Cambridge AS & A Level · Physics 9702 · Notes

Alternating currents A2

Read online at **pastopic.com/cambridge/physics-9702/notes/alternating-currents**

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Read first: **Electricity**, **Oscillations**, **Capacitance**

What you need to know

By the end of this topic you should be able to:

1. **Understand and use the terms period, frequency and peak value** for an alternating current or voltage.
2. **Use equations of the form** $x = x_0 \sin \omega t$ for a current or voltage that alternates sinusoidally.
3. **Recall and use the fact that the mean power** in a resistor is **half the maximum power** for a sinusoidal alternating current.
4. **Tell apart root-mean-square (r.m.s.) and peak values**, and **recall and use** $I_{\text{r.m.s.}} = \dfrac{I_0}{\sqrt{2}}$ **and** $V_{\text{r.m.s.}} = \dfrac{V_0}{\sqrt{2}}$ for a sinusoidal alternating current.
5. **Tell half-wave and full-wave rectification apart on a graph.**
6. **Explain how a single diode gives half-wave rectification.**
7. **Explain how four diodes (a bridge rectifier) give full-wave rectification.**
8. **Analyse how a single capacitor smooths the output**, including the effect of the capacitance and of the load resistance.

Power $P = VI = I^2R = \dfrac{V^2}{R}$ and diodes come from Electricity and D.C. circuits; $\omega = 2\pi f$ and sine graphs from Oscillations; the exponential discharge $V = V_0 e^{-t/RC}$ from Capacitance. The practical advantages of sending power by electricity are assumed from IGCSE.

Understand it

Describing an alternating current

A **direct current** flows one way only. An **alternating current** (a.c.) keeps reversing: it flows one way, then the other, over and over. The mains supply and the output of a generator vary **sinusoidally**:

$$I = I_0 \sin \omega t \qquad V = V_0 \sin \omega t$$

- The **peak value** (I_0 or V_0) is the largest value in either direction: the amplitude.
- The **period** T is the time for one complete cycle.

- The **frequency** f is the number of complete cycles per unit time: $f = \dfrac{1}{T}$, in hertz.
- The **angular frequency** ω (rad s^{-1}) is the number in front of t: $\omega = 2\pi f = \dfrac{2\pi}{T}$. Use radians on your calculator.

So $V = 170\sin(100\pi t)$ has $V_0 = 170$ V and $\omega = 100\pi$ rad s^{-1}, giving $f = 50$ Hz and $T = 0.020$ s. The equation $x = x_0 \sin\omega t$ is on the Paper 4 data sheet. If the graph starts at a peak instead of at zero, the equation is $x = x_0\cos\omega t$: same peak, same period, a quarter-cycle earlier.

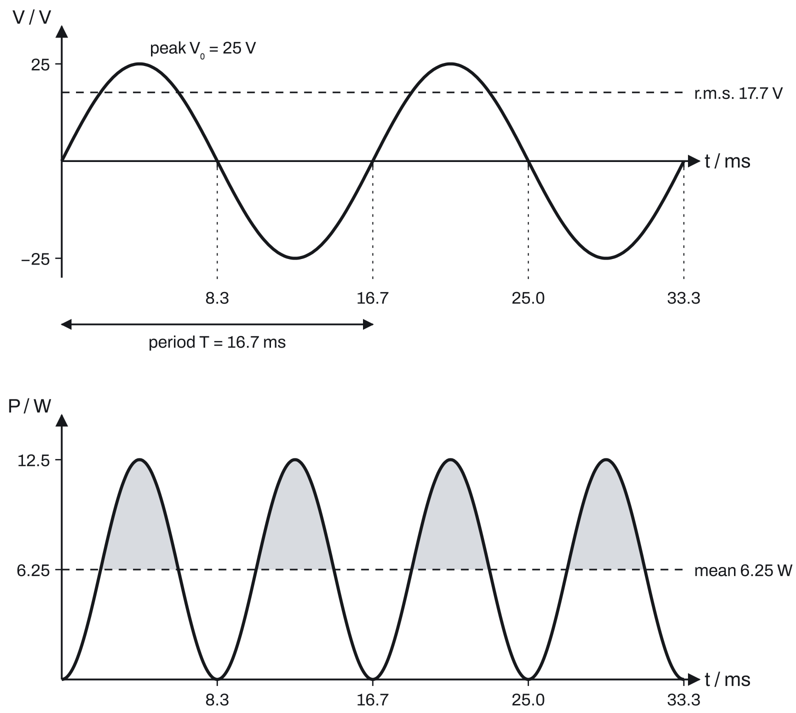
Power in a resistor, and r.m.s. values

The power in a resistor is $P = I^2R = \dfrac{V^2}{R}$. It depends on I^2, so it is **never negative**: the resistor heats up whichever way the current flows. With $V = V_0\sin\omega t$,

