Alternating Current

Class 12 Physics · Chapter 7 · CBSE

Handwritten Notes · Sequence: NCERT + S.L. Arora

How to use these notes: Topics follow the NCERT order. Extra topics from S.L. Arora are added where they fit and marked [S.L. Arora]. Topics removed from the current NCERT book are marked [old NCERT]. Boxed formulas are the ones to remember.

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1. Introduction NCERT 7.1

Alternating current (AC): a current (or voltage) whose magnitude changes continuously with time and whose direction reverses periodically. Simplest form: $v = v_m \sin \omega t$.

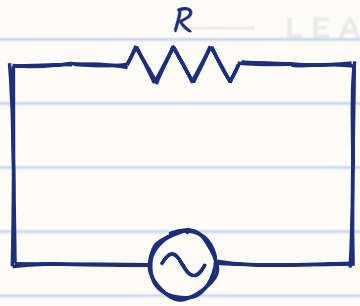
→ Most electrical devices at home and in industry run on AC. In India the mains supply is 220 V (rms), 50 Hz.

→ AC voltage can be easily **stepped up or down** by transformers, so it can be sent over long distances with little loss.

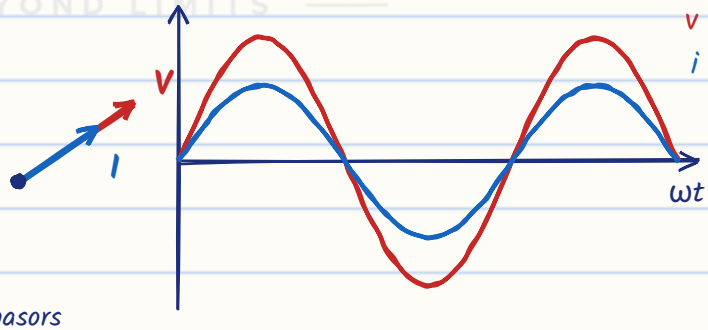
AC vs DC [S.L. Arora]

Advantages of AC	Disadvantages of AC
Cheaper to generate	More dangerous (peak 311 V for 220 V)
Voltage changed by transformers	Cannot be used for electroplating
Less loss in transmission	Skin effect: flows near wire surface
Easily converted to DC (rectifier)	Needs rms meters (hot-wire)

2. AC Voltage Applied to a Resistor NCERT 7.2



$v = v_m \sin \omega t$



phasors

$\Rightarrow v_m \sin \omega t = i R \Rightarrow i = (v_m/R) \sin \omega t$

$$i = i_m \sin \omega t, \quad i_m = v_m / R$$

→ Voltage and current are in phase — both reach zero, maximum and minimum together.

→ Average current over a complete cycle is **zero**, but the average power is not, because i^2 is always positive.

⇒ Power $p = i^2R = i_m^2 R \sin^2 \omega t$. Average of $\sin^2 \omega t$ over a cycle = ½

$$P_{av} = \tfrac{1}{2} i_m^2 R$$

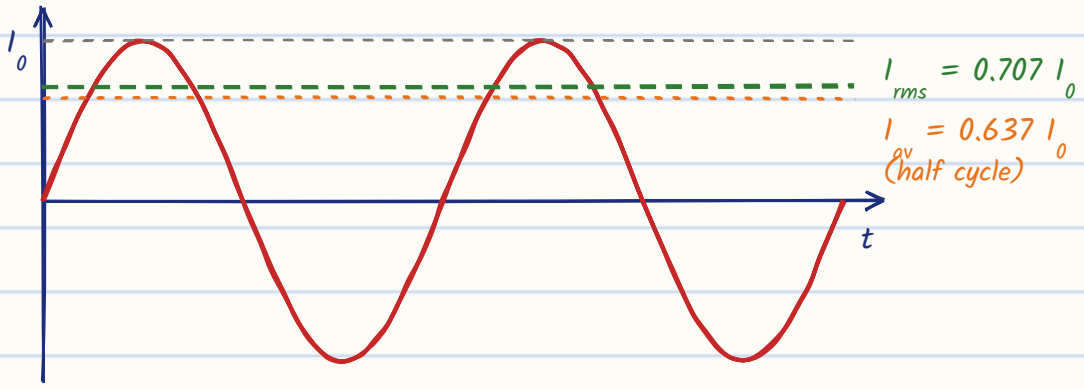
3. RMS (Effective) and Mean Values NCERT 7.2

RMS current: the steady (DC) current that produces the **same heat** in a resistor, in the same time, as the AC does.

