

CUET · PHYSICS · CLASS XII · CODE 322

# Alternating Current

CUET unit: Alternating Current

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## Snapshot

- Establishes that ac voltage and current vary sinusoidally with time and that the electric mains supply in homes is sinusoidal (NCERT §7.1).
- Introduces rms (effective) values so that ac power expressions take the same form as dc,  $V = v_m/\sqrt{2}$  and  $I = i_m/\sqrt{2}$  (NCERT §7.2).
- Builds reactance for inductors ( $X_L = \omega L$ , current lags by  $\pi/2$ ) and capacitors ( $X_C = 1/\omega C$ , current leads by  $\pi/2$ ), and uses phasors to handle phase (NCERT §§7.3–7.5).
- Develops the series LCR circuit: impedance  $Z = \sqrt{R^2 + (X_C - X_L)^2}$ , phase  $\tan \phi = (X_C - X_L)/R$ , resonance at  $\omega_0 = 1/\sqrt{LC}$ , and power  $P = VI \cos \phi$  with  $\cos \phi$  as the power factor (NCERT §§7.6–7.7).
- Explains transformers ( $V_s/V_p = N_s/N_p$ ,  $I_s/I_p = N_p/N_s$ ), step-up vs step-down, sources of loss, and the role of step-up transformers in long-distance power transmission (NCERT §7.8).

## Detailed Notes

### 2.1 Core concepts

- Alternating voltage varies like a sine function with time,  $v = v_m \sin \omega t$ ; the electric mains supply in homes and offices is such a sinusoidal voltage, and most electrical devices today require ac voltage (NCERT §7.1, p. 178).
- The main reason for preferring ac over dc is that ac voltages can be easily and efficiently transformed from one value to another using transformers, enabling economical long-distance transmission (NCERT §7.1, p. 178).
- For an ac source  $v = v_m \sin \omega t$  connected across a pure resistor  $R$ , Kirchhoff's loop rule gives  $i = (v_m/R) \sin \omega t = i_m \sin \omega t$ , so voltage and current are exactly in phase — they reach zero, minima and maxima at the same instants (NCERT §7.2, p. 178; Eqs. 7.1–7.3).
- Although the average of an ac current over a cycle is zero, Joule heating depends on  $i^2$  (always positive); the average power dissipated in a resistor is  $P = (1/2) i_m^2 R$ , which is recast as  $P = I^2 R$  using rms current  $I = i_m/\sqrt{2} = 0.707 i_m$  (NCERT §7.2, pp. 179–180; Eqs. 7.5c–7.7).
- The rms (or effective) voltage is  $V = v_m/\sqrt{2} = 0.707 v_m$ ; for household line voltage of 220 V (rms), the peak is  $v_m = \sqrt{2} \times 220 \text{ V} = 311 \text{ V}$  (NCERT §7.2, p. 180).