$$P = \frac{V_0^2}{R}\sin^2\omega t = P_0\sin^2\omega t$$

where $P_0 = \dfrac{V_0^2}{R} = I_0V_0$ is the **peak power**. The graph of P against t is a smooth $\sin^2$ curve: it sits on the time axis each time V is zero, reaches P_0 at every peak of V (positive **and** negative), so it has **twice the frequency** of V. It is **symmetrical about** $\frac{1}{2}P_0$: the parts above that line exactly fill the gaps below it. So:

$$\langle P\rangle = \tfrac{1}{2}P_0 \qquad \text{(sinusoidal a.c. only)}$$



P = V²/R: always positive, two peaks per period of V

The **root-mean-square (r.m.s.) value** of an alternating current is the **steady (direct) current that would give the same mean power (heating effect) in a resistor**. Likewise for an r.m.s. voltage. It is one fixed value, not something that varies. For a sine wave,

$$I_{\mathrm{r.m.s.}}^2 R = \tfrac{1}{2} I_0^2 R \quad \Rightarrow \quad I_{\mathrm{r.m.s.}} = \frac{I_0}{\sqrt{2}}, \qquad V_{\mathrm{r.m.s.}} = \frac{V_0}{\sqrt{2}}$$

The name says how it is found: the **square root** of the **mean** of the **squares** of the current. Mean power is then $\langle P \rangle = I_{\mathrm{r.m.s.}} V_{\mathrm{r.m.s.}} = I_{\mathrm{r.m.s.}}^2 R = \dfrac{V_{\mathrm{r.m.s.}}^2}{R}$, just like d.c.

Supply voltages are quoted as r.m.s. values. A 230 V, 50 Hz supply has $V_0 = 230\sqrt{2} = 325$ V and $\omega = 2\pi \times 50 = 314$ rad s⁻¹. A 46 Ω heater on it has mean power $\dfrac{230^2}{46} = 1150$ W and peak power 2300 W.

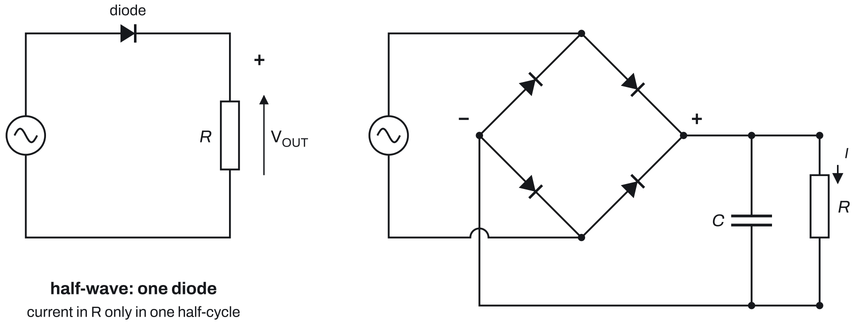
Not a sine wave? $\sqrt{2}$ is only for sinusoids. Find the **mean power** from the P–t graph, then $I_{\mathrm{r.m.s.}} = \sqrt{\dfrac{\langle P \rangle}{R}}$. A square wave switching between $+I_0$ and $-I_0$ gives constant power $I_0^2 R$, so its r.m.s. value is I_0 itself. The **mean** current of any symmetrical a.c. is zero, so the mean is useless for heating; that is why r.m.s. values are used.

Rectification

Rectification is converting alternating current (or voltage) into direct current: an output that is always in one direction. It uses **diodes**, which let current through in one direction only (the way the triangle points) and have a very high resistance the other way. Take the diodes as ideal: no p.d. across them when they conduct.

Half-wave rectification: one diode in series with the load. In the half-cycles when the supply drives current the way the diode points, the diode conducts and the output follows the input. In the other half-cycles the diode blocks, the current is zero and the output is zero. Half of each cycle is **removed**.

