Alternating Currents

A Level Physics 9702

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By the end of this topic I can. . .

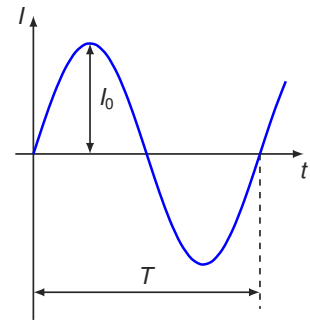
- describe sinusoidal a.c.; use peak, r.m.s. and mean power
- read an oscilloscope trace
- explain transformers and high-voltage transmission
- explain rectification and smoothing

Sinusoidal a.c.

A current that reverses direction repeatedly:

$$I = I_0 \sin \omega t$$

$$\omega = 2\pi f = \frac{2\pi}{T}$$



- I_0, V_0: **peak** values
- mean current over a cycle is **zero**
- power $P = I^2R \geq 0$: heating still happens

r.m.s. values

r.m.s. value

The **steady d.c.** value that delivers the **same mean power** to a resistive load.

- $V_{\mathrm{rms}} = V_0/\sqrt{2}$ (sine waves only)
- mains voltages are r.m.s. values

$$\langle P \rangle = I_{\mathrm{rms}}^2 R = \frac{V_{\mathrm{rms}}^2}{R}$$

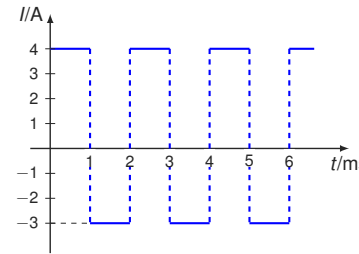
$$I_{\mathrm{rms}} = \frac{I_0}{\sqrt{2}}$$

Example: square wave

The alternating current in a 120 Ω resistor is shown (square wave: $+4$ A for half the period and -3 A for the other half). Find (a) the r.m.s. current and (b) the mean power.

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(a) $\langle I^2 \rangle = \dfrac{4^2 + (-3)^2}{2} = 12.5\ \text{A}^2$, so

$I_{\text{rms}} = \sqrt{12.5} = 3.54\ \text{A}$

(b) $\langle P \rangle = I_{\text{rms}}^2 R = 12.5 \times 120 = 1500\ \text{W}$

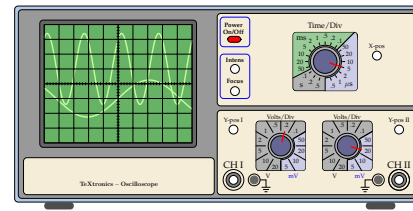
Example: energy from an a.c. supply

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$$V_{\text{rms}} = \frac{75}{\sqrt{2}} = 53.0 \text{ V}, \quad \langle P \rangle = \frac{53.0^2}{30} = 93.8 \text{ W}$$
$$W = \langle P \rangle \, t = 93.8 \times 120 \approx 1.13 \times 10^4 \text{ J}$$

The oscilloscope

- electron beam deflected by **vertical plates**
- time base moves the beam **horizontally**
- **Y-gain**: volts per division
- **time base**: time per division



Example: reading a trace

The trace is shown (4 divisions peak to peak, 3 divisions per cycle). The time base is 10 ms/div and the Y-gain is 5 V/div. Find the peak voltage, period and frequency.

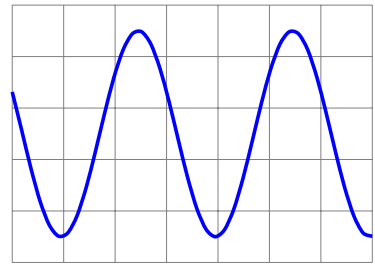
Example: reading a trace

The trace is shown (4 divisions peak to peak, 3 divisions per cycle). The time base is 10 ms/div and the Y-gain is 5 V/div. Find the peak voltage, period and frequency.

$V_0 = \frac{1}{2} \times 4 \times 5 = 10$ V

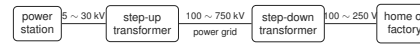
$T = 3 \times 10 = 30$ ms

$f = \frac{1}{T} = \frac{1}{30 \times 10^{-3}} = 33.3$ Hz



High-voltage transmission

- cable loss is I^2R: want **low current**
- $P = IV$ fixed, so **high voltage**
- safe low voltages at each end: **transformers**



The transformer

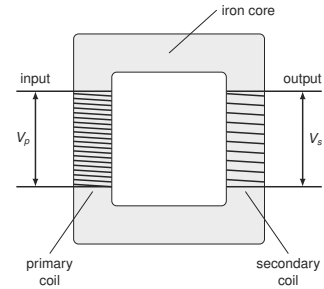
Transformer

Changing flux from the **primary** coil links through an **iron core** to the **secondary** coil.

- $N_s > N_p$: step-up; $N_s < N_p$: step-down
- losses: eddy currents (laminate), coil resistance, flux leakage

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

$$I_p V_p = I_s V_s$$



Example: ideal transformer

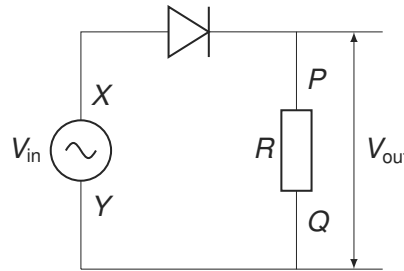
Example: ideal transformer

$$\frac{V_{s,0}}{V_{p,0}} = \frac{N_s}{N_p} \text{ and } V_{p,0} = \sqrt{2} \times 8.0 = 11.3 \text{ V}$$

$$V_{s,0} = 11.3 \times \frac{5000}{200} = 283 \text{ V}$$

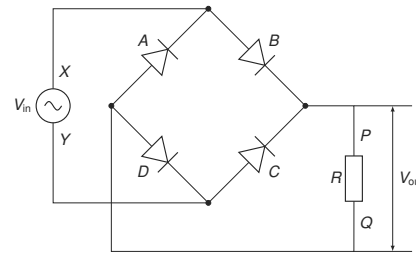
Half-wave rectification

- a single **diode** conducts for half the cycle
- output is one direction only
- half of the supply power is lost



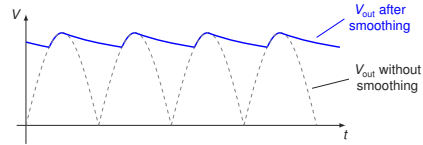
Full-wave rectification

- **bridge** of four diodes
- current through *R* is always in the **same direction**
- both halves of the cycle are used



Smoothing

- capacitor in **parallel** with the load
- stores energy as voltage rises, discharges as it falls
- larger *RC*: **less ripple**



Key equations

sine wave $I = I_0 \sin \omega t$

r.m.s. current $I_{\text{rms}} = \dfrac{I_0}{\sqrt{2}}$

angular freq. $\omega = 2\pi f = \dfrac{2\pi}{T}$

transformer $\dfrac{V_s}{V_p} = \dfrac{N_s}{N_p}$

mean power $\langle P \rangle = I_{\text{rms}}^2 R = \dfrac{V_{\text{rms}}^2}{R}$