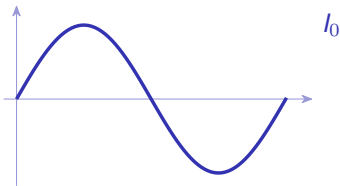


Alternating Currents

A2 Physics ■ Topic 21

A-Level Physics



What we will cover

- 1 Characteristics of a.c. 21.1
- 2 Rectification and smoothing 21.2
- 3 Recap

1

Characteristics of a.c.

Sheet 21.1 – what you need to know

You must be able to:

- read V_0 , ω , f and T off a trace or an equation
- use r.m.s. values: $I_{\text{r.m.s.}} = I_0/\sqrt{2}$ for a sine wave
- find the mean power, including for rectified and square waves

What the exam asks

“Show that the period is 0.050 s.”
[1]

“State three conclusions that can be drawn from Fig. 7.3.” [3]

“Determine an expression for I in terms of t , where I is in A and t is in s.” [2]

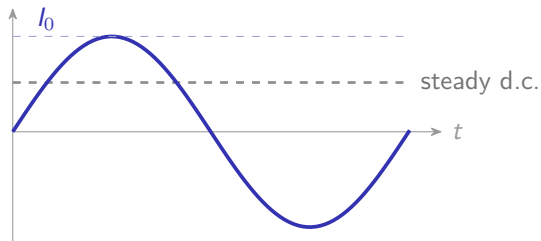
Practise on exercise sheet 21.1, then try the real exam questions on past-paper sheet 21.1.

Current that keeps reversing

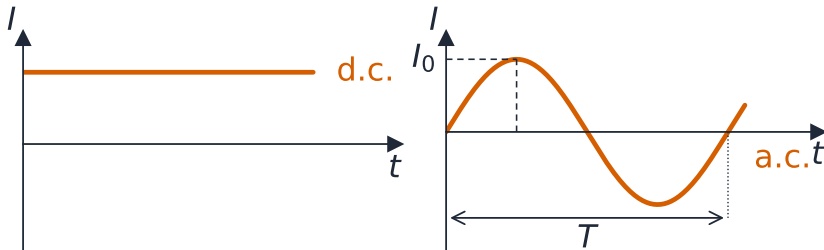
An **alternating current** 交流电 keeps reversing direction. Mains is sinusoidal:

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

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

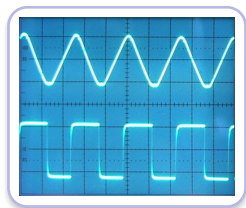
$V_{\text{rms}} = V_0/\sqrt{2}$: the d.c. voltage that would deliver the same mean power in the same **resistance** 电阻.

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



Reading an a.c. equation, and writing one

$V = 18 \cos(40\pi t)$. Show that the period is 0.050 s, and find $V_{\text{r.m.s.}}$.

$$V_0 = 18 \text{ V}, \quad \omega = 40\pi \text{ rad s}^{-1}$$

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{40\pi} = 0.050 \text{ s}$$

$$V_{\text{r.m.s.}} = \frac{V_0}{\sqrt{2}} = 12.7 \text{ V}$$

The number multiplying t is ω , not f .
here $f = 20 \text{ Hz}$.

Electrons in a wire ($n = 8.5 \times 10^{28} \text{ m}^{-3}$, $A = 1.0 \text{ mm}^2$) oscillate with amplitude $1.5 \times 10^{-7} \text{ m}$ at 50 Hz. Write I in terms of t .

$$\begin{aligned} v_0 &= \omega x_0 = 100\pi \times 1.5 \times 10^{-7} \\ &= 4.7 \times 10^{-5} \text{ m s}^{-1} \end{aligned}$$

$$\begin{aligned} I_0 &= nAqv_0 = (8.5 \times 10^{28})(10^{-6}) \\ &\quad \times (1.6 \times 10^{-19})(4.7 \times 10^{-5}) = 0.64 \text{ A} \end{aligned}$$