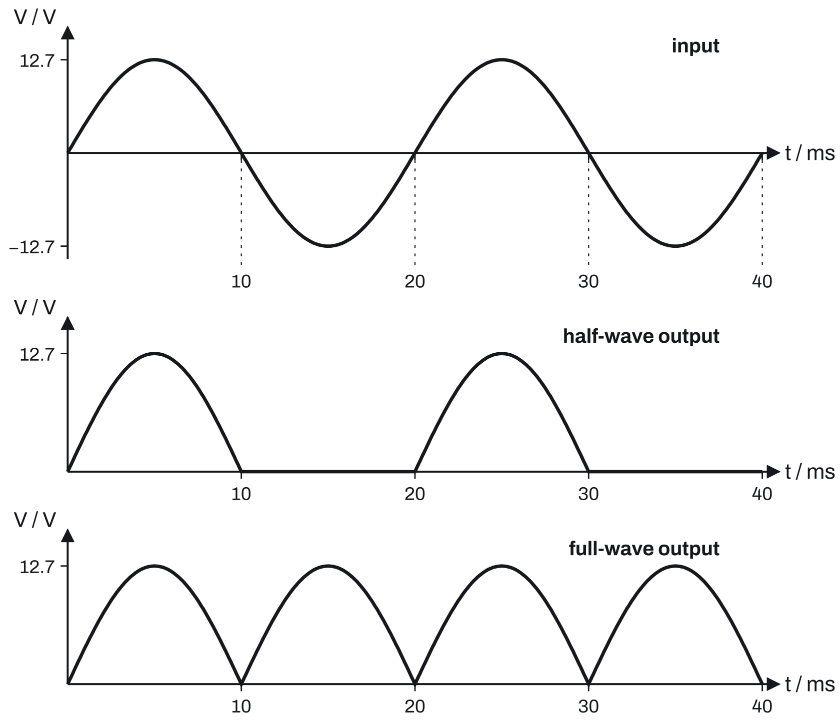
Full-wave rectification: a bridge rectifier of four diodes. The supply connects to two opposite corners of the diamond and the load to the other two. In each half-cycle two diodes conduct, and they send the current through the load **in the same direction**; in the next half-cycle the other two conduct. The negative half-cycles are **reversed** (turned over), not removed.



half-wave: one diode
current in R only in one half-cycle

full-wave: bridge of four diodes (+ smoothing capacitor C)

Drawing a bridge. Every diode at the **positive** output corner points **towards** it; every diode at the **negative** output corner points **away** from it. So going round the diamond, the diodes on the left pair and the right pair "point the same way" (all four towards the + side). Check it: with the top input corner positive, current goes through the top-right diode, down through R, back through the bottom-left diode to the bottom corner. With the bottom corner positive, it goes through the bottom-right diode, down through R **the same way**, and back through the top-left diode. The current in the load always flows from the + terminal through the load to the – terminal.



Power after rectification. The power depends on V^2, so turning a half-cycle over changes nothing:

- **Full-wave**: the P–t graph is **identical** to the unrectified one, so $\langle P \rangle = \frac{1}{2} P_0$ and $V_{\text{r.m.s.}} = \frac{V_0}{\sqrt{2}}$, the same as the supply.
- **Half-wave**: every other hump of power is missing, so $\langle P \rangle = \frac{1}{2} \times \frac{1}{2} P_0 = \frac{1}{4} P_0$ and $V_{\text{r.m.s.}} = \sqrt{\frac{1}{4}}\, V_0 = \dfrac{V_0}{2}$.

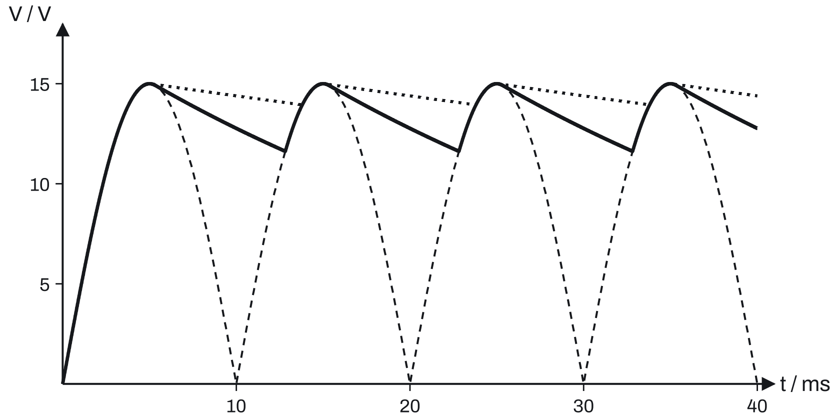
The full-wave output has humps at **twice the supply frequency** (a 50 Hz supply gives 100 humps per second); the half-wave output has one hump per supply cycle.

