

PHYSICS • CLASS 12

CHAPTER 7

Alternating Current

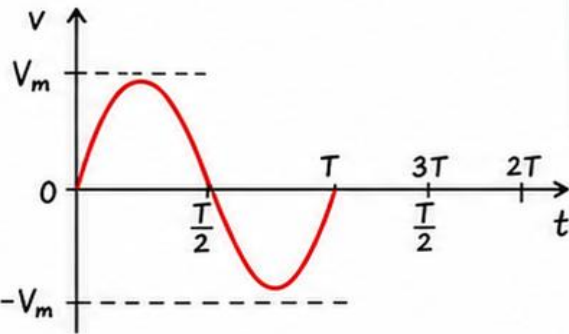
CHAPTER NOTES



CHAPTER ROADMAP: ALTERNATING CURRENT (AC CIRCUITS)

DEFINITION

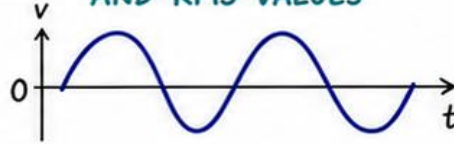
Alternating voltage or current are quantities that vary periodically with time and reverse sign at regular intervals.



$$v(t) = V_m \sin \omega t$$

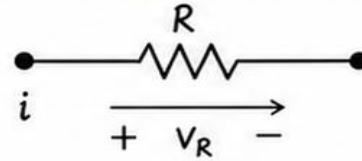
where V_m = maximum (peak) value
 ω = angular frequency (rad/s)
 T = time period (s)
 f = frequency = $\frac{1}{T}$ (Hz)

1 SINUSOIDAL AC AND RMS VALUES



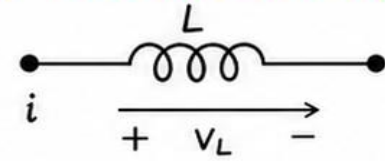
- $v(t) = V_m \sin \omega t$
- RMS value: $V = V_m / \sqrt{2}$
 $I = I_m / \sqrt{2}$

2 PURE RESISTOR (R)



- V_R and i are in phase ($\phi = 0^\circ$)
- $V_R = iR$
- $p = vi = i^2 R$ (always ≥ 0)

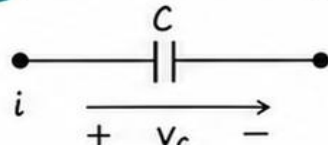
3 PURE INDUCTOR (L)



- i lags v_L by 90°
- $v_L = L \frac{di}{dt}$
- $X_L = \omega L$

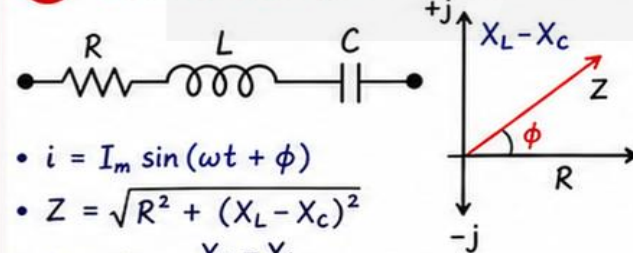
ALTERNATING CURRENT (AC) CIRCUITS

4 PURE CAPACITOR (C)



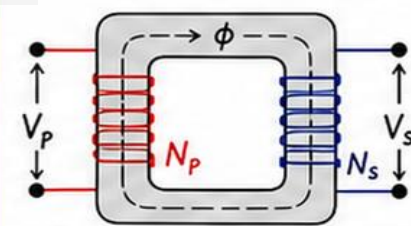
- i leads v_C by 90°
- $i = C \frac{dv_C}{dt}$
- $X_C = \frac{1}{\omega C}$

5 SERIES LCR RESONANCE



- $i = I_m \sin(\omega t + \phi)$
- $Z = \sqrt{R^2 + (X_L - X_C)^2}$
- $\tan \phi = \frac{X_C - X_L}{R}$
- Resonance: $X_L = X_C \Rightarrow \phi = 0, Z = R(\text{min}), I(\text{max})$

6 TRANSFORMERS AND POWER TRANSMISSION



$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

$$\frac{I_S}{I_P} = \frac{N_P}{N_S}$$

- Easy to step up ($V_S > V_P$) for transmission
- Step down ($V_S < V_P$) for safe use
- Reduces I for a given $P = VI$

★ **CONCLUSION:** AC is easy to transform between voltage levels using transformers, enabling efficient long-distance power transmission with reduced losses.