$$I = 0.64 \sin(100\pi t)$$

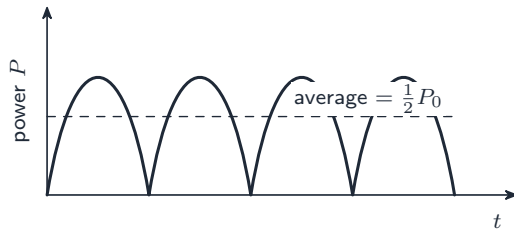
Power in a resistor pulses at $2f$

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

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

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

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



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

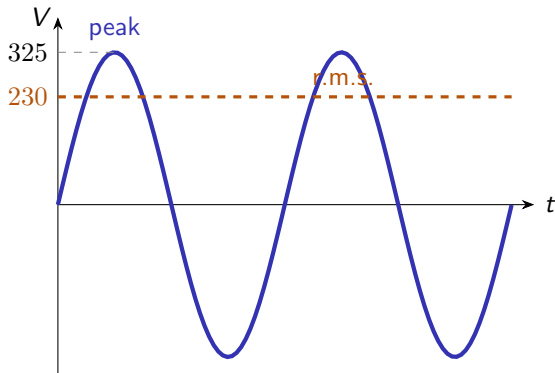
Why r.m.s. matters

“230 V mains” means the **r.m.s.** value:

$$V_{\text{r.m.s.}} = \frac{V_0}{\sqrt{2}}$$

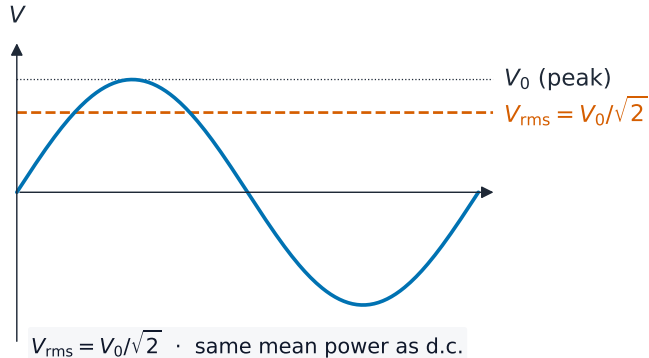
Peak: $V_0 = 230\sqrt{2} \approx 325 \text{ V}$.

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



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 : $I_{\text{r.m.s.}} = I_0/\sqrt{2}$, $V_{\text{r.m.s.}} = V_0/\sqrt{2}$.



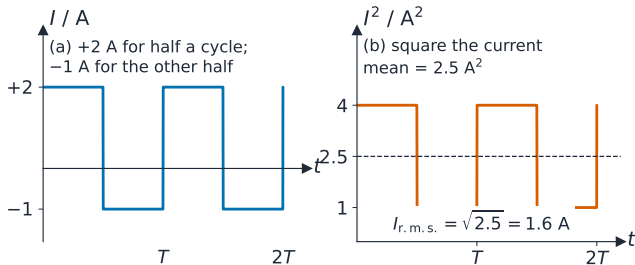
Worked example – r.m.s. values in use

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

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

r.m.s. of a wave that is not a sine



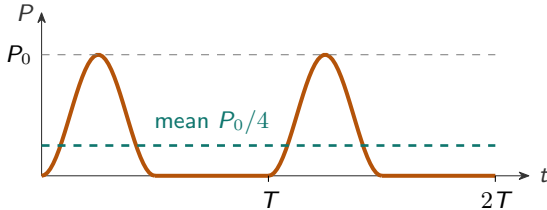
Square the current, take the **mean** of I^2 over a cycle, then the square root.

$$\begin{aligned}\langle I^2 \rangle &= \frac{1}{2}(2^2) + \frac{1}{2}(1^2) \\ &= 2.5 \text{ A}^2\end{aligned}$$

$$I_{r.m.s.} = \sqrt{2.5} = 1.6 \text{ A}$$

Never $I_0/\sqrt{2}$ here: that holds for sine waves only.

Power from a half-wave rectified supply



“State three conclusions from the P - t graph.” [3]

Power is **never negative**: the resistor heats whichever way current flows.
Each pulse lasts half a cycle; the power varies at $2f$ while on.

No power for alternate half cycles: **mean** $= \frac{P_0}{4}$.

Connected directly (no diode) the mean is $P_0/2$: the diode **halves** the mean power.

2

Rectification and smoothing

Sheet 21.2 – what you need to know

You must be able to:

- draw half-wave and bridge rectifiers, diodes the right way round
- add a smoothing capacitor and sketch the output
- find the ripple from $V = V_0 e^{-t/RC}$

What the exam asks

“Complete the circuit by drawing the three missing diodes inside the dashed circles.” [2]

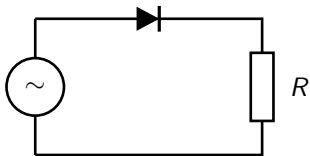
“The capacitor discharges for 0.14 s. Determine the minimum value of the smoothed output voltage.” [2]

“Determine, in terms of T , the time constant of the smoothing circuit.” [3]

Practise on exercise sheet 21.2, then try the real exam questions on past-paper sheet 21.2.