⇒ Set $I^2R = \tfrac{1}{2} i_m^2 R \Rightarrow I = i_m/\sqrt{2}$

$$I = i_m/\sqrt{2} = 0.707\, i_m \qquad V = v_m/\sqrt{2} = 0.707\, v_m$$

So $P = V I = I^2R$, just like DC. Household 220 V is the rms value; its peak is $220 \times \sqrt{2} \approx$ **311 V**. AC ammeters and voltmeters read rms values.



Mean (average) value [S.L. Arora]

⇒ Over a full cycle, average = 0 (positive and negative halves cancel).

⇒ Over a half cycle: $I_{av} = (2/\pi)\, i_m = 0.637\, i_m$

Order to remember: peak (i_m) > rms ($0.707\, i_m$) > mean over half cycle ($0.637\, i_m$).

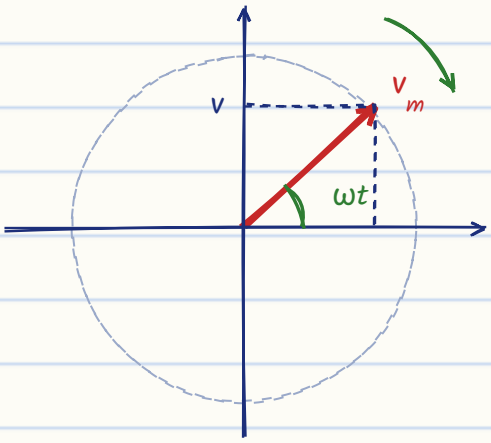
Example (NCERT): A light bulb is rated 100 W for a 220 V supply. Find (a) its resistance (b) the peak voltage (c) the rms current.

(a) $R = V^2/P = 220^2/100 =$ **484 ohm** (b) $v_m = \sqrt{2} \times 220 =$ **311 V**

(c) $I = P/V = 100/220 =$ **0.454 A**

4. Phasors NCERT 7.3

Phasor: a vector that rotates anticlockwise about the origin with angular speed ω. Its length = peak value; its **projection on the vertical axis** = instantaneous value.



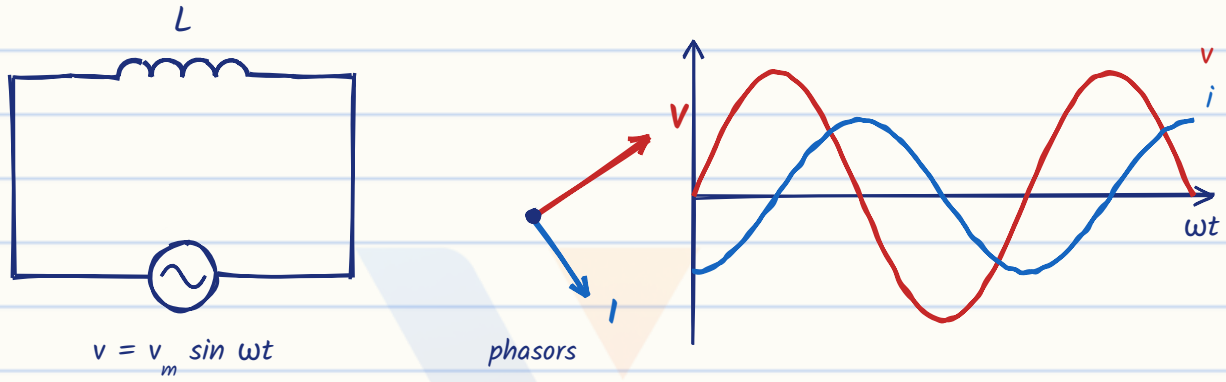
Phasor rotates anticlockwise with angular speed ω.

Projection on vertical axis = instantaneous value $v_m \sin \omega t$

→ The angle between the V and I phasors = phase difference ϕ.

→ Phasors let us add voltages that are out of phase, using vector addition.

5. AC Voltage Applied to an Inductor NCERT 7.4



⇒ Kirchhoff's loop rule: $v_m \sin \omega t - L\, di/dt = 0 \Rightarrow di/dt = (v_m/L) \sin \omega t$

⇒ Integrating: $i = -(v_m/\omega L) \cos \omega t = (v_m/\omega L) \sin(\omega t - \pi/2)$

$$i = i_m \sin(\omega t - \pi/2), \quad i_m = v_m/X_L, \quad X_L = \omega L$$

→ **Inductive reactance** $X_L = \omega L = 2\pi\nu L$ (ohm). It grows with frequency; for DC ($\nu = 0$), $X_L = 0$.