ALTERNATING CURRENT (AC): SINE WAVE BASICS

In an AC circuit, the voltage (and current) vary with time, reversing direction periodically. The most common form is the sinusoidal (sine) wave.

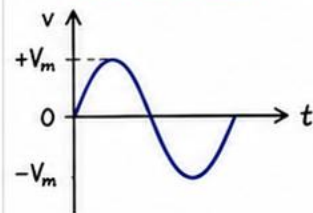
During the positive half-cycle, the instantaneous voltage is positive and current flows in the chosen (reference) direction.

During the negative half-cycle, the instantaneous voltage is negative, which means the polarity reverses and current flows in the opposite direction.

Over one complete cycle, positive and negative areas are equal, so the average value over a full cycle is zero.

AC versus DC

AC (sine wave)

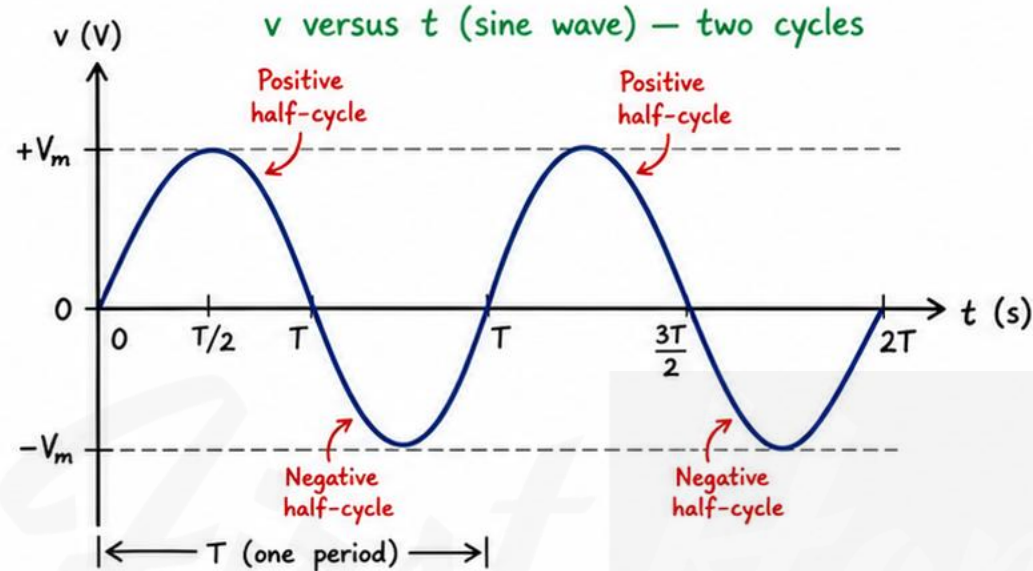


Value changes with time and reverses direction periodically.

DC (direct current)



Value is constant with time. Polarity and direction do not change.



$$f = \frac{1}{T} \quad (\text{frequency}) \quad \omega = 2\pi f \quad (\text{angular frequency})$$

- **Instantaneous value, $v(t)$:** value of voltage at any instant t . For a sine wave, $v(t) = V_m \sin(\omega t)$.
- **Peak (maximum) value, V_m :** maximum magnitude reached by the voltage (or current) in either direction.
- **RMS (root mean square) value, V_{rms} :** the effective value that produces the same heating effect in a resistor as the DC voltage.

$$\text{For a sine wave: } V_{rms} = \frac{V_m}{\sqrt{2}} \approx 0.707 V_m$$

Ordinary AC ratings (e.g., 230 V) are RMS values, unless otherwise stated.



SAFETY FIRST!