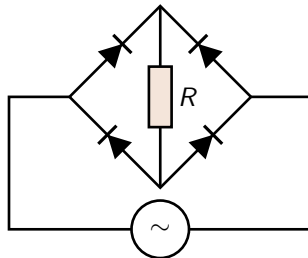
Drawing the diagrams

half-wave



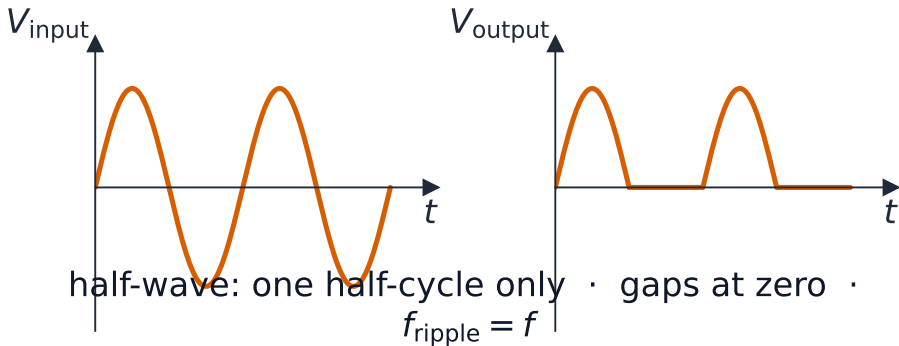
source – **one diode** – load, in series

full-wave bridge



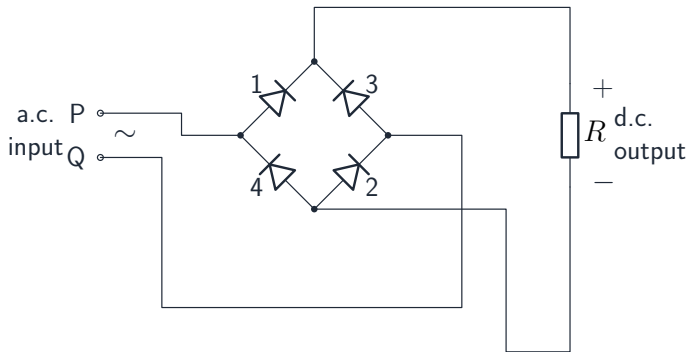
a.c. across one pair of corners, load across the other

Half-wave rectification



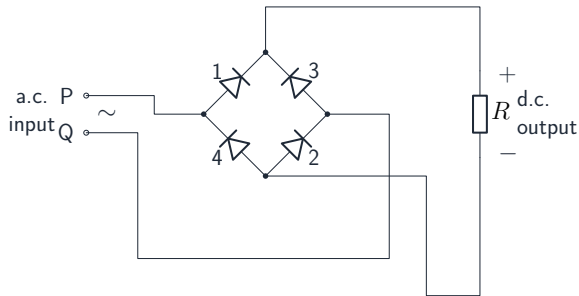
In half-wave rectification a single diode passes only the positive half-cycles

Full-wave rectification (bridge rectifier)



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

Orienting the bridge diodes



Rule: both diodes at the **positive** output corner point **into** it; both at the negative corner point **away**.

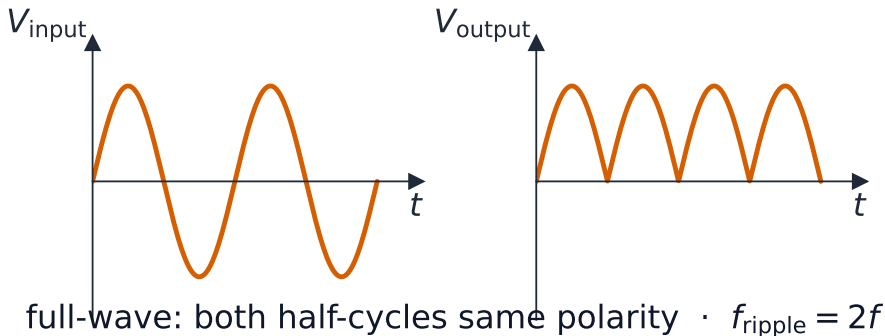
Check by tracing each half cycle:

- P positive: $P \rightarrow 1 \rightarrow + \rightarrow R \rightarrow 2 \rightarrow Q$
- Q positive: $Q \rightarrow 3 \rightarrow + \rightarrow R \rightarrow 4 \rightarrow P$

Either way, current goes **down** through R . For smoothing, the capacitor goes **across the load**, in parallel with R .