- A phasor is a vector that rotates about the origin with angular speed  $\omega$ ; its vertical projection gives the instantaneous value of the sinusoidally varying voltage or current, and its magnitude equals the peak (amplitude) value (NCERT §7.3, p. 181).
- For an ac voltage applied to a pure inductor of self-inductance  $L$ , Kirchhoff's loop rule  $v - L(di/dt) = 0$  leads to  $i = (v_m/\omega L) \sin(\omega t - \pi/2)$ , so the current lags the voltage by  $\pi/2$  (NCERT §7.4, pp. 181–182; Eqs. 7.10–7.12).
- Inductive reactance  $X_L = \omega L$  has units of ohm and is directly proportional to  $L$  and to the frequency; it limits current the way resistance does in a dc circuit, and the average power supplied to a pure inductor over a complete cycle is zero (NCERT §7.4, pp. 182–183; Eqs. 7.13–7.14).
- For an ac voltage applied to a pure capacitor  $C$ ,  $q = Cv$  and  $i = dq/dt$  give  $i = \omega C v_m \cos \omega t = i_m \sin(\omega t + \pi/2)$ , so the current leads the voltage by  $\pi/2$  (NCERT §7.5, p. 184; Eq. 7.16).
- Capacitive reactance  $X_C = 1/\omega C$  has units of ohm and is inversely proportional to both  $C$  and frequency; the average power supplied to a pure capacitor over a complete cycle is zero (NCERT §7.5, pp. 184–185; Eqs. 7.17–7.19).
- For a series LCR circuit driven by  $v = v_m \sin \omega t$ , the steady-state current is  $i = i_m \sin(\omega t + \phi)$  with  $i_m = v_m/Z$ , where the impedance is  $Z = \sqrt{R^2 + (X_C - X_L)^2}$  and the phase angle satisfies  $\tan \phi = (X_C - X_L)/R$  (NCERT §7.6.1, pp. 187–188; Eqs. 7.25–7.27).
- If  $X_C > X_L$ ,  $\phi$  is positive and the circuit is predominantly capacitive (current leads source voltage); if  $X_C < X_L$ ,  $\phi$  is negative and the circuit is predominantly inductive (current lags source voltage) (NCERT §7.6.1, p. 188).
- Because  $V_L$  and  $V_C$  are  $\pi$  out of phase with each other, the rms voltages across individual elements can each exceed the source rms voltage; they must be combined using the Pythagorean theorem, not added algebraically (NCERT §7.6, Ex. 7.6, p. 190).
- Resonance occurs in a series LCR circuit when  $X_C = X_L$ ; at the resonant angular frequency  $\omega_0 = 1/\sqrt{LC}$ , the impedance is minimum ( $Z = R$ ) and the current amplitude is maximum,  $i_m = v_m/R$  (NCERT §7.6.2, pp. 188–189; Eq. 7.28).
- Resonance requires the presence of both  $L$  and  $C$ ; with only an RL or RC combination, voltages across  $L$  and  $C$  cannot cancel each other and so there is no resonance (NCERT §7.6.2, p. 189; Points to Ponder 8, p. 199).
- Tuning circuits of radios/TVs exploit resonance: varying capacitance shifts the resonant frequency to match a particular broadcasting station, making the current at that frequency maximum (NCERT §7.6.2, p. 189).
- The instantaneous power for an LCR circuit averages to  $P = VI \cos \phi$  over a cycle; the quantity  $\cos \phi$  is called the power factor and decides what fraction of the apparent power  $VI$  is actually dissipated (NCERT §7.7, pp. 190–191; Eq. 7.30a).