Mains electricity is dangerous. Never handle live wires or appliances with wet hands. Always switch OFF before working on any circuit.

GIVEN

AC supply: 230 V (rms), 50 Hz

REQUIRED

- Peak voltage, V_m
- Angular frequency, ω

PRINCIPLE / FORMULA

$$V_{rms} = \frac{V_m}{\sqrt{2}} \quad \omega = 2\pi f$$

UNIT CONVERSION

No conversion needed.

SUBSTITUTION

$$V_{rms} = 230 \text{ V}, \quad f = 50 \text{ Hz}$$

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

$$\omega = 2\pi f$$

CALCULATION

$$V_m = 230 \times \sqrt{2} = 230 \times 1.4142 = 325.27 \text{ V}$$

$$\omega = 2\pi \times 50 = 100\pi = 314.16 \text{ rad s}^{-1}$$

FINAL ANSWER

$$V_m \approx 325 \text{ V (peak)}$$

$$\omega \approx 314 \text{ rad s}^{-1}$$

QUICK CHECK

- $V_{rms} = \frac{V_m}{\sqrt{2}} \approx \frac{325}{1.414} \approx 230 \text{ V} \quad \checkmark$
- $f = \frac{\omega}{2\pi} = \frac{314.16}{2\pi} \approx 50 \text{ Hz} \quad \checkmark$

★ Modern note: The nominal Indian domestic supply is about **230 V rms, 50 Hz**. Thus the sinusoidal peak voltage is about **325 V**.

AC CIRCUIT WITH PURE RESISTOR

GIVEN → A sinusoidal source is connected only to a resistor R , $v(t) = V_m \sin \omega t$ is the applied voltage.

REQUIRED → Obtain $i(t)$ starting from $v = V_m \sin \omega t$ and $v = iR$.
Determine I_m . Derive rms law $V = IR$.
Show waveforms, phasors and power.

PRINCIPLE / FORMULA → Ohm's law for a resistor: $v = iR$ $v(t) = V_m \sin \omega t$
If $v = V_m \sin \omega t$, then $i = \frac{v}{R} = \frac{V_m}{R} \sin \omega t$

$$i = I_m \sin \omega t, \quad I_m = \frac{V_m}{R}$$

RMS (effective) values: $V = \frac{V_m}{\sqrt{2}}, \quad I = \frac{I_m}{\sqrt{2}} \quad \boxed{V = IR}$

UNIT CONVERSION → No conversion needed.

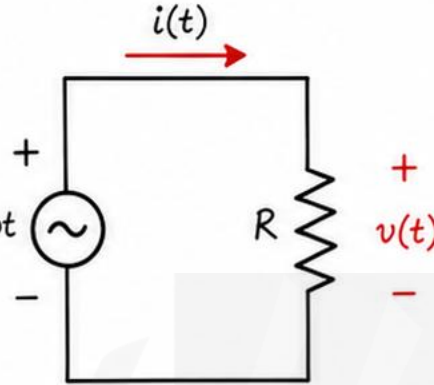
SUBSTITUTION → $i = \frac{v}{R} = \frac{V_m \sin \omega t}{R} = \frac{V_m}{R} \sin \omega t$

CALCULATION → $I_m = \frac{V_m}{R}, \quad V = \frac{V_m}{\sqrt{2}}, \quad I = \frac{I_m}{\sqrt{2}} = \frac{V_m}{\sqrt{2}R} = \frac{V}{R}$
 $\boxed{V = IR}$

