan\theta = -X_C \div R}$

→ Negative phase angle shows voltage lags behind current.

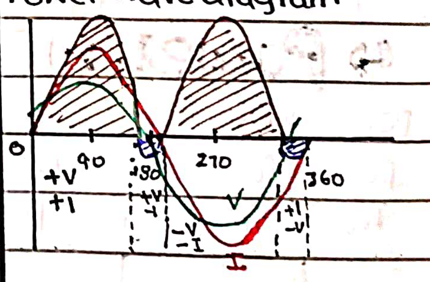
↳ **Power:** equations for voltage and current are → $\boxed{I = I_m \sin(\omega t + \phi)}$ $\boxed{V = V_m \sin\omega t}$

Average power, (P) $\langle P\rangle = \langle V\rangle\langle I\rangle = VI\cos\phi$

Brown shaded area: Greater +ve brown area, power is consumed by the circuit.

Blue shaded area: Small -ve shaded peak shows how capacitor returns some power to the circuit.

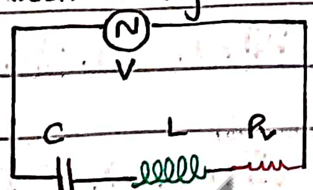
Power wave diagram



4) R-L-C Series A-C Circuit:

Resistor, Inductor and capacitor are joined in series in AC circuit.

Circuit Diagram:

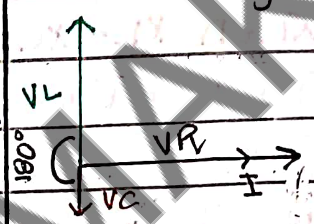


→ **For Resistor:** V_R and I are in phase $\phi = 0°$

→ **For Inductor:** V_L and I are having a phase difference of 90° V_L leads I by 90°

→ **For Capacitor:** V_C and I are having a phase difference of -90°. V_C lags I by 90°.

Phasor diagram:



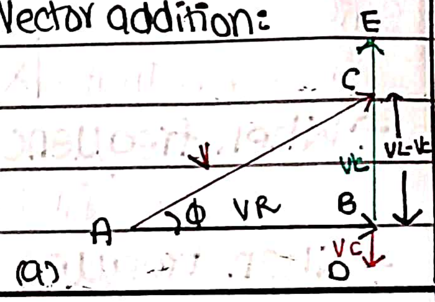
→ **Phase difference b/w V_C and V_L in R·L·C circuit:**

V_C and V_L are completely out of phase $90° + 90° = 180°$

→ **Applied voltage:** By vector addition of phasors, we will find applied voltage of circuit V.

- Voltage drop accross L-C combination will be $V_L - V_C$
- If $V_L > V_C$ then their resutant will be in direction of V_L represented by BC
- Applied voltage is therefore phasor sum of V_R and $V_L - V_C$ and is represented by AC.

Vector addition:



↳ Impedance of circuit:

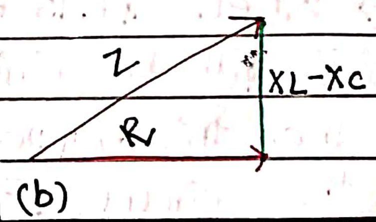
"combined opposition offered to current flow by L, C and R"

Mathematically Applying pythagorus theorem

$V^2 = V_R^2 + (V_L - V_C)^2$ $\quad V = \sqrt{V_R^2 + (V_L - V_C)^2}$

$V = \sqrt{(IR)^2 + (IX_L - IX_C)^2}$ $\quad \boxed{V = I\sqrt{R^2 + (X_L - X_C)^2} = IZ}$

Impedance triangle:



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

→ **Reactance:** $(X_L - X_C)$ is called reactance X of circuit thus $\boxed{X^2 = (X_L^2 - X_C)^2}$

$\boxed{V = IZ}$ where $\boxed{Z = \sqrt{R^2 + X^2}}$

→ **Circuit power factor:** $\cos\phi = \frac{Base}{hyp} = \frac{V_R}{V_Z} = \frac{R}{\sqrt{R^2 + X^2}}$

→ **Phase angle:** $\tan\phi = \frac{V_L - V_C}{V_R}$

→ **Result:** If current is represented by a cos function,

$I = I_m \cos\omega t$

Source voltage leads I (if $V_L > V_C$) then $V = V_m \cos(\omega t + \phi)$

→ **Power consumed:** $P = VI\cos\theta$

→ Varrying Phase angles with varrying V_C and V_L

(i) When $X_L - X_C$ is +ve: phase angle ϕ is positive circuit will be inductive **Votage leads I by ϕ**

(ii) When $X_L - X_C$ is -ve: phase ϕ is negative ∴ circuit will be capacitive. **Current leads V by ϕ**

(iii) When $X_L - X_C$ is 0: phase ϕ is 0 circuit is purely resistive **Current and votage are in phase**. circuit will have unity power factor $\cos 0° = 1$