- In a purely inductive or capacitive circuit  $\phi = \pi/2$ ,  $\cos \phi = 0$  and no power is dissipated even though current flows — such a current is called wattless current (NCERT §7.7, p. 191).
- At resonance in an LCR circuit,  $X_C = X_L$ , so  $\phi = 0$  and  $\cos \phi = 1$ ; maximum power is dissipated, all of it in the resistor (NCERT §7.7, p. 191).
- A low power factor in transmission means a larger current must be drawn to deliver the same power  $VI \cos \phi$ , increasing  $I^2R$  losses; the power factor can be improved by adding a capacitor of appropriate value in parallel to cancel the lagging wattless current (NCERT §7.7, Ex. 7.7, pp. 191–192).
- A transformer has a primary coil of  $N_p$  turns and a secondary coil of  $N_s$  turns wound on a common soft-iron core; an ac voltage on the primary sets up an alternating flux that links the secondary and induces an emf there by mutual induction (NCERT §7.8, p. 194).
- For an ideal transformer,  $v_s/v_p = N_s/N_p$ , and assuming 100% efficiency,  $i_p v_p = i_s v_s$ , giving  $i_p/i_s = N_s/N_p$ ; so a step-up transformer ( $N_s > N_p$ ) raises voltage while reducing current, and a step-down transformer ( $N_s < N_p$ ) does the reverse (NCERT §7.8, p. 195; Eqs. 7.33–7.36).
- Real transformers suffer energy losses due to (i) flux leakage, (ii) resistance of the windings ( $I^2R$  heating, reduced by using thick wire), (iii) eddy currents in the iron core (reduced by using a laminated core), and (iv) hysteresis (reduced by using a magnetic material with low hysteresis loss) (NCERT §7.8, pp. 195–196).
- Large-scale power transmission steps up the generator's voltage so that current — and hence  $I^2R$  loss in the transmission line — is small; the voltage is later stepped down at sub-stations and again at utility poles before a 240 V supply reaches homes (NCERT §7.8, p. 196).
- The quality factor of a series LCR resonant circuit,  $Q = \omega_0 L/R = 1/(\omega_0 CR)$ , measures sharpness of resonance — large  $Q$  means a sharply peaked current-vs- $\omega$  curve, so the circuit is highly selective in tuning (NCERT §7.6.2, p. 189; Quantity table p. 198).
- The bandwidth  $\Delta \omega$  of the resonance curve (full width at the points where  $i_m$  falls to  $i_{m,\max}/\sqrt{2}$ ) equals  $R/L$ ; hence  $Q = \omega_0/\Delta \omega$  — large  $Q \leftrightarrow$  narrow band  $\leftrightarrow$  sharper tuning. This explains why radio tuners use high- $Q$  LC tanks (NCERT §7.6.2, p. 189).
- At resonance the rms voltages across  $L$  and  $C$  individually can be much larger than the source rms voltage ( $V_L = QV$ ,  $V_C = QV$  with  $V_L$  and  $V_C$   $\pi$  out of phase) — the so-called voltage magnification, which is why tuned circuits can drive sensitive detectors even with weak input signals (NCERT §7.6.2, p. 189; Ex. 7.6, p. 190).
- For a series LCR circuit the resistance  $R$  alone determines the actual energy dissipation, since  $\cos \phi = R/Z$  — at resonance  $Z = R$  and the entire source power is dissipated in  $R$ ; for capacitive or inductive limits the power factor falls and dissipation drops (NCERT §7.7, p. 190).

## 2.2 Definitions to memorise

Term	Definition	Page
Alternating voltage	A voltage that varies sinusoidally with time, $v = v_m \sin \omega t$ , where $v_m$ is the amplitude and $\omega$ the angular frequency.	178
rms (effective) current	$I = i_m/\sqrt{2} = 0.707 i_m$ ; the dc current that would produce the same average power loss as the given ac current.	179–180
rms voltage	$V = v_m/\sqrt{2} = 0.707 v_m$ ; gives $V = IR$ and $P = VI = I^2R$ , identical in form to dc.	180
Phasor	A vector which rotates about the origin with angular speed $\omega$ ; its vertical projection represents the instantaneous value of the sinusoidally varying quantity.	181
Inductive reactance (XL)	$X_L = \omega L$ ; the opposition offered by a pure inductor to ac, measured in ohm and directly proportional to L and frequency.	182
Capacitive reactance (XC)	$X_C = 1/(\omega C)$ ; opposition offered by a pure capacitor to ac, measured in ohm and inversely proportional to C and frequency.	184
Impedance (Z)	$Z = \sqrt{R^2 + (X_C - X_L)^2}$ ; the effective opposition offered by a series LCR circuit to ac, $i_m = v_m/Z$ .	187
Phase angle ( $\phi$ )	$\tan \phi = (X_C - X_L)/R$ ; phase difference between source voltage and circuit current in a series LCR circuit.	188
Resonant (angular) frequency	$\omega_0 = 1/\sqrt{LC}$ ; the frequency at which $X_C = X_L$ , $Z = R$ , and current is maximum.	189
Power factor	$\cos \phi$ in $P = VI \cos \phi$ ; equals $R/Z$ for a series LCR circuit and decides the fraction of apparent power actually dissipated.	190–191
Wattless current	The current in a purely inductive or capacitive circuit, for which $\cos \phi = 0$ and no average power is dissipated.	191
Quality factor (Q)	$Q = \omega_0 L/R = 1/(\omega_0 CR)$ for a series RLC circuit; a dimensionless measure of the sharpness of resonance.	198
Step-up / step-down transformer	A transformer with $N_s > N_p$ (raises voltage, lowers current) or $N_s < N_p$ (lowers voltage, raises current).	195
Peak (amplitude) value	$v_m$ (or $i_m$ ); maximum instantaneous value of a sinusoidal $v$ or $i$ .	178
Average power	$P = VI \cos \phi$ ; the time-averaged value of $v_i$ over one full cycle.	191
Resonance condition	$X_L = X_C$	189
Bandwidth	$2\Delta\omega = R/L$ ; full width of resonance curve at $i_{m,max}/\sqrt{2}$ .	189
Sharpness of resonance	Larger Q $\Rightarrow$ narrower resonance curve $\Rightarrow$ more selective.	198