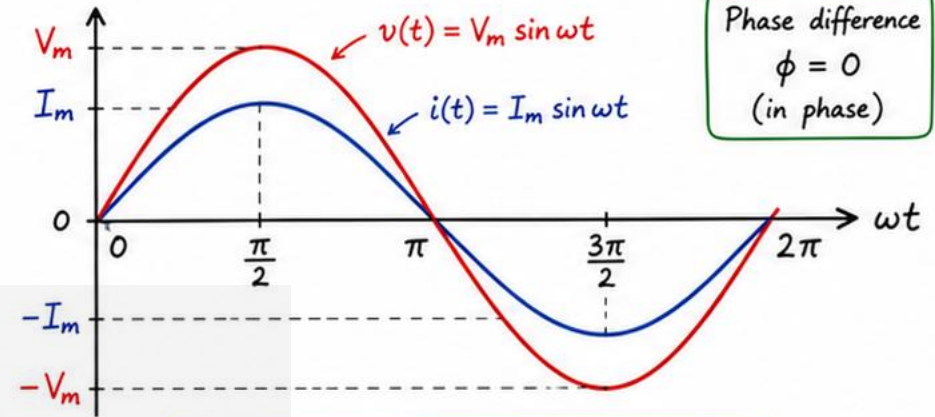
FINAL ANSWER → $i(t) = I_m \sin \omega t, \quad I_m = \frac{V_m}{R}, \quad V = IR$

QUICK CHECK → If R increases, current decreases. V and I are in phase.
Power $p(t) = i^2 R \geq 0$ always → resistor converts electrical energy to heat in both half-cycles.

CIRCUIT DIAGRAM

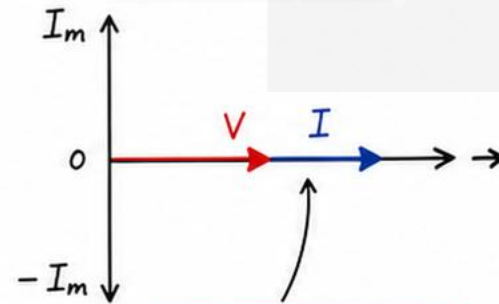


WAVEFORMS (v AND i ARE IN PHASE)



v and i have simultaneous zeros and extrema.

PHASOR DIAGRAM

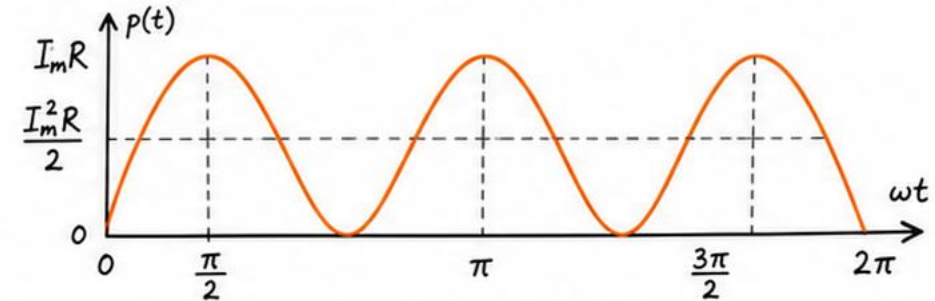


V and I are collinear.
 $\phi = 0^\circ$ (in phase)

INSTANTANEOUS POWER

$$p(t) = v(t) i(t) = i^2(t) R = [I_m \sin \omega t]^2 R$$

$$p(t) = I_m^2 R \sin^2 \omega t = \frac{I_m^2 R}{2} (1 - \cos 2\omega t) \geq 0$$



Since $p(t) \geq 0$ for all t , the resistor converts electrical energy to heat during both half-cycles.

RMS VALUES AND AVERAGE POWER IN AC CIRCUITS

WHAT IS RMS?

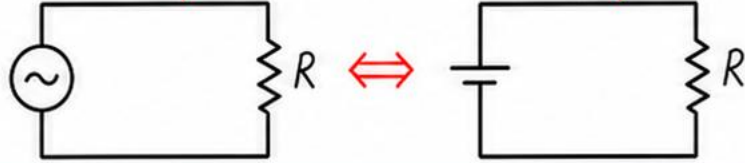
The rms (root-mean-square) value of an alternating current or voltage is the value of a steady (dc) current or voltage that would produce the same average heating in the same resistor over one complete cycle.

Since heating power in a resistor R is $i^2 R$, "same heating" means the average of $i^2 R$ over a period T equals the heating by I_{dc} in the same R , i.e., $\langle i^2 R \rangle = I_{dc}^2 R$. Therefore $I_{dc} = I_{rms}$. Similarly for voltage.