Smoothing with a capacitor

A rectified output is in one direction but still rises and falls. A **capacitor in parallel with the load** smooths it:

1. While the output rises to its peak, the capacitor **charges** to the peak voltage V_0.
2. As the rectified voltage falls away, the diodes stop conducting and the capacitor **discharges through the load resistor**, keeping the current flowing the same way. The output falls **exponentially**: $V = V_0 e^{-t/RC}$.
3. When the next hump rises above the capacitor's voltage, the diodes conduct again and recharge it to V_0.

The output is now a "saw-tooth" of slow exponential falls and quick rises: a small **ripple** on an almost steady voltage. Smoothing **raises** the mean output voltage; it doesn't lower it.



The ripple depends on the **time constant** $\tau = RC$ compared with the time between peaks:

- **Larger** C or **larger load resistance** R: larger τ, slower discharge, **smaller ripple** (smoother, higher mean output).
- **Smaller** C or R (a load taking more current): more ripple.
- **Full-wave** output is easier to smooth than half-wave: the capacitor only has to hold up for half as long between peaks.

For example, with $\tau = 0.10$ s, a 12 V peak falls for 8.0 ms to $12e^{-0.008/0.10} = 11.1$ V.

Key facts and formulas

"Given" means it is on the Paper 4 data sheet. "Learn it" means you must remember it.

Formula	Status
Alternating current or voltage $x = x_0 \sin \omega t$	Given
$\omega = 2\pi f = \dfrac{2\pi}{T}$, $f = \dfrac{1}{T}$	Learn it
$I_{\text{r.m.s.}} = \dfrac{I_0}{\sqrt{2}}$, $V_{\text{r.m.s.}} = \dfrac{V_0}{\sqrt{2}}$ (sinusoidal only)	Learn it
Mean power $\langle P \rangle = \frac{1}{2}P_0$ (sinusoidal); $\langle P \rangle = I_{\text{r.m.s.}}V_{\text{r.m.s.}} = I_{\text{r.m.s.}}^2 R = \dfrac{V_{\text{r.m.s.}}^2}{R}$	Learn it
Peak power $P_0 = I_0 V_0 = I_0^2 R = \dfrac{V_0^2}{R}$	Learn it
Half-wave rectified sinusoid: $\langle P \rangle = \frac{1}{4}P_0$, $V_{\text{r.m.s.}} = \dfrac{V_0}{2}$	Learn it
Capacitor discharge $x = x_0 e^{-t/RC}$	Given
Time constant $\tau = RC$	Learn it
Energy in a capacitor $W = \frac{1}{2}CV^2$	Learn it

How to do it

In the Paper 4 questions we have tagged for this topic (19 different questions, 2021–2025; 8 more appear on two papers), the types came up this often. 16 of the 19 questions mix two or more types, so the counts add up to more than 19.

Question type	Questions
R.m.s. values and mean power	14
Rectification: circuits and output graphs	13
The sinusoidal equation, period and sketching	10
Definitions and short statements	9
Smoothing with a capacitor	8

1. R.m.s. values and mean power (14 questions)

1. **Peak or r.m.s.?** Equations and graphs give **peak** values; "the supply is 9.0 V" or "r.m.s." means r.m.s. Convert with $\sqrt{2}$ (sinusoids only).
2. **Peak power**: $P_0 = \dfrac{V_0^2}{R}$ (from the **peak** voltage).
3. **Mean power**: $\frac{1}{2}P_0$, or $\dfrac{V_{\text{r.m.s.}}^2}{R}$; for half-wave, $\frac{1}{4}P_0$.
4. **Back to r.m.s.**: $V_{\text{r.m.s.}} = \sqrt{\langle P \rangle R}$, $I_{\text{r.m.s.}} = \sqrt{\dfrac{\langle P \rangle}{R}}$.