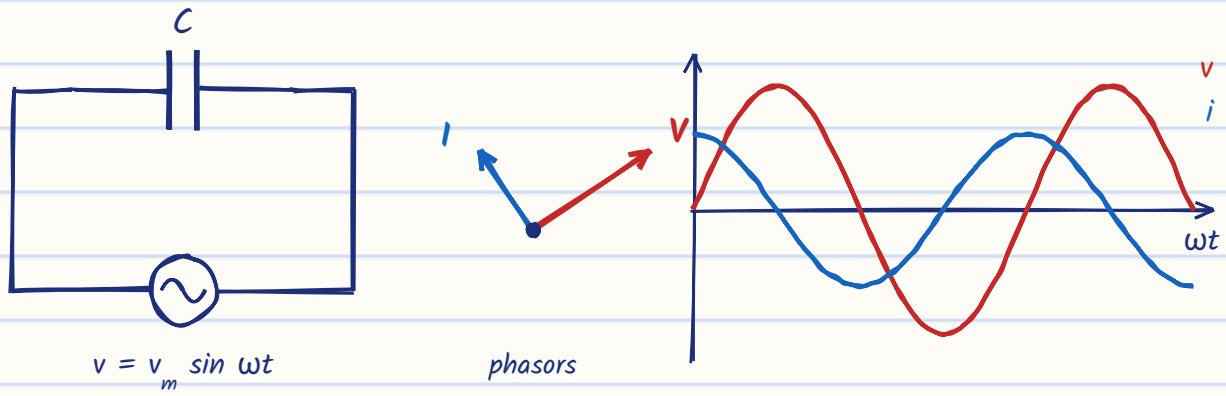
→ Current **lags** the voltage by $\pi/2$ (90°).

→ Average power over a cycle = **zero**. Energy is stored in the magnetic field in one quarter and returned in the next.

Example (NCERT): A pure inductor of 25.0 mH is connected to a 220 V, 50 Hz source. Find X_L and the rms current.

$X_L = 2\pi\nu L = 2 \times 3.14 \times 50 \times 25 \times 10^{-3} =$ **7.85 ohm**; $I = V/X_L = 220/7.85 =$ **28 A**

6. AC Voltage Applied to a Capacitor NCERT 7.5



$\Rightarrow q = C v = C v_m \sin \omega t$

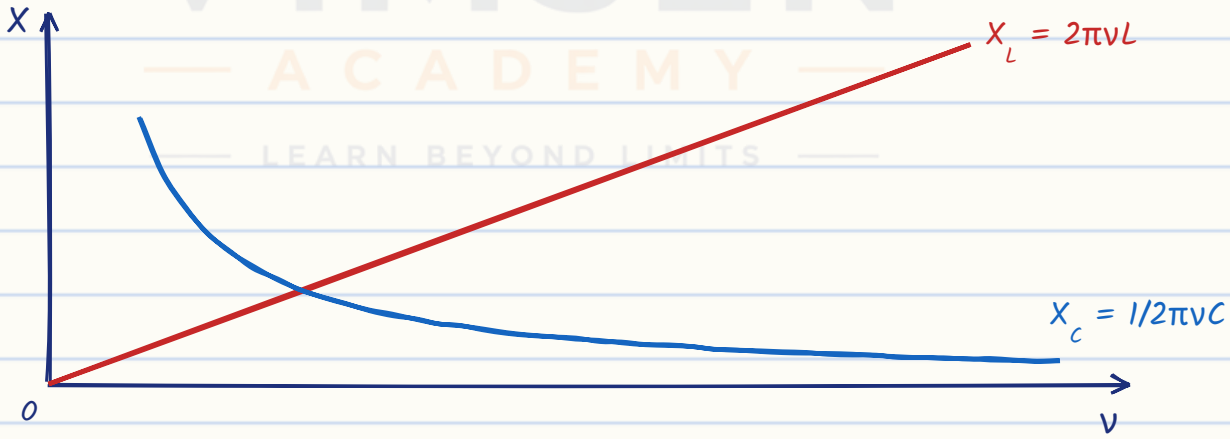
$\Rightarrow i = dq/dt = \omega C v_m \cos \omega t = (v_m/(1/\omega C)) \sin(\omega t + \pi/2)$

$$i = i_m \sin(\omega t + \pi/2), \quad X_C = 1/\omega C$$

→ **Capacitive reactance** $X_C = 1/\omega C = 1/2\pi\nu C$ (ohm). For DC ($\nu = 0$), $X_C = \infty$ → a capacitor blocks DC.

→ Current **leads** the voltage by $\pi/2$ (90°).

→ Average power over a cycle = **zero**.



