6(a)(i)	conversion of a.c. to d.c.	**B1**

6(a)(ii)	full-wave (rectification)	**B1**

6(a)(iii)	three diodes with correct symbols connected into the circuit	**B1**
	lower-left diode shown pointing towards the right **and** upper-left and lower-right diodes both shown pointing towards the left	**B1**

6(b)(i)	$\omega = 18$ (rad s^{-1})	**C1**
	$T = 2\pi / 18 = 0.35$ s	**A1**

6(b)(ii)	$V_{r.m.s.} = 34 / \sqrt{2}$ $= 24$ V	**A1**

6(b)(iii)	sinusoidal 'humps' with minimum $V_{OUT} = 0$ and non-zero V_{OUT} all same sign	**B1**
	peak V_{OUT} shown as 34 V **or** –34 V	**B1**
	two 'humps' shown, with V_{OUT} always with same sign **and** $V_{OUT} = 0$ at $t = 0$, $t = 0.175$ s and $t = 0.350$ s **and** non-zero in between	**B1**

6(c)(i)	correct circuit symbol for capacitor, connected in parallel with resistor	**B1**

6(c)(ii)	time constant = RC	**C1**
	$= 56 \times 10^{3} \times 12 \times 10^{-6}$ $= 0.67$ s	**A1**

6(c)(iii)	V_{min} = 34 exp (–0.14 / 0.67)	**C1**
	= 28 V	**A1**

Question 6

(a) (i) Most candidates gave the correct answer.

(ii) Most candidates gave the correct answer.

(iii) Some candidates drew correct diode symbols but did not show them connected into the circuit. A significant minority of candidates had incorrect orientations of one or more of the diodes.

(b) (i) Most candidates gained full credit. As always with a 'show that' question, credit is not awarded for the numerical answer, but for showing the working that leads to the answer. The full substitution $T = 2\pi/18$ was required for a complete answer.

(ii) Most candidates gave the correct answer.

(iii) Most candidates gained full credit, but some candidates showed inaccurate peak values and some weaker candidates drew unrectified waveforms.

(c) (i) The majority of the candidates gave the correct answer. Many candidates placed the capacitor connected in parallel with V_{IN} and a small number drew a symbol which was more like the symbol for a cell.

(ii) Most candidates gave the correct answer.

(iii) Most candidates gave the correct answer. A common mistake was to substitute the r.m.s. voltage instead of the peak voltage into the correct equation.

7(a)(i)	$T = 2\pi / 40\pi = 0.050$ s	**A1**

7(a)(ii)	$V_{\text{r.m.s.}} = 18 / \sqrt{2}$ $= 13$ V	**A1**

7(b)	sinusoidal curve of period 50 ms from $t = 0$ to $t = 100$ ms	**B1**
	correct phase (V_{MAX} at $t = 0$, 50, 100 ms and $-V_{\text{MAX}}$ at 25, 75 ms etc.)	**B1**
	maximum and minimum voltages shown as ± 18 V	**B1**

7(c)	*Any three points from*: • rectification is full-wave • mean power = 14 W • resistance of R = 12 Ω • peak current in R = 1.6 A **or** r.m.s. current in R = 1.1 A • period of <u>output</u> voltage / power = 25 ms ***or*** frequency of <u>output</u> voltage / power = 40 Hz **or** angular frequency of <u>output</u> voltage / power = 250 rad s^{-1}	**B3**

Question 7

(a) Both parts of this question were well answered by most candidates.

(b) The main challenges with drawing the sketch graph (aside from the skill of being able to draw a sinusoidal variation) were establishing the correct phase and the correct amplitude. Common errors were to draw sine curves rather than cosine curves, and to draw curves with an amplitude of 16 V rather than 18 V.

(c) It is important for candidates to understand, when answering this type of open question about conclusions that may be drawn from a graphical representation, that there is no credit available for simply describing the graphs. Credit is available for doing something with the data that goes beyond simply reading a value from the axis. There were many ways in which candidates could access credit for this question.

One common misconception concerns using the phrase ‘r.m.s. power’ to describe mean power. Whilst determining r.m.s power is beyond the expectations of the syllabus (given that it involves integrating a $\sin^4 \theta$ function and in any case has no physical significance), candidates ought to appreciate that the mean value of a variation and the r.m.s. value of a variation are different concepts. For a.c. power, the quantity that candidates are expected to know about is mean power.