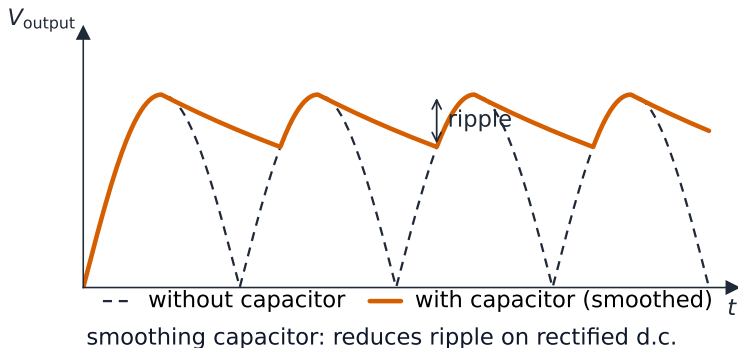
The rectified output

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.

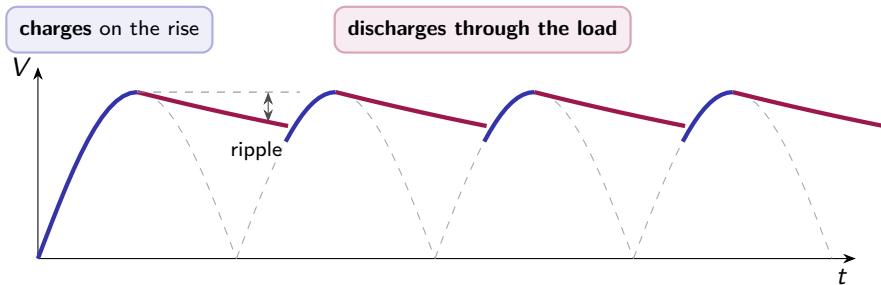


Smoothing – a capacitor across the load

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.



How it works



Between peaks the diodes are **reverse-biased**; the capacitor alone keeps current flowing. Result: a **steadier d.c.** for sensitive electronics.

Worked example – the size of the ripple

A full-wave output peaks at 34 V. $RC = 0.50$ s, and each discharge lasts 0.14 s. Find the minimum output p.d.

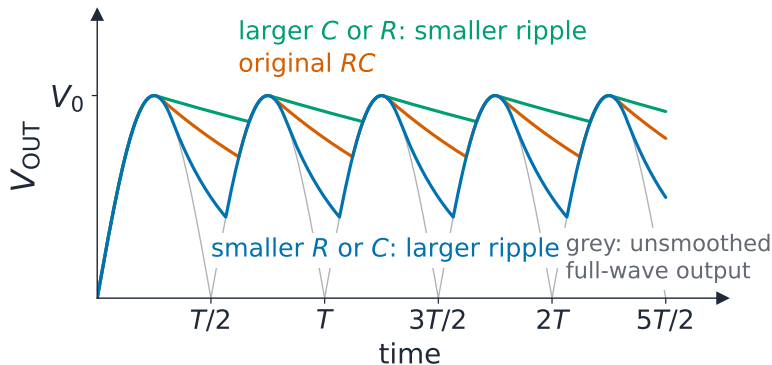
$$\begin{aligned} V &= V_0 e^{-t/RC} \\ &= 34 e^{-0.14/0.50} = 34 \times 0.756 \\ &= 26 \text{ V} \end{aligned}$$

The output falls by 33% in each discharge, which lasts about $T/2$. Find the time constant in terms of T .

$$\begin{aligned} 0.67 &= e^{-(T/2)/RC} \\ RC &= \frac{T/2}{-\ln 0.67} = \frac{0.5 T}{0.40} = 1.25 T \end{aligned}$$

The discharge is the capacitor decay of topic 19: the diode stops conducting, and C empties through R alone.

What changes the ripple



Good smoothing needs $RC \gg$ the time between peaks. A heavier load (smaller R) gives **more** ripple; full-wave halves the gap (peaks every $T/2$).

3

Recap

Exam tips

- $I_{rms} = I_0/\sqrt{2}$ for a sinusoidal current; use r.m.s. values for power ($P = I_{rms}^2 R$).
- 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.

Topic 21 – key takeaways

1 a.c.

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

2 r.m.s.

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

3 Rectify

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

4 Smooth

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

Check yourself

- 1 Peak of 230 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. ≈ 325 V 2. half 3. four 4. larger C or R , or full-wave (higher frequency)