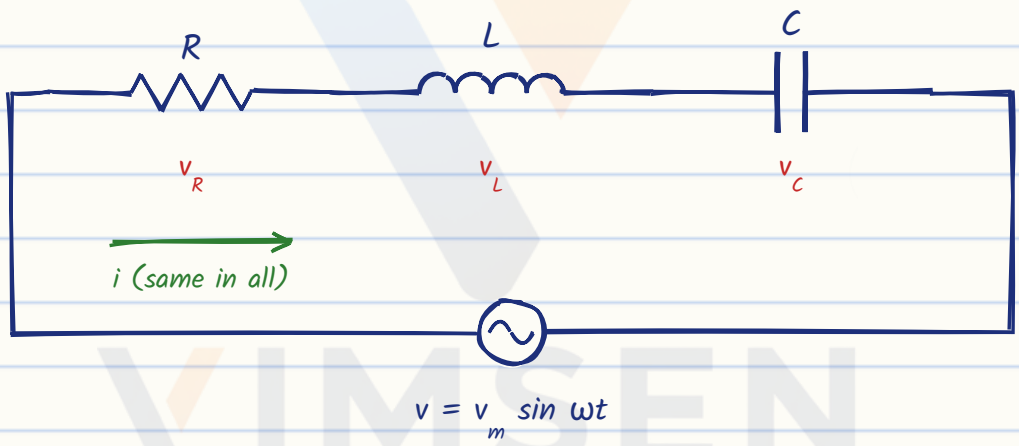
Memory trick — "ELI the ICE man": in an inductor (L), E (voltage) comes before I; in a capacitor (C), I comes before E.

Example (NCERT): A 15.0 μF capacitor is connected to a 220 V, 50 Hz source. Find X_C, the rms and peak current. What if the frequency is doubled?

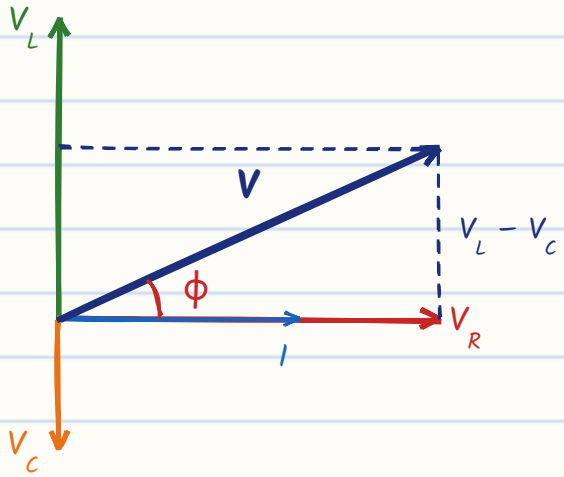
$X_C = 1/(2\pi \times 50 \times 15 \times 10^{-6}) =$ **212 ohm**; $I = 220/212 =$ **1.04 A**; $i_m = \sqrt{2} \times 1.04 =$ **1.47 A**

Frequency doubled → X_C halves → current **doubles**.

7. AC Voltage Applied to a Series LCR Circuit NCERT 7.6



Phasor-diagram solution



$V_L = I X_L$

$V_C = I X_C$

$V_R = I R$

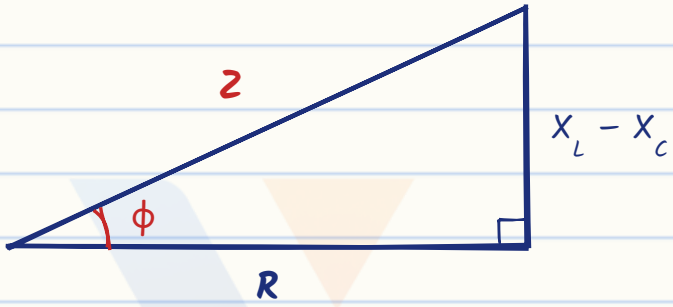
(case $X_L > X_C$)

⇒ Same current i in R, L, C. Take I along the x-axis: V_R is along I, V_L is 90° ahead, V_C is 90° behind.

⇒ V_L and V_C are opposite, so their resultant is $(V_L - V_C)$.

⇒ $V^2 = V_R^2 + (V_L - V_C)^2 = I^2[R^2 + (X_L - X_C)^2]$

$$Z = \sqrt{[R^2 + (X_L - X_C)^2]} \qquad \tan\phi = (X_L - X_C)/R$$



→ Z = **impedance** (ohm); $i_m = v_m/Z$.

→ $X_L > X_C$: circuit inductive, current lags. $X_C > X_L$: capacitive, current leads.