Variations you will meet:

- **Sketch P against t**: a $\sin^2$ shape with **smooth, rounded troughs sitting on the time axis** (not the sharp V-shaped troughs of $|\sin|$), peaks at P_0, and **half the period** of V. Mark the peak value and the times of the zeros.
- **"Use your graph to explain why the mean power is $\frac{1}{2}P_0$"**: the curve is **symmetrical about $\frac{1}{2}P_0$**; the areas above and below that line are equal.
- **Reading a power graph**: its peak is P_0; its period is half the supply's. With V_0 known, $R = \dfrac{V_0^2}{P_0}$ and $I_0 = \dfrac{P_0}{V_0}$. A graph with peaks of 40 W for $V_0 = 20$ V gives $R = 10$ Ω, $I_0 = 2.0$ A and mean power 20 W. Humps with no gaps: no rectification or full-wave; gaps of zero power between humps: half-wave.
- **A non-sinusoidal current** (square or stepped): find the power in each part, I^2R, average over one period weighting by time, then $I_{\text{r.m.s.}} = \sqrt{\langle P \rangle / R}$. Never divide by $\sqrt{2}$ here.
- **Show that the mean power is half the peak**: compute I_0^2R and $I_{\text{r.m.s.}}^2R$ with numbers and compare.
- **Rectified vs not**: full-wave rectifying doesn't change the P–t graph, so the mean power and r.m.s. value are **unchanged**; say why: power depends on V^2, not the sign of V.

- **A generator coil turned faster**: the rate of change (cutting) of flux linkage doubles when the speed doubles, so the peak and r.m.s. e.m.f. double **and** the period halves. Joining a resistor across it lets a current flow; the forces on the current oppose the rotation and the kinetic energy becomes thermal energy in the resistor, so a freely turning coil slows down and stops.

2. Rectification: circuits and output graphs (13 questions)

1. **Name it**: one diode is **half-wave**; a bridge of four diodes is **full-wave**. Always include the word "wave".
2. **Complete a bridge**: every diode points **towards** the positive output corner and **away** from the negative one; copy the direction of any diode already drawn. Use the proper diode symbol (triangle and bar), not a logic gate.
3. **Mark the polarity or current**: the + output is the corner both diodes point to; in the load, current goes from + to −.
4. **Sketch the output**: half-wave, alternate humps with **zero** between them; full-wave, a hump every **half** supply period, touching zero between humps, never negative. Keep the peak at V_0 and the input's timing.

Variations you will meet:

- **Complete a half-wave circuit**: one diode in series in one lead, the other lead a plain wire.
- **Difference between them**: half-wave **removes** the voltage in one direction; full-wave **reverses** it.
- **A square-wave input**: half-wave gives $+V_0$ for half the time and 0 for the other half; full-wave gives a **steady** V_0, because both halves have the same size.
- **Mean power after rectifying**: full-wave $\frac{1}{2}P_0$, half-wave $\frac{1}{4}P_0$. A supply of maximum power 16 W gives 8.0 W and 4.0 W.

3. The sinusoidal equation, period and sketching (10 questions)

1. **Read the equation**: in $V = V_0 \sin \omega t$, the peak is V_0 and ω is the number multiplying t.
2. **Period**: $T = \dfrac{2\pi}{\omega}$; frequency $f = \dfrac{\omega}{2\pi}$.
3. **From a graph to an equation**: read V_0 and T, then $\omega = \dfrac{2\pi}{T}$ and write the equation **with numbers**: a peak of 5.0 V and period 8.0 ms give $\omega = \dfrac{2\pi}{0.0080} = 785$ rad s^{-1} (250π), so $V = 5.0 \sin(785t)$. Use cos if the graph starts at a peak.
4. **Sketch**: a smooth sine (or cosine) curve, the right number of cycles, peaks at $\pm V_0$.

Variations you will meet:

- **"Show that the period is ..."**: write $T = \dfrac{2\pi}{\omega}$ with the numbers in, and one more significant figure than printed.
- **Label axis scales**: at least two values on each axis; one peak-to-peak spacing on a full-wave graph is **half** a period of the supply.
- **Find ω (or "k") from a frequency**: $2\pi \times 50 = 314$ rad s^{-1}; give the significant figures asked.

- **Resistance from mean power and a supply equation**: $R = \dfrac{V_0^2}{2\langle P\rangle}$.

4. Definitions and short statements (9 questions)

- **Frequency**: the number of complete cycles (oscillations) per unit time.
- **Peak value**: the maximum value of the current or voltage (in either direction).
- **R.m.s. value**: the **steady (direct) current or voltage** that produces the **same mean power (heating effect)** in a resistor as the alternating one.
- **Rectification**: the conversion of **alternating** current or voltage into **direct** current or voltage.
- **Purpose (or effect) of the capacitor**: **smoothing**: it reduces the variation of the output voltage.
- **Purpose of a diode circuit**: rectification, naming the type (half-wave or full-wave).