Thus if applied voltage $\boxed{V = V_m \sin \omega t}$ then circuit current will be $\boxed{I = I_m \sin(\omega t \pm \phi)}$

↳ Resonance in R·L·C series circuit:

In R·L·C series circuit, inductor, capacitor and resistor all impede current.

we know that $\boxed{X_L = \omega L}$ and $\boxed{X_C = 1/\omega C}$ and $\boxed{Z = \sqrt{R^2 + (X_L - X_C)^2}}$

→ **When frequency is very small:** Capacitive reactance is large and circuit will behave like R·C series circuit. $\boxed{\uparrow X_C \propto 1/2\pi f \downarrow}$, $\boxed{X_C \approx Z}$

→ **When frequency is very large:** Inductive reactance is large and circuit behaves like R·L series circuit. $\boxed{X_L \approx Z}$, $\boxed{\uparrow X_L \propto 2\pi f \uparrow}$

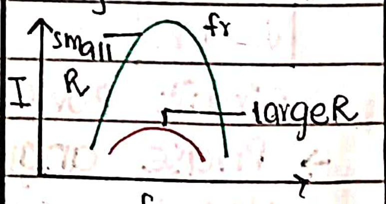
→ **When X_L is equal to X_C:** $X_L = X_C$ thus $X_L - X_C = 0$. This means Z will be minimum and I will be maximum $\boxed{\uparrow I \propto 1/Z \downarrow}$

→ When this happens, resistance provides the only impedance in the circuit. $\boxed{Z = R}$ This condition is called resonance when Z = R.

Mathematically. $Z = \sqrt{R^2 + (X_L - X_C)^2}$ $Z = \sqrt{R^2 + 0}$ $Z = R$.

→ **Resonant frequency:** Frequency at which resonance occurs. 'f_r'

Diagram



resonance curve

Mathematically: at resonance $X_L = X_C$

$$2\pi f_r L = 1/2\pi f_r C$$

$$f_r^2 = \frac{1}{4\pi^2 LC}, \quad \boxed{f_r = \frac{1}{2\pi\sqrt{LC}}}$$

→ on increasing either L or C resonant frequency decreases → For a given value of L and C there is only one resonant frequency

1. light:

→ Visible region of spectrum, electromagnetic radiation emitted by the Sun. → wavelength varies from 400nm to about 700nm

→ Light is omitted by excitation and de-exitation of electrons ie optical transitions.

2. Infrared:

→ wavelength longer than visible light 0·7μm – 1mm

→ Emitted by atoms or molecules when they change their vibrational or rotational motion. → Important means of heat: All objects emit thermal radiation because of their temprature most intense radiations are emitted by objects having temprature 3K to 3000K

→ invisible to human eye. signal b/w remote control handset and device

→ Used for cooking surface of food.

3. Microwaves:

→ short radio waves with typical wavelength in range 1mm-1m

→ Produced by electromagnetic oscillators in electric circuits.

→ often used to transmit telephone conversations.

→ Neutral hydrogen atoms in extraterrestrial space emit these with a wavelength of 21cm

4. Radiowaves:

→ have wavelength longer than 1m. Produced through electrons oscillating in wires of electric circuits. Through antenna we can the distribution of these waves.

→ Sun is a major source that often interferes w/ radio or TV reception on Earth.

→ Radioastronomy has provided information about the universe that is often not attainable by optical telescopes.

5. Ultra Violet:

→ have wavelength 1nm to 400nm. Produced by atomic transitions and Sun

→ Ozone absorbs UV rays thus little of these radiations reach the ground

→ Brief exposure may cause sun burn. Long term may cause cancer.

→ UV lamp is extremely effective in killing bacteria, yeast, viruses, molds and other harmful organisms.

6. X-Rays :

→ Have wavelength 0.01nm to 10nm. Can be produced by transitions among inner electrons of an atom. Can also be produced when charged particle decelerates.

→ These can easily penetrate soft tissue but stopped by bone.

7. Gamma Rays:

→ These have the shortest wavelength less than 10pm

→ most penetrating e.m radiations. exposure to human can be very harmful.

→ Can be emitted in transitions of an atomic nucleus from one state to another and can also occur in decay of certain elemantary particles. for example a neutral pion decays into 2 γ-rays $\pi^0 \rightarrow \gamma + \gamma$

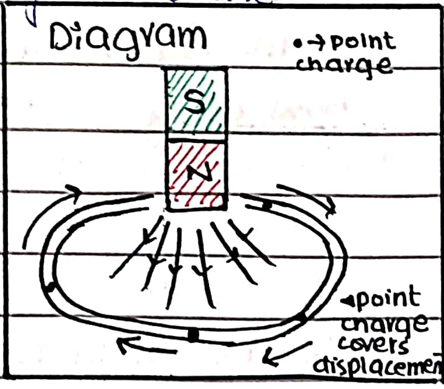
↳ Maxwell's Equations:

→ **Introduction :** James Maxwell unified the experimental laws i.e, Guass's Law, Faraday's law and Ampere's Law, into a set of equations. The maxwell equations explain existence of electromagnetic waves and that when electric charges are accelerated, electromagnetic radiations are produced.