→ RL circuit: $Z = \sqrt{(R^2 + X_L^2)}$. RC circuit: $Z = \sqrt{(R^2 + X_C^2)}$. [S.L. Arora]

Remember: the rms voltages across R, L and C do **not** add up to the source voltage, because they are out of phase. Add them as phasors.

Example (NCERT): A 200 ohm resistor and a 15.0 μF capacitor are in series across a 220 V, 50 Hz source. Find the current and the voltages across R and C. Is $V_R + V_C = 220$ V?

$X_C = 212.3$ ohm; $Z = \sqrt{(200^2 + 212.3^2)} \approx 291.6$ ohm; $I = 220/291.6 \approx$ **0.755 A**

$V_R = IR \approx$ **151 V**; $V_C = IX_C \approx$ **160.3 V**; sum = 311.3 V ≠ 220 V (out of phase)

8. Resonance NCERT 7.6.3

As ω changes, X_L and X_C change. At one frequency they become equal: $X_L = X_C$.

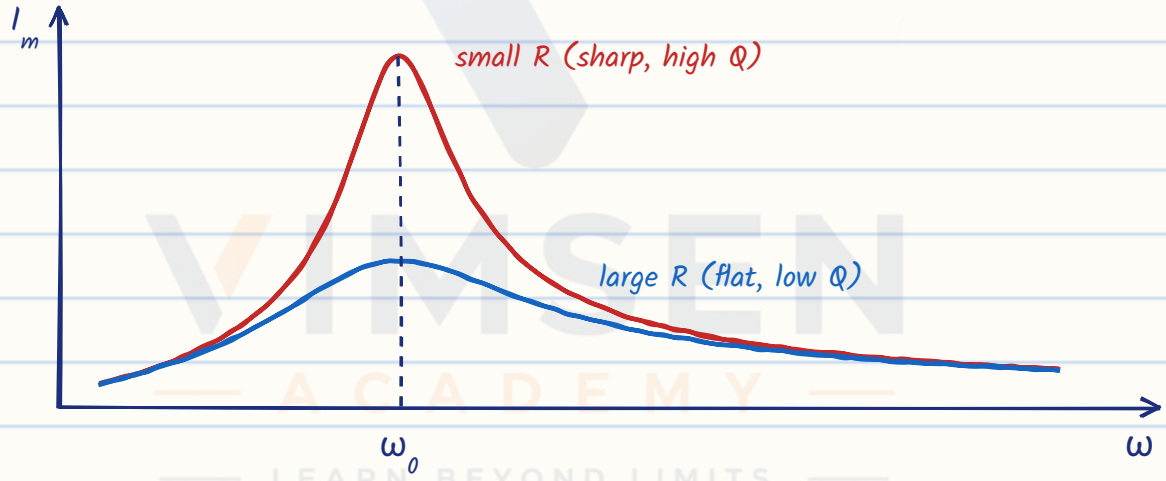
⇒ $\omega_0 L = 1/\omega_0 C \Rightarrow \omega_0 = 1/\sqrt{(LC)}$

$$\omega_0 = 1/\sqrt{(LC)} \qquad \nu_0 = 1/(2\pi\sqrt{(LC)})$$

→ At resonance $Z = R$ (**minimum**), current is **maximum** $= v_m/R$, $\phi = 0$ (V and I in phase).

→ Resonance is possible only if **both L and C** are present.

→ Used in the tuning circuit of a radio/TV: C is varied until ν_0 equals the frequency of the station.



Sharpness of resonance: Q-factor [S.L. Arora · old NCERT]

$$Q = \omega_0 L / R = (1/R)\sqrt{(L/C)} = \omega_0 / 2\Delta\omega$$

$2\Delta\omega = R/L$ is the **bandwidth**. Smaller R → narrower bandwidth → larger Q → sharper resonance (better selectivity in a radio).

9. Power in AC Circuit: Power Factor NCERT 7.7

⇒ $v = v_m \sin \omega t$, $i = i_m \sin(\omega t + \phi) \Rightarrow p = v\, i$

⇒ Average over a cycle: $P = \frac{1}{2} v_m i_m \cos \phi$

$P = V I \cos\phi$ $\cos\phi = R / Z$ = power factor

Circuit	ϕ	$\cos\phi$	Power
Pure R	0	1	V I (maximum)
Pure L or C	$\pm\pi/2$	0	zero (wattless)
LCR	$\tan^{-1}(X/R)$	R/Z	I^2R only in R
LCR at resonance	0	1	V^2/R (maximum)

Wattless current: the component of current I sin ϕ, which is 90° out of phase with the voltage. It consumes **no power**. The power comes only from I cos ϕ.