DC EQUIVALENT (SAME AVERAGE HEATING)

AC current $i(t)$
through R
 $i(t) \rightarrow$

DC current I_{rms}
through same R
 $I_{rms} \rightarrow$

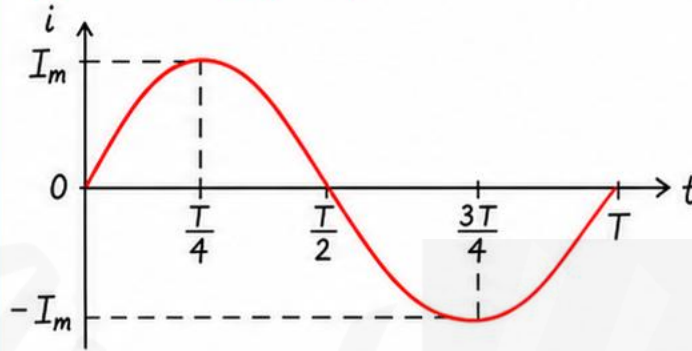


PRECISION NOTE

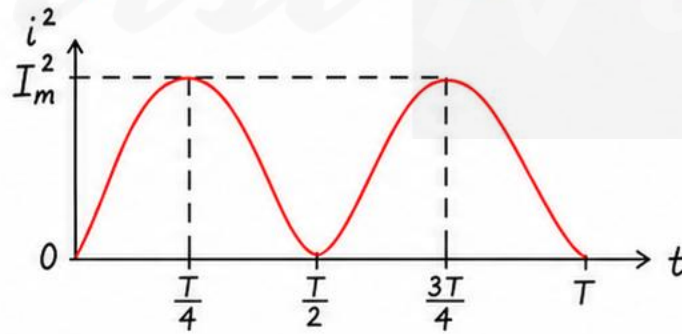
- The factor $1/\sqrt{2}$ is specific to a sinusoidal waveform.
- The definition $I_{rms} = \sqrt{\frac{1}{T} \int_0^T i^2(t) dt}$ (and similarly for V_{rms}) works for any periodic waveform.

WAVEFORMS OVER ONE PERIOD (0 TO T)

(a) Current $i(t) = I_m \sin \omega t$



(b) Square of current: $i^2(t) = I_m^2 \sin^2 \omega t (\geq 0)$



KEY FACT

Over one period, the average of $\sin^2 \omega t$ is $\frac{1}{2}$.

$$\langle \sin^2 \omega t \rangle = \frac{1}{T} \int_0^T \sin^2 \omega t dt = \frac{1}{2}$$

DERIVATION OF RMS CURRENT

$$i(t) = I_m \sin \omega t$$

$$\begin{aligned} I_{rms} &= \sqrt{\frac{1}{T} \int_0^T i^2(t) dt} = \sqrt{\frac{1}{T} \int_0^T I_m^2 \sin^2 \omega t dt} \\ &= I_m \sqrt{\frac{1}{T} \int_0^T \sin^2 \omega t dt} = I_m \sqrt{\langle \sin^2 \omega t \rangle} \\ &= I_m \sqrt{\frac{1}{2}} = \frac{I_m}{\sqrt{2}} \end{aligned}$$

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

For a sinusoid,
 $1/\sqrt{2}$ is
sinusoid-specific.

The integral
definition is
general.

RMS VOLTAGE (SIMILAR)

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

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

AVERAGE POWER IN A RESISTOR R

$$p(t) = i^2(t) R \text{ (instantaneous power)}$$

$$\begin{aligned} P_{avg} &= \langle p(t) \rangle = \langle i^2(t) R \rangle = R \langle i^2(t) \rangle \\ &= R I_{rms}^2 = I_{rms}^2 R = (I_{rms} R) I_{rms} \end{aligned}$$

All three forms
are equivalent.

$$\text{Since } V = I_{rms} R, \quad P_{avg} = V I = \frac{V^2}{R}$$

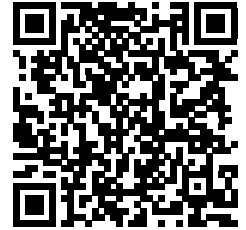


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