5. Smoothing with a capacitor (8 questions)

1. **Connect it**: the capacitor goes **in parallel with the load resistor** (across the output), never in series or on the input side.
2. **Sketch it**: from each peak draw a **downward curve** (exponential decay, getting less steep) until it meets the next rising hump, then follow the hump up to the peak. Show the drop the question states (for example 10% of V_0).
3. **Time constant from a graph**: take two points on **one** discharge curve, V_0 and V, and the **time between them** t; then $V = V_0 e^{-t/\tau}$ gives $\tau = \dfrac{t}{\ln(V_0/V)}$. From 12.0 V to 10.0 V in 6.0 ms, $\tau = \dfrac{6.0}{\ln 1.2} = 32.9$ ms.
4. **Then R or C**: $\tau = RC$.

Variations you will meet:

- **Minimum voltage**: $V_{\min} = V_0 e^{-t/RC}$ with t the discharge time.
- **The drop given as a percentage**: a ripple of 33% of the peak means $V_{\min} = 0.67V_0$. If the discharge time isn't given, find it from the graph: it runs from one peak until the next hump rises back to $V_{\min}$, a little less than the gap between peaks. On a full-wave graph that rises as $V_0|\cos|$, the rise from $V_{\min}$ to the peak takes $\dfrac{\cos^{-1}(V_{\min}/V_0)}{2\pi}$ of a supply period.
- **Capacitance from stored energy**: $W = \frac{1}{2}CV_0^2$ at the peak, so $C = \dfrac{2W}{V_0^2}$.
- **Change R or C**: state the effect on τ and then on the ripple: bigger RC, slower discharge, smaller ripple, higher mean output.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

A sinusoidal alternating voltage V, in volts, varies with time t, in seconds, as $V = 25\sin(120\pi t)$. It is connected across a resistor of resistance $50\ \Omega$.

(a) State what is meant by the root-mean-square value of an alternating voltage. **[2]**

(b) Calculate the frequency and the period of the voltage. **[2]**

(c) Calculate V at $t = 2.0$ ms. **[1]**

(d) Calculate the r.m.s. voltage and use it to show that the mean power in the resistor is half the peak power. **[3]**

(e) Describe the graph of the power P in the resistor against t for one period of V. **[2]**

Solution

(a) The steady (direct) voltage **M1** that would produce the same mean power in a resistor as the alternating voltage. **A1**

(b) $\omega = 120\pi$, so $f = \dfrac{120\pi}{2\pi} = 60$ Hz **A1** and $T = \dfrac{1}{60} = 0.0167$ s (16.7 ms). **A1**

(c) $V = 25\sin(120\pi \times 0.0020) = 17.1$ V (calculator in radians). **A1**

(d) $V_{\text{r.m.s.}} = \dfrac{25}{\sqrt{2}} = 17.7$ V. **C1** Peak power $= \dfrac{25^2}{50} = 12.5$ W; mean power $= \dfrac{V_{\text{r.m.s.}}^2}{R} = \dfrac{(25/\sqrt{2})^2}{50} = 6.25$ W, **M1** which is $\frac{1}{2} \times 12.5$ W. **A1**

(e) A $\sin^2$ curve, never negative, with smooth troughs on the time axis at $t = 0$, 8.33 ms and 16.7 ms **B1**, and two peaks of 12.5 W in the period (see the first diagram). **B1**

Example 2

A current in a $20\ \Omega$ resistor is $+3.0$ A for the first third of each period and -1.0 A for the other two-thirds.

(a) Calculate the power in the resistor during each part of the cycle. **[2]**

(b) Calculate the mean power and the r.m.s. current. **[3]**

(c) A student says the r.m.s. current is $\dfrac{3.0}{\sqrt{2}}$ A. Explain why this is wrong. **[1]**

Solution

(a) $P = I^2R$: $3.0^2 \times 20 = 180$ W **A1** and $1.0^2 \times 20 = 20$ W. **A1**

(b) $\langle P \rangle = 180 \times \frac{1}{3} + 20 \times \frac{2}{3} = 60 + 13.3 = 73.3$ W. **C1 A1** $I_{\text{r.m.s.}} = \sqrt{\dfrac{73.3}{20}} = 1.91$ A. **A1**

(c) Dividing by $\sqrt{2}$ only applies to a sinusoidal current; this one is not sinusoidal. **B1** (Its mean current is $3.0 \times \frac{1}{3} - 1.0 \times \frac{2}{3} = 0.333$ A, which is a different quantity again.)

Example 3

A sinusoidal supply of r.m.s. voltage 9.0 V and frequency 50 Hz is connected to a 30 Ω load resistor through a single ideal diode.

(a) State the type of rectification and draw the circuit. **[2]**

(b) Calculate the peak power in the resistor. **[2]**

(c) Determine the mean power and the r.m.s. voltage across the resistor. **[3]**

(d) The diode is replaced by a bridge rectifier. State the mean power now, and how many humps of output voltage there are each second. **[2]**

Solution

(a) Half-wave. **B1** Supply, diode and resistor in series (left of the second diagram). **B1**

(b) $V_0 = 9.0\sqrt{2} = 12.7$ V **C1**; $P_0 = \dfrac{12.7^2}{30} = 5.40$ W. **A1**

(c) Power flows only in alternate half-cycles, and the mean within each hump is $\frac{1}{2}P_0$, **M1** so $\langle P \rangle = \frac{1}{4} \times 5.40 = 1.35$ W. **A1** $V_{\text{r.m.s.}} = \sqrt{1.35 \times 30} = 6.36$ V ($= \frac{V_0}{2}$). **A1**

(d) Full-wave: $\langle P \rangle = \frac{1}{2}P_0 = 2.70$ W (the r.m.s. voltage is back to 9.0 V). **B1** 100 humps per second, twice the supply frequency. **B1**

Example 4

The output of a bridge rectifier connected to a 50 Hz supply has a peak of 15 V. It is applied to a 2.2 kΩ load resistor, and a 100 μF capacitor is added to smooth it.

(a) State where the capacitor is connected. **[1]**

(b) Calculate the time constant. **[1]**

(c) The capacitor discharges for 9.1 ms in each cycle. Calculate the minimum output voltage and the ripple (the difference between maximum and minimum). **[3]**

(d) The bridge is replaced by a single diode, and the capacitor now discharges for 17.5 ms each cycle. Calculate the new minimum voltage. **[1]**

(e) State and explain the effect on the smoothed output of using a load resistor of larger resistance. **[2]**

Solution

(a) In parallel with the load resistor, across the output. **B1**

(b) $\tau = RC = 2.2 \times 10^3 \times 100 \times 10^{-6} = 0.22$ s. **A1**

(c) $V = V_0 e^{-t/RC} = 15e^{-0.0091/0.22}$ **C1** $= 14.4$ V. **A1** Ripple $= 15 - 14.4 = 0.61$ V. **A1**

(d) $V = 15e^{-0.0175/0.22} = 13.9$ V (a ripple of 1.15 V, nearly twice as big). **A1**

(e) The time constant RC increases, so the capacitor discharges more slowly **M1**: the ripple is smaller and the mean output voltage higher. **A1**

Common mistakes

- **Mixing up peak, r.m.s. and mean.** In June 2021, March 2022 and November 2022 many used the r.m.s. voltage for peak power, or the peak voltage with the mean power (giving twice the right resistance), or gave peak power when mean power was asked. Label every value V_0, $V_{\text{r.m.s.}}$, P_0 or $\langle P \rangle$ as you write it.
- **Dividing a square wave by $\sqrt{2}$.** June 2021: $\sqrt{2}$ is for sine waves only. Use the heating definition: find the mean power.
- **Wrong r.m.s. definition.** June 2021 and November 2021: r.m.s. is a **steady** current or voltage with the **same heating effect**, not an average or a peak, and it doesn't vary. Quoting $\frac{V_0}{\sqrt{2}}$ is not a definition.
- **Drawing $|\sin|$ for power.** November 2021, November 2022 and June 2023: the P–t graph has smooth rounded troughs touching the axis ($\sin^2$), not sharp V-shaped ones, and it is not the same shape as the rectified voltage graph. Without the right shape you can't explain the half-power result from its symmetry.
- **Not rectifying.** March 2021 and June 2023: weaker answers drew an ordinary sine wave for a rectified output.
- **Equation without numbers.** March 2022: writing $V = V_0 \sin \omega t$ earns nothing; put in the values of V_0 and ω.
- **Capacitor in the wrong place.** March 2021 and June 2022: in series, or on the input side. It goes across the load.
- **Smoothing sketches and times.** June 2022: discharge lines curving upwards or straight, and the stated drop not shown. June 2022 and June 2023: using a clock reading (the time at the end of the discharge) instead of the **time interval** of the discharge. June 2023: a capacitor does **not** lower the output; it raises the mean.
- **One label is not a scale.** June 2022: put at least two numbers on each axis, and remember one full-wave hump is only half a supply period.
- **Diode drawn wrong.** June 2023: a diode, not a NOT gate symbol. Name rectification "half-wave" or "full-wave", with the word "wave" (June 2022).