→ **Low power factor** means a large current for the same power, so large I^2R losses in transmission lines.

→ Power factor is improved by connecting a capacitor in parallel with inductive loads.

Choke coil [S.L. Arora]

An inductor with large L and very small R, used to **reduce AC current** (e.g. in tube lights). Since $\phi \approx 90°$, $\cos\phi \approx 0$, it wastes almost no power. A resistor would do the same job but would waste energy as heat.

Example (NCERT): A sinusoidal voltage of peak 283 V, 50 Hz is applied to a series LCR circuit with R = 3 ohm, L = 25.48 mH, C = 796 μF. Find (a) Z (b) ϕ (c) power dissipated (d) power factor.

$X_L = 2\pi \times 50 \times 25.48 \times 10^{-3} = 8$ ohm; $X_C = 1/(2\pi \times 50 \times 796 \times 10^{-6}) = 4$ ohm

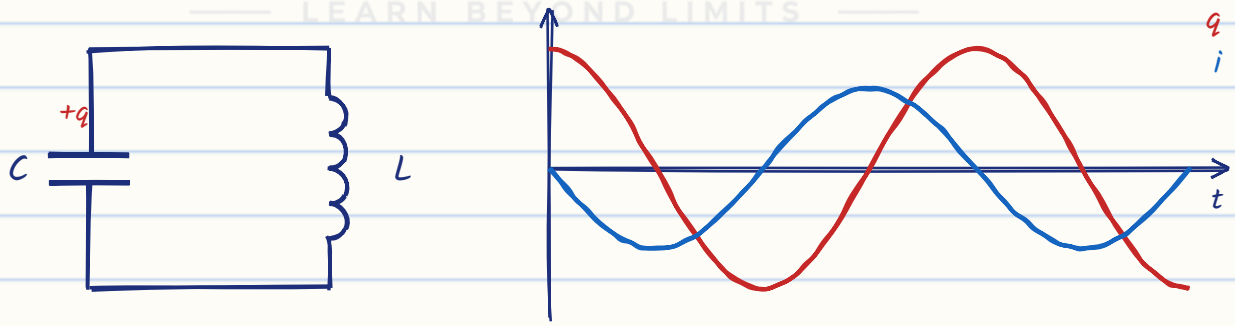
(a) $Z = \sqrt{(3^2 + 4^2)} =$ **5 ohm** (b) $\tan\phi = 4/3 \Rightarrow \phi =$ **53.1°** (current lags)

(c) $I = (283/\sqrt{2})/5 = 40$ A; $P = I^2R =$ **4800 W** (d) $\cos\phi = 3/5 =$ **0.6**

At resonance: $\nu_0 = 1/(2\pi\sqrt{LC}) \approx$ **35.4 Hz**; $I = 200/3$ A; $P \approx$ **13.3 kW**

10. LC Oscillations [S.L. Arora · old NCERT 7.8]

Syllabus note: LC oscillations were removed from the current NCERT book. Keep them for concepts and competitive exams.



energy: C (electric) ⇄ L (magnetic)