8(a)	four diodes shown (one in each gap) with correct circuit symbols	**B1**
	all four diodes connected in correct direction (pointing left to right)	**B1**

8(b)(i)	three lines showing exponential decay from the peaks at 0.5*T*, 1.0*T* and 1.5*T*, ending at the point where the decay meets the next rising peak	**B1**
	three curved lines rising along the upwards dotted lines from the minima to the peaks at 1.0*T*, 1.5*T* and 2.0*T*	**B1**
	minimum V at $(2/3)\ V_0$	**B1**

8(b)(ii)	from graph: discharge time (from V_0 to $(2/3)V_0$) = $(11/30)\ T$	**C1**
	$(2/3)\ V_0 = V_0 \exp(-(11/30)T/\tau)$	**C1**
	$\ln(2/3) = -11T/30\tau$ $\tau = 0.90\ T$	**A1**

8(b)(iii)	time constant is increased	**B1**
	line shows a larger minimum voltage **or** smaller difference between maximum and minimum voltages	**B1**

Question 8

(a) The four diodes were correctly and carefully drawn by most candidates. The correct diode directions were identified less often, and incomplete connections to the diodes were occasionally seen.

(b) (i) Many candidates of all abilities drew an incomplete graph, omitting the charging section of the curve from the minima to the peaks. The decay sections of the graph curved the correct way in most answers. More careful reading of the question might have prevented the incorrect choice of $V_0 / 3$ as the minimum voltage.

(ii) This question highlighted the importance of showing every step of the working clearly. Here, evidence of the derivation of the decay period from the graph was often missing. This meant that, if the final answer was also incorrect, there was no opportunity to award credit for the working.

(iii) Stronger candidates were able to identify both that the time constant increased and that this reduced the difference between minimum and maximum output voltage. Weaker candidates often wrongly implied that the output voltage was always increased (including the maximum V_0).

8(a)(i)	half-wave (rectification)	**B1**

8(a)(ii)	$V_0 = 6.0 \times \sqrt{2}$ $= 8.5\ \text{V}$	**A1**

8(b)(i)	$P = V^2 / R$	**C1**
	$P_0 = 8.5^2 / 45$ $= 1.6\ \text{W}$	**A1**

8(b)(ii)	two humps of width $0.5T$ and two sections of zero power of width $0.5T$	**B1**
	all humps drawn have width $0.5T$, minima at $P = 0$ and peaks at $P = P_0$	**B1**
	correct sinusoidal shape, with smooth troughs sitting on t-axis at $P = 0$	**B1**

8(b)(iii)	mean power within each hump is $\frac{1}{2}P_0$ from the symmetry of the curve	**B1**
	additional half factor from removal of half of the power in each cycle	**B1**

8(b)(iv)	$\langle P \rangle = V_{\text{r.m.s.}}{}^2 / R$ $V_{\text{r.m.s.}} = \sqrt{[(1.6 / 4) \times 45]}$ $= 4.2\ \text{V}$	**A1**

Question 8

(a) (i) Most candidates were able to identify the type of rectification as half-wave from the circuit in Figure 8.1.

(ii) This question was generally well answered, with most candidates able to calculate the peak value of a sinusoidal alternating voltage from its r.m.s. value.

(b) (i) Again this question was generally well answered, with most candidates able to use the peak voltage correctly with $P = V^2 / R$ to calculate the peak power.

(ii) Whilst most candidates were able to achieve at least partial credit for this graph, full credit was relatively rare. The two common mistakes were to draw the power–time graph for full-wave rectification rather than for half-wave rectification, and to not draw the correct shaped curve, particularly in the region close to the time axis. Most of the graphs seen, whether full- or half-wave rectified, were based on $|\sin|$ curves rather than $\sin^2$ curves, without smooth troughs at the base.

(iii) This was a challenging question that required candidates to explain the two relevant $\times\frac{1}{2}$ factors, one from the symmetry of the non-zero power sections giving a mean power of $\frac{1}{2}P_0$ within those sections, and the other from the removal of half of the power by the half-wave rectification. Common misconceptions were that the whole power–time graph was symmetrical about $\frac{1}{4}P_0$, and that the effect of half-wave rectification was to halve the peak power.

(iv) Candidates who understood the concept of r.m.s. voltage were able to use the information that the mean power is a quarter of the peak power together with their value of the peak power to calculate the correct r.m.s. voltage. Many candidates found this question challenging.

6(a)(i)	conversion from a.c. to d.c.	**B1**

6(a)(ii)	smoothing	**B1**

6(b)(i)	$A = 12\,\text{V}$	**A1**
	$B = 2\pi / (20 \times 10^{-3})$ $= 310\,\text{rad s}^{-1}$	**A1**

6(b)(ii)	full-wave (rectification)	**B1**

6(b)(iii)	four diodes shown, with correct circuit symbols	**B1**
	four diodes correctly connected to form a bridge rectifier	**B1**

6(b)(iv)	$V = V_0 \exp(-t / \tau)$ **or** $V = V_0 \exp(-t / RC)$ **and** $\tau = RC$	**C1**
	$8.0 = 12 \exp(-7.3 \times 10^{-3} / \tau)$	**C1**
	$\tau = 0.018\,\text{s}$	**A1**

6(c)	time constant = RC	**C1**
	$R = (0.018 / 570 \times 10^{-6})$ $= 32\,\Omega$	**A1**

Question 6

(a) (i) Most candidates gave the correct answer.