Term	Definition	Page
Eddy current loss	Power lost as heat through circulating currents in the iron core; mitigated by lamination.	196
Hysteresis loss	Power lost per cycle as the core's magnetic domains reverse; mitigated by low-hysteresis material.	196
Flux leakage	Magnetic flux through the primary that does not link the secondary; degrades transformer efficiency.	196

### 2.3 Diagrams / processes to remember

- Fig. 7.1 (p. 178) — Ac source connected to a pure resistor; current and voltage in phase.
- Fig. 7.2 (p. 178) — Plots of  $v$  and  $i$  versus  $\omega t$  for a pure resistor, showing simultaneous zeros, minima and maxima.
- Fig. 7.3 (p. 179) — Relationship between peak current  $i_m$  and rms current  $I = i_m/\sqrt{2} \approx 0.707 i_m$  for sinusoidal ac.
- Fig. 7.4 (p. 181) — Phasor diagram and  $v$ - $i$  waveforms for a resistor;  $V$  and  $I$  phasors aligned.
- Fig. 7.5, 7.6 (pp. 181–183) — Pure inductor circuit and phasor diagram: current phasor  $I$  is  $\pi/2$  behind voltage phasor  $V$ .
- Fig. 7.7, 7.8 (pp. 184–185) — Pure capacitor circuit and phasor diagram: current phasor  $I$  is  $\pi/2$  ahead of voltage phasor  $V$ .
- Fig. 7.10, 7.11 (pp. 186–187) — Series LCR circuit and the phasor construction giving  $Z$  and  $\phi$ .
- Fig. 7.12 (p. 188) — Impedance diagram: right triangle with  $Z$  as the hypotenuse,  $R$  and  $(XC - XL)$  as legs.
- Fig. 7.14 (p. 189) — Variation of current amplitude  $i_m$  with  $\omega$  for two values of  $R$  ( $100 \Omega$  and  $200 \Omega$ ) in an LCR circuit — peak at  $\omega_0$ , sharper peak for smaller  $R$ .
- Fig. 7.15 (p. 192) — Phasor decomposition of current into the power component ( $I_p$  in phase with  $V$ ) and wattless component ( $I_q$  perpendicular to  $V$ ).
- Fig. 7.16 (p. 194) — Two arrangements of primary and secondary windings on a soft-iron transformer core.

### 2.4 Common confusions / NTA trap points

- "Average current is zero, so no power is dissipated." Wrong — Joule heating depends on  $i^2$ , which is always positive; average power in a resistor is  $(1/2) i_m^2 R = I^2 R$ , not zero (NCERT §7.2, p. 179).
- Adding  $V_R$ ,  $V_L$ ,  $V_C$  algebraically across elements of a series LCR circuit. The voltages are out of phase; the source voltage is the phasor sum,  $v_m = \sqrt{(v_R^2 + (v_C - v_L)^2)}$  (NCERT Ex. 7.6, p. 190).