⇒ A charged capacitor C discharges through an inductor L: $q/C + L\,di/dt = 0$

⇒ ⇒ $d^2q/dt^2 + q/(LC) = 0$ — simple harmonic motion of charge

$$q = q_0 \cos \omega_0 t, \qquad \omega_0 = 1/\sqrt{(LC)}$$

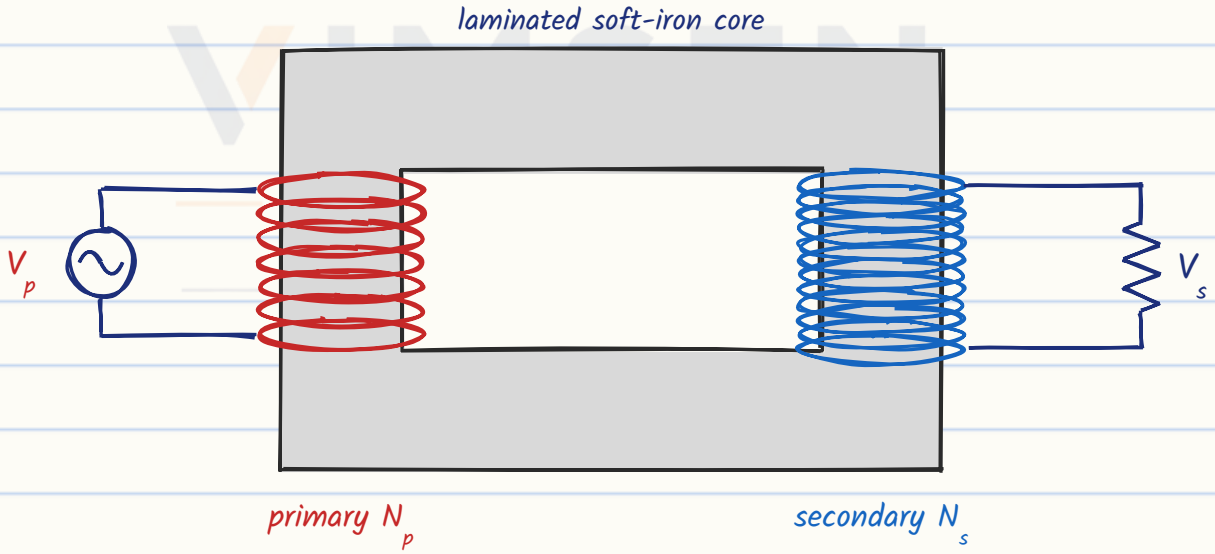
→ Energy keeps changing between the **electric field** of C and the **magnetic field** of L: $q^2/2C + \frac{1}{2}Li^2 = q_0^2/2C$ = constant.

→ Analogy with a spring–mass system: $q \leftrightarrow x$, $L \leftrightarrow m$, $1/C \leftrightarrow k$, $i \leftrightarrow v$.

→ In a real circuit, resistance makes the oscillations die out (damped).

11. Transformers NCERT 7.9

Principle: mutual induction. An alternating current in the primary coil produces a changing flux in the core, which induces an emf in the secondary coil.



⇒ Same flux Φ links each turn: $\varepsilon_s = -N_s\, d\Phi/dt$, $\varepsilon_p = -N_p\, d\Phi/dt$

⇒ Ideal transformer (no losses): $V_s/V_p = N_s/N_p$ and $V_p I_p = V_s I_s$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$$

→ **Step-up** ($N_s > N_p$): voltage increases, current decreases. **Step-down**: the reverse.

→ A transformer works only on AC — steady DC gives no changing flux.

Energy losses and how to reduce them

Loss	Reduced by
Flux leakage	winding primary and secondary over each other
Resistance of windings (I^2R)	thick copper wires
Eddy currents	laminated iron core
Hysteresis	soft-iron core (low hysteresis loss)

Efficiency η = output power / input power. Large transformers reach **95–99%**. Power is sent at high voltage (low current) to cut I^2R losses, then stepped down near the town.

Example (NCERT): A line feeds 2300 V to a step-down transformer with 4000 primary turns. How many secondary turns give 230 V output?

$N_s = N_p \times V_s/V_p = 4000 \times 230/2300 =$ **400 turns**

12. Formula Sheet – Quick Revision

AC voltage	$v = v_m \sin \omega t$, $\omega = 2\pi\nu$
RMS values	$I = i_m/\sqrt{2}$, $V = v_m/\sqrt{2}$
Mean (half cycle)	$I_{av} = 2i_m/\pi = 0.637\, i_m$
Resistor	in phase, $P = I^2R$
Inductor	$X_L = \omega L$, i lags by $\pi/2$, $P = 0$
Capacitor	$X_C = 1/\omega C$, i leads by $\pi/2$, $P = 0$
Impedance	$Z = \sqrt{[R^2 + (X_L - X_C)^2]}$
Phase	$\tan \phi = (X_L - X_C)/R$
Resonance	$\omega_0 = 1/\sqrt{LC}$, $Z = R$, I maximum
Q-factor	$Q = \omega_0 L/R = (1/R)\sqrt{(L/C)}$
Power	$P = VI \cos \phi$, $\cos \phi = R/Z$
Wattless current	$I \sin \phi$ ($\phi = 90° \rightarrow P = 0$)
LC oscillations	$q = q_0 \cos \omega_0 t$, $\omega_0 = 1/\sqrt{LC}$
Transformer	$V_s/V_p = N_s/N_p = I_p/I_s$

VIMSEN — ACADEMY — LEARN BEYOND LIMITS

13. Previous Year Questions CBSE Board

How to use: Try each question first, then read the solution. The Concept line tells you the idea the examiner is testing. Paper codes are given so you can check the original papers.

PYQ 1 · CBSE 2025 (55/7/2) · MCQ

An alternating current is given by $I = I_0 \cos(100\pi t)$. The least time taken by the current to decrease from its maximum value to zero is: (A) 1/200 s (B) 1/150 s (C) 1/100 s (D) 1/50 s

$\omega = 100\pi \Rightarrow T = 2\pi/\omega = 1/50$ s. Maximum → zero takes a quarter cycle: $T/4$ = **1/200 s (A)**

Concept: Peak to zero is always **T/4**; peak to opposite peak is T/2. Read ω from the expression, then find T.