To memorize the topic, we will make headings.

(a) Production of Electric field by varrying magnetic field:

→ **Theory :** Suppose a conducting loop through which a bar magnet is moved back and forth. This will cause change in magnetic flux through loop which will inturn generate 'emf' in loop. Induced emf will perform work on unit charge inside loop inturn charge will cover distance S.



→ **Mathematically** emf = change in magnetic flux

$$\boxed{\mathcal{E} = \frac{\Delta\phi}{\Delta t} = \frac{\Delta(B \cdot A)}{\Delta t} = \frac{A\,\Delta B}{\Delta t}}$$ (keeping 'A' with changing quantity). ①

work done $W = F \times S$ (distance charge covers is $2\pi r$; circumference of circle)

$W = F \times 2\pi r$

electric force is given by $F=qE$ thus $\boxed{W=2\pi r(qE)}$

By definition of emf we know it is work per unit charge ②

$\boxed{\mathcal{E}=W/q}$ (putting value of W) $\mathcal{E}=2\pi r\cancel{q}E/\cancel{q}$ $\boxed{\mathcal{E}=2\pi rE}$ (← This equation tells us that emf is responsible for production of electric field)

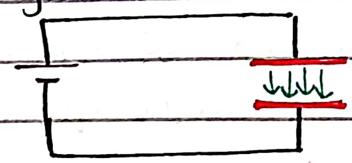
By eq ① and ② we have

$\boxed{2\pi rE = \frac{A\Delta B}{\Delta t}}$ or $\boxed{E \propto \frac{\Delta B}{\Delta t}}$ ← (This relation tells us that wether there is a conducting loop or not, Electric feild will be produced due to changing magnetic flux)

(b) Production of Magnetic field by changing electric field:

→ **Theory:** When a capacitor is connected to a d.c source, after capacitor is charged, current stops flowing through the circuit but if DC is replaced with A.C, current begins to flow through the circuit. Maxwell conceived that with AC, electric field changes and this change cause current through the circuit to flow.

Diagram



capacitor connected to voltage source.

→ **Mathematically:** charge on capacitor is given by

$\boxed{Q=CV=\frac{\varepsilon_0 AV}{d}=\varepsilon_0 A(E)}$ ① $(V/d=E)$

we know, current '$I=\Delta Q/\Delta t$' thus $\Delta(\varepsilon_0 AE)/\Delta t = I$, $\boxed{I=\frac{\varepsilon_0\Delta(EA)}{\Delta t}}$

$EA=$ flux Φ_E $\boxed{I=\frac{\varepsilon_0\Delta\Phi}{\Delta t}}$ ②

→ **Displacement current:** This equation shows changing electric flux produces current. such current is called displacement current.

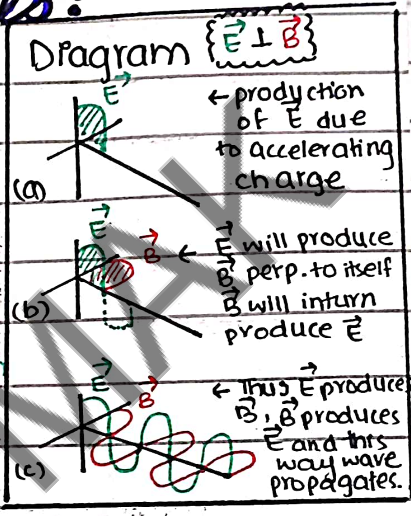
Now using amperes law according to which every type of current has a magnetic field $B=\mu_0 nI$ (putting value of I)

$\boxed{B=\mu_0 n\frac{\varepsilon_0\Delta\Phi}{\Delta t}}$ ③ or $\boxed{B\propto\frac{\Delta\Phi}{\Delta t}}$

We can conclude, changing electric flux produces magnetic field.

(c) generation of Electromagnetic waves:

→Theory: Changing electric field produces a magnetic field. which inturn generates electric field. Both fields propagate together perpendicular to each other. Condition is that the electric charge producing the whole wave should be oscillating or accelerating (changing velocity) Diagram shows propagation of E.M wave through vacuum.



(d) Light:

→Theory: Maxwell explained electromagnetic nature of light and was the first to determine that speed of light was equal to that of propagation of electromagnetic waves. Hence both are same.

→Mathematically

$$\boxed{c = \frac{1}{\sqrt{\varepsilon_o \mu_o}}} \quad \text{(putting values)}$$

$$c = \frac{1}{\sqrt{8.85 \times 10^{-12} \times 4\pi \times 10^{-7}}} = \boxed{3 \times 10^8 ms^{-1}}$$

← speed of light/ electromagnetic waves.