- Confusing  $X_L = \omega L$  with  $X_C = 1/(\omega C)$ .  $X_L$  grows with frequency;  $X_C$  falls with frequency — questions on what happens to current when  $\nu$  is doubled exploit this (NCERT §§7.4–7.5, pp. 182–185; Ex. 7.4).
- Direction of phase shift: in a pure inductor the current lags voltage by  $\pi/2$ ; in a pure capacitor the current leads voltage by  $\pi/2$ . NTA distractors often flip the two (NCERT §§7.4–7.5, pp. 182–185).
- Assuming resonance is possible in any ac circuit. Resonance requires both L and C; an RL or RC circuit alone cannot resonate (NCERT §7.6.2, p. 189; Points to Ponder 8, p. 199).
- For a step-up transformer thinking "voltage and current both go up". The current is reduced by the same factor by which voltage is stepped up — this is what conserves energy (NCERT §7.8, p. 195; Points to Ponder 11, p. 199).
- Using rms values vs peak values inconsistently:  $P = VI \cos \phi$  uses rms values;  $P = (1/2) i_m v_m \cos \phi$  uses peak values. Mixing them gives an answer off by 2.
- Quality factor and selectivity: smaller R (not larger R) gives larger Q and sharper resonance — easy to invert.
- Power factor in pure L or pure C:  $\cos \phi = 0$ , so even when current is large no power is dissipated; the source supplies energy in one quarter-cycle and the element returns it in the next.
- Forgetting that resonance frequency  $\omega_0 = 1/\sqrt{LC}$  does NOT depend on R — only L and C set it; R controls sharpness, not location, of the resonance peak.
- Soft-iron core misconception: students think the core "carries the current" — actually it only confines the magnetic flux so it links primary and secondary efficiently; the windings carry current.

## 2.5 Key formulas table

Quantity	Symbol / Formula	NCERT reference
Ac voltage	$v = v_m \sin \omega t$	§7.1, p. 178
Pure R current	$i = (v_m/R) \sin \omega t$	§7.2, Eq. 7.2, p. 178
rms current	$I = i_m/\sqrt{2}$	§7.2, Eq. 7.7, p. 180
rms voltage	$V = v_m/\sqrt{2}$	§7.2, p. 180
Inductive reactance	$X_L = \omega L = 2\pi \nu L$	§7.4, Eq. 7.13, p. 182
Capacitive reactance	$X_C = 1/(\omega C) = 1/(2\pi \nu C)$	§7.5, Eq. 7.18, p. 184
Impedance (series LCR)	$Z = \sqrt{R^2 + (X_C - X_L)^2}$	§7.6.1, Eq. 7.26, p. 187
Phase angle (LCR)	$\tan \phi = (X_C - X_L)/R$	§7.6.1, Eq. 7.27, p. 188
Current amplitude	$i_m = v_m/Z$	§7.6.1, p. 187
Resonant angular frequency	$\omega_0 = 1/\sqrt{LC}$	§7.6.2, Eq. 7.28, p. 189

Quantity	Symbol / Formula	NCERT reference
Power factor	$\cos \phi = R/Z$	§7.7, p. 190
Average power	$P = VI \cos \phi = \frac{1}{2} v_m i_m \cos \phi$	§7.7, Eq. 7.30a, p. 191
Power in pure R	$P = I^2R = V^2/R$	§7.2, Eq. 7.7, p. 180
Power in pure L or C	$P = 0$ (wattless)	§7.7, p. 191
Power at resonance	$P_{\max} = VI = I^2R$	§7.7, p. 191
Quality factor	$Q = \omega_0 L/R = 1/(\omega_0 CR)$	§7.6.2, p. 189; table p. 198
Bandwidth	$\Delta \omega = R/L$	§7.6.2, p. 189
Transformer voltage ratio	$V_s/V_p = N_s/N_p$	§7.8, Eq. 7.33, p. 195
Transformer current ratio	$I_s/I_p = N_p/N_s$	§7.8, Eq. 7.36, p. 195
Phase lag / lead in L / C	$\pi/2$ (lag) / $\pi/2$ (lead)	§§7.4–7.5, pp. 182–185

## Practice MCQs

## PYQ Alignment

Alternating Current is a regular CUET (UG) Physics topic: questions every year typically test rms vs peak values, XL vs XC frequency dependence, the impedance and power-factor formulas for a series LCR circuit, the resonance condition  $\omega_0 = 1/\sqrt{LC}$ , and the transformer turn-ratio relations. Numerical questions modelled on Examples 7.2, 7.4, 7.6 and 7.8 of the NCERT, and conceptual questions on wattless current and the necessity of both L and C for resonance, are especially common.