PYQ 2 · CBSE 2025 (55/1/2) · MCQ

A voltage $v = v_0 \sin \omega t$ applied to a circuit drives a current $i = i_0 \sin(\omega t + \phi)$. The average power consumed over a cycle is: (A) zero (B) $i_0 v_0 \cos \phi$ (C) $i_0 v_0/2$ (D) $(i_0 v_0/2) \cos \phi$

$P = V_{rms} I_{rms} \cos \phi = (v_0/\sqrt{2})(i_0/\sqrt{2}) \cos \phi =$ **$(i_0 v_0/2) \cos \phi$ (D)**

Concept: Average power uses **rms** values and the power factor. With peak values, a factor ½ appears.

PYQ 3 · CBSE 2025 (55/1/3) · MCQ

An ideal transformer has turns ratio $N_p : N_s = 20 : 1$. A 240 V AC supply is applied to the primary and a 6.0 ohm resistor is connected across the secondary. The current drawn from the source is: (A) 4.0 A (B) 3.8 A (C) 0.97 A (D) 0.10 A

$V_s = 240/20 = 12$ V; $I_s = 12/6 = 2.0$ A; $I_p = I_s \times N_s/N_p = 2/20 =$ **0.10 A (D)**

Concept: Voltage follows the turns ratio, current follows its **inverse** ($V_pI_p = V_sI_s$). Step-down transformer → small primary current.

PYQ 4 · CBSE 2025 (55/7/2) · MCQ

A capacitor and an inductor are connected in series across an AC source of variable frequency. The frequency is increased continuously. The nature of the circuit before and after resonance is: (A) inductive only (B) capacitive only (C) capacitive and inductive respectively (D) inductive and capacitive respectively

Below ν_0: X_C ($\propto 1/\nu$) > X_L → capacitive. Above ν_0: X_L ($\propto \nu$) > X_C → inductive ⇒ **(C)**

Concept: Look at the reactance graph: X_C wins at low frequency, X_L wins at high frequency, and they cross at resonance.

PYQ 5 · CBSE 2025 (55/7/3)

An AC source $V = V_0 \sin \omega t$ is connected to a circuit element X. The current is $I = I_0 \sin(\omega t - \pi/2)$. (a) Identify X and write its reactance. (b) Plot the variation of its reactance with the frequency of the applied voltage.

(a) Current **lags** voltage by $\pi/2 \Rightarrow$ X is a **pure inductor**; $X_L = \omega L = 2\pi\nu L$

(b) $X_L \propto \nu$: a **straight line through the origin** (see the red line in the reactance graph, Topic 6).

Concept: "ELI the ICE man". Lag by $\pi/2$ → L; lead by $\pi/2$ → C; in phase → R.

PYQ 6 · CBSE 2025 (55/1/3)

An AC source $v = v_m \sin \omega t$ is connected to a series LCR circuit. Draw the phasor diagram and use it to obtain the expressions for (i) the impedance of the circuit and (ii) the phase difference between the applied voltage and the current.

Draw I along the x-axis, V_R along I, V_L up, V_C down (Topic 7 diagram).

$V^2 = V_R^2 + (V_L - V_C)^2 \Rightarrow$ **$Z = \sqrt{[R^2 + (X_L - X_C)^2]}$**

From the triangle: **$\tan \phi = (X_L - X_C)/R$** (current lags if $X_L > X_C$)

Concept: The **current** is common to all three elements, so it is the reference phasor. The voltages add as vectors.

PYQ 7 · CBSE 2024 (55/5/3)

For a series LCR circuit connected to an AC source, show how the current varies with the frequency of the source. Also write the conditions for (i) minimum impedance and (ii) wattless current.

$I = V/Z = V / \sqrt{[R^2 + (\omega L - 1/\omega C)^2]}$. At low ω, X_C is huge → I small; at high ω, X_L is huge → I small.

I is maximum at $\omega_0 = 1/\sqrt{(LC)}$ — the resonance curve (Topic 8).

(i) Minimum impedance: $X_L = X_C$ (resonance), $Z = R$.

(ii) Wattless current: power factor $\cos\phi = 0$, i.e. $\phi = 90°$ — a **purely inductive or capacitive circuit ($R = 0$)**.

Concept: Resonance gives maximum current and $\cos\phi = 1$. Wattless current is the opposite extreme, with $\cos\phi = 0$.