How to get the marks

- **Definitions**: the bold phrases in type 4 are the marks. For r.m.s., "steady" and "same power (heating) in a resistor" are both needed.
- **"Show that"**: write the formula ($T = \frac{2\pi}{\omega}$, $P = \frac{V^2}{R}$), substitute, and give more significant figures than the printed value.
- **"Use your graph to explain"**: refer to the graph itself: its symmetry about $\frac{1}{2}P_0$, its gaps, or its values.
- **"State three conclusions" from a graph**: each conclusion is a mark: the type of rectification, the peak and mean power, the resistance, peak or r.m.s. current, and the period or frequency of the output. Give numbers with units.
- **Sketches**: shape, timing (zeros and peaks at the right times, the right number of cycles) and values (peaks labelled) each earn a mark. Keep the curve smooth.
- **Circuit completions**: correct symbols **and** correct directions are separate marks; a capacitor must be clearly in parallel with the resistor.
- **Calculations**: the **C1** is for the right equation with numbers in; the **A1** is the answer to 2 or 3 significant figures, or the number asked. Convert kΩ, μF and ms first.
- **"State and explain the effect"**: say what changes (the time constant) **and** what that does (ripple smaller or larger, mean output higher or lower).

Quick check

1. A current is given by $I = 4.0\sin(314t)$, with I in A and t in s. State its peak value and calculate its r.m.s. value and frequency.
2. An electric kettle has a mean power of 2300 W on a 230 V r.m.s. supply. Calculate its peak power, the r.m.s. and peak currents, and its resistance.
3. A square-wave voltage switches between $+6.0$ V and -6.0 V across a 12 Ω resistor. State its r.m.s. value and calculate the mean power. It is then half-wave rectified: calculate the new mean power and r.m.s. voltage.
4. On a smoothed output the voltage falls from 10.0 V to 9.0 V in 8.0 ms. Calculate the time constant, and the capacitance if the load is 1.5 kΩ.
5. A bridge rectifier has one diode drawn, pointing towards the right-hand output terminal. Which output terminal is positive, and which way do the other three diodes point?

Answers

1. $I_0 = 4.0$ A; $I_{\text{r.m.s.}} = \dfrac{4.0}{\sqrt{2}} = 2.83$ A; $f = \dfrac{314}{2\pi} = 50$ Hz.
2. Peak power $= 2 \times 2300 = 4600$ W. $I_{\text{r.m.s.}} = \dfrac{2300}{230} = 10$ A, $I_0 = 10\sqrt{2} = 14.1$ A, $R = \dfrac{230}{10} = 23\,\Omega$.
3. The power is $\dfrac{6.0^2}{12} = 3.0$ W all the time, so $V_{\text{r.m.s.}} = 6.0$ V and $\langle P \rangle = 3.0$ W. Half-wave: 3.0 W for half the time, so $\langle P \rangle = 1.5$ W and $V_{\text{r.m.s.}} = \sqrt{1.5 \times 12} = 4.24$ V.
4. $\tau = \dfrac{8.0 \times 10^{-3}}{\ln(10.0/9.0)} = 0.0759$ s (75.9 ms); $C = \dfrac{0.0759}{1.5 \times 10^3} = 5.06 \times 10^{-5}$ F (50.6 μF).
5. The right-hand terminal is positive (current leaves the bridge there). The other diode at that corner also points towards it, and both diodes at the left-hand terminal point away from it: all four point towards the + side.

Past questions to try

- **9702/42/O/N/24 Q8**: frequency, period from an equation, a sketch, and showing mean power is half the peak.
- **9702/43/O/N/23 Q7**: a stepped current: power in each part, mean power and the r.m.s. current.
- **9702/43/M/J/22 Q5**: a bridge's polarity, axis scales from the equation, and a capacitor from a 10% ripple.
- **9702/42/M/J/23 Q7**: completing a bridge, and the power–time graph of a full-wave output.