### CUET 2025 — Actual PYQs from this chapter

**Q.26 (CUET 2025)** For  $L = 500$  mH and frequency  $0.4$  kHz, capacitance for resonance is:

- A)  $2.3 \mu\text{F}$  B)  $0.32 \mu\text{F}$  C)  $6.3 \mu\text{F}$  D)  $0.6 \mu\text{F}$  Tests: LC resonance —  $f = 1/(2\pi\sqrt{LC})$ , find C for given L, f Answer: Not in extracted key

**Q.28 (CUET 2025)** AC supply  $220$  V,  $50$  Hz. Correct statement about average value over a cycle:

- A)  $220$  V B)  $220/\sqrt{2}$  V C)  $0$  V D)  $220/\sqrt{2}$  V Tests: Average value of sinusoidal AC over a full cycle is zero Answer: Not in extracted key

## CUET 2024 — Actual PYQs from this chapter

**Q.12 (CUET 2024)** In AC circuit, current leads voltage by  $\pi/2$ . Circuit is:

- A) Purely resistive B) R = reactance C) Purely inductive D) Purely capacitive **Tests:** Phase relations in AC — purely capacitive circuit (I leads V by  $\pi/2$ ) **Answer:** Not in extracted key

**Q.15 (CUET 2024)** Match frequency vs opposition graphs with: I. Impedance II. Capacitive reactance III. Inductive reactance IV. Resistance Options given.

- (options not in extracted source — see official paper) **Tests:** Frequency-dependence of  $X_L$ ,  $X_C$ , R and Z **Answer:** Not in extracted key

**Q.43 (CUET 2024)** A coil of inductance 0.5 H connected to AC source of 50 Hz. Inductive reactance will be:

- A) 75 V B) 150 V C) 100 V D) 200 V **Tests:** Inductive reactance  $X_L = 2\pi fL$  **Answer:** Not in extracted key

## CUET 2023 — Actual PYQs from this chapter

**Q.19 (CUET 2023)** If the rms voltage is  $100\sqrt{2}$  V, the peak voltage is:

- A) 200 V B) 100 V C) 141 V D) 70.5 V **Tests:** RMS and peak values in AC **Answer:** Not in extracted key

**Q.21 (CUET 2023)** Find the effective impedance in the circuit if the source is (a) DC source and (b) High-frequency AC source.

- A) For DC: ( $Z = R_2 + R_3$ ) ; For AC: ( $Z = R_1 + R_3$ ) B) For DC: ( $Z = R_1$ ) ; For AC: ( $Z = R_2 + R_3$ ) C) For DC: ( $Z = \infty$ ) ; For AC: ( $Z = 0$ ) D) For DC: ( $Z = 0$ ) ; For AC: ( $Z = \infty$ ) **Tests:** Impedance of LC/RLC circuit at DC vs high-frequency AC **Answer:** Not in extracted key

**Q.22 (CUET 2023)** In AC circuits, the relation ( $Z = \sqrt{R^2 + (X_L - X_C)^2}$ ) holds when: A. AC circuit containing R and L in series B. AC circuit containing R and C in series C. AC circuit containing L and C in series D. AC circuit containing R, L and C in series Options:

- A) A and C only B) A and B only C) A, B and D only D) A, B, C and D only **Tests:** Impedance formula  $Z = \sqrt{R^2 + (X_L - X_C)^2}$  for series RLC **Answer:** Not in extracted key

**Q.23 (CUET 2023)** When 100 V dc current is applied, the current in a coil is 1 A. When 100 V ac is applied, the current becomes 0.5 A. If frequency is 50 Hz, find the impedance and inductance.

- A) 200  $\Omega$  and 0.55 H B) 100  $\Omega$  and 0.86 H C) 200  $\Omega$  and 1.0 H D) 100  $\Omega$  and 0.93 H **Tests:** Impedance, reactance and inductance from DC vs AC currents **Answer:** Not in extracted key