(ii) Most candidates gave the correct answer.

(b) (i) Most candidates gave the correct answer for *A*, but many candidates left the answer for *B* as a multiple of π rather than calculating the numerical answer.

(ii) Most candidates gave the correct answer.

(iii) Most candidates had the correct symbols for four diodes, but only the strongest candidates drew a circuit diagram which would work as a full-wave rectifier, with all of the diodes in the correct orientation.

(iv) Most candidates knew the correct starting equation(s). Many candidates substituted times which were larger than the discharge time shown in Fig. 6.2. Some weaker candidates made a power-of-ten error.

(c) Most candidates gave the correct answer, including those given credit on the basis of an error carried forward from **(b)(iv)**.

8(a)	number of cycles per unit time	**B1**

8(b)(i)	period = $2\pi / 40\pi$ = 0.050 s = 50 ms	**A1**

8(b)(ii)	sinusoidal curve, starting at (0, 0) and initially increasing from there	**B1**
	periodic line showing 2 cycles with period 50 ms from $t = 0$ to $t = 100$ ms	**B1**
	all peaks shown at $I = +3.5$ A and all troughs shown at $I = -3.5$ A	**B1**

8(b)(iii)	$I_{r.m.s} = 3.5 / \sqrt{2}$ $= 2.5$ A	**A1**

8(c)	$P = I^2R$	**C1**
	peak power = $3.5^2 \times 680$ (= 8330 W) **or** mean power = $2.47^2 \times 680$ (= 4170 W)	**M1**
	peak and mean powers both calculated correctly, with supporting working, and compared leading to conclusion that mean power is half the peak power	**A1**

Question 8

(a) Candidates found it difficult to define frequency correctly. Common incorrect answers included discussing the number of 'waves' rather than the number of cycles/oscillations, attempting to define a quantity in terms of units, and defining frequency as the reciprocal of period.

(b)(i) This question was generally well answered.

(ii) This was also a well answered question, with many candidates achieving full credit.

(iii) This question was generally well answered.

(c) This was a more demanding question. The aim of the question was to show separately the calculation of the mean and peak powers, from the r.m.s. and peak currents respectively, and then to use them to prove that the mean power is half the peak power. It was common for weaker candidates to take the relationship to be proved as the starting point, and to calculate one of the powers using it. This was not what they were asked to do and could not achieve full credit.

6(a)(i)	conversion (from a.c.) to d.c.	**B1**

6(a)(ii)	half-wave: voltage in one direction is removed	**B1**
	full-wave: voltage in one direction is reversed	**B1**

6(b)(i)	one gap connected by a single diode and other gap connected directly	**B1**
	diode drawn (in a circuit) with correct circuit symbol	**B1**

6(b)(ii)	smoothing	**B1**

6(c)(i)	$E = ½CV^2$	**C1**
	$C = 2 \times 0.041 / 12^2 = 5.7 \times 10^{-4}$ F = 570 μF	**A1**

6(c)(ii)	$8.0 = 12.0 \exp(-0.010 / RC)$	**C1**
	$\ln(8.0 / 12.0) = -0.010 / (R \times 5.7 \times 10^{-4})$	**C1**
	$R = 43\ \Omega$	**A1**

NOT FOUND:

9702_w24_qp_41 EXAMINER REPORT (Qu 6)

7(a)	rectification (of the input voltage)	**M1**
	full-wave	**A1**

7(b)(i)	$P = V^2 / R$ **or** maximum V = 9.0 V	**C1**
	$P_{MAX} = 9.0^2 / 370 = 0.22$ W	**A1**

7(b)(ii)	sinusoidal shape with minima sitting on the time axis	**B1**
	correct frequency and phase, with minima at 0, 0.02, 0.04, 0.06 and 0.08 s and maxima at 0.01, 0.03, 0.05 and 0.07 s	**B1**
	all maxima shown at 0.22 W	**B1**

7(b)(iii)	mean power = peak power / 2 = 0.22 / 2 = 0.11 W	**A1**

7(c)	power–time graph is identical	**B1**
	(so) mean powers are equal	**B1**

Question 7

(a) The majority of candidates recognised that rectification was taking place, but 'full-wave' was not always included in their response. A small number of candidates tried to describe a different circuit that included a capacitor, and therefore wrongly talked about smoothing.

(b) (i) Most candidates recognised that this 'show that' question required full working to be shown.

(ii) The majority of the candidates found it difficult to appreciate the impact of squaring the voltage to produce the sinusoidal shape of the power–time graph, and they repeated a full-wave rectification graph instead. Phase and period were generally incorporated correctly into the sketch graph. Weaker answers showed a lack of precision in the sketching of the curves, resulting in errors in the position of one or more of the maxima. Stronger candