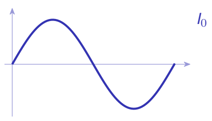
Alternating Currents

A2 Physics ▪ Topic 21

A-Level Physics



What we will cover

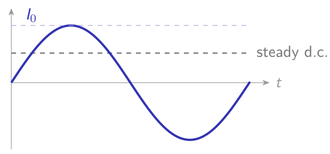
1 AC basics

Current that keeps reversing

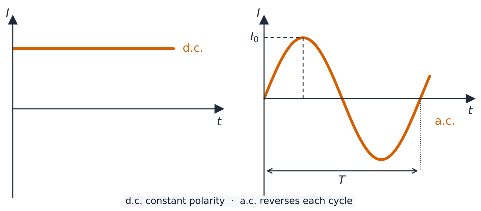
An **alternating current** 交流电 keeps reversing direction. Mains is sinusoidal:

$$I = I_0 \sin(\omega t), \qquad V = V_0 \sin(\omega t)$$

For a purely resistive load, V and I are in phase.



Alternating current basics



d.c. constant polarity · a.c. reverses each cycle

> A steady direct current compared with a sinusoidal alternating current of peak I_0 and period T

The words on a CRO trace

period T	time for one full cycle. $f = 1/T$. Mains is 50 or 60 Hz.
angular frequency	$\omega = 2\pi f = 2\pi/T$
peak I_0 **or** V_0	the largest value in a cycle (amplitude)
peak-to-peak	$2I_0$ – from $+I_0$ to $-I_0$; useful on a CRO

The values you read off an a.c. trace

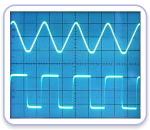
Peak value	The **peak value** 峰值 I_0 or V_0: the largest value in a cycle – the amplitude.
Peak-to-peak value	The **peak-to-peak value** 峰峰值 $2I_0$: from $+I_0$ down to $-I_0$, which is what a CRO screen shows most directly.
Period and frequency	One cycle spans the period T; the frequency is $f = 1/T$. Read T off the time-base setting.
R.m.s. value	$V_{\text{rms}} = V_0/\sqrt{2}$: the d.c. voltage that would deliver the same mean power in the same **resistance** 电阻.

> Mains "230 V" is an r.m.s. value; the peak is about 325 V, and insulation has to survive the peak.

Reading a CRO

Same as any wave (Topic 7), using a **cathode-ray oscilloscope** 示波器:

- horizontal divisions × **time-base** 时基 → period T, so $f = 1/T$
- vertical divisions × y-gain → peak voltage V_0 (centre to peak, or peak-to-peak then halve)



2 Power

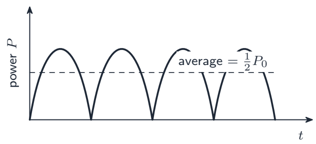
Power in a resistor pulses at $2f$

Instant power $P(t) = I(t)^2R$. With $I = I_0 \sin(\omega t)$:

$$P(t) = I_0^2 R \sin^2(\omega t)$$

Always positive; peak I_0^2R; minimum zero; oscillates at twice the frequency of I. The mean of $\sin^2$ over a cycle is $\frac{1}{2}$, so

$$\langle P \rangle = \tfrac{1}{2} I_0^2 R = \tfrac{1}{2} P_{\text{peak}}$$



> Average a.c. power in a resistor is half the peak power.

Why r.m.s. matters

"230 V mains" means $V_{\text{r.m.s.}} = 230$ V, with peak $V_0 = 230\sqrt{2} \approx 325$ V.

> Components must be rated for the peak, not the r.m.s.

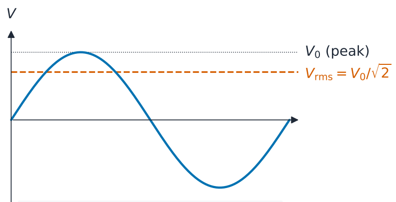
Drawing the diagrams

- half-wave: a.c. source – single diode – load R, in series.
- full-wave bridge: four diodes as the arms of a "diamond"; the a.c. input goes to one pair of opposite corners, the load R across the other pair.

3 Root-mean-square

r.m.s. is the equivalent steady d.c.

$I_{\text{r.m.s.}}$ is the steady direct current giving the same average power in the same R: $I_{\text{r.m.s.}} = I_0/\sqrt{2}$, $V_{\text{r.m.s.}} = V_0/\sqrt{2}$.

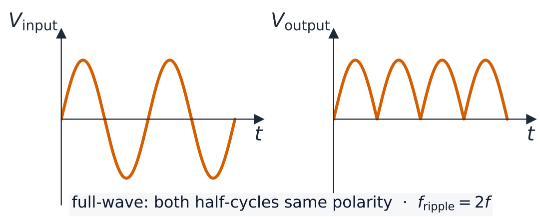


$V_{\text{rms}} = V_0/\sqrt{2}$ · same mean power as d.c.

4 Rectification

The rectified output

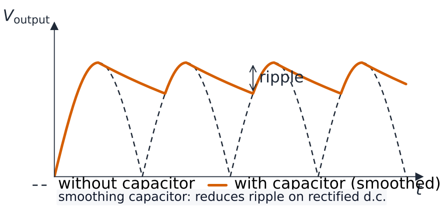
Full-wave flips the negative half rather than discarding it, so the output never rests at zero and its mean is twice the half-wave value.



full-wave: both half-cycles same polarity · $f_{\text{ripple}} = 2f$

Smoothing – a capacitor across the load

The capacitor charges to near the peak, then discharges through the load (time constant RC) while the diodes are cut off. The dips left are the **ripple** 纹波: smaller for larger C, larger R, or full-wave rectification.



smoothing capacitor: reduces ripple on rectified d.c.

How it works

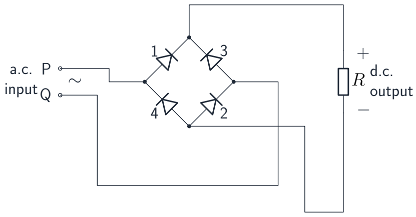
- on the **rising part** of each pulse, the capacitor charges up to near the peak.
- on the **falling part** (and any gap), the diodes are reverse-biased, so the capacitor **discharges through the load**, keeping current flowing.
- at the next peak, the capacitor charges again, and the cycle repeats.

Purpose in summary

The smoothing capacitor reduces the ripple, giving a steadier d.c.

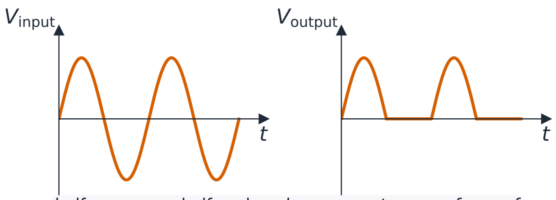
> voltage suitable for sensitive electronics.

Full-wave rectification (bridge rectifier)



> A four-diode bridge sends the load current the same way whichever a.c. terminal is positive

Half-wave rectification



half-wave: one half-cycle only · gaps at zero · $f_{\text{ripple}} = f$

> In half-wave rectification a single diode passes only the positive half-cycles

Worked example – r.m.s. values in use

(a) An a.c. supply has a peak voltage of 12 V: find its r.m.s. voltage. (b) A $50\ \Omega$ heater runs on the 230 V r.m.s. mains: find the r.m.s. current and the average power.

- (a) $V_{\text{rms}} = V_0/\sqrt{2} = 12/\sqrt{2} \approx 8.5$ V.
- (b) $I_{\text{rms}} = V_{\text{rms}}/R = 230/50 = 4.6$ A.
- $\langle P\rangle = V_{\text{rms}} I_{\text{rms}} = 230 \times 4.6 \approx 1.06$ kW.

> Use r.m.s. values for power, peak values for insulation. Mixing them is the standard error here.

Exam tips

- $I_{rms} = I_0/\sqrt{2}$ for a sinusoidal current; use r.m.s. values for power ($P = I^2_{rms}R$).
- Mean power in a resistor $= \frac{1}{2}$ of the peak power.
- Explain **rectification** (diode or bridge) and how a **smoothing capacitor** reduces the ripple.

5 Recap

Topic 21 – key takeaways

1 a.c.

$I = I_0 \sin(\omega t)$; $f = 1/T$; $\omega = 2\pi f$

2 r.m.s.

$I_{\rm rms} = I_0/\sqrt{2}$; power uses r.m.s.

3 Rectify

one diode (half) or four-diode bridge (full)

4 Smooth

C in parallel with R; large $RC \Rightarrow$ small ripple

Alternating Currents
└Recap

Check yourself

1. Peak of $230\,\mathrm{V}$ r.m.s. mains?
2. Average power in a resistor, as a fraction of peak power?
3. How many diodes in a bridge rectifier?
4. Two ways to reduce ripple?

Answers **1.** $\approx 325\,\mathrm{V}$ **2.** half **3.** four **4.** larger C or R, or full-wave (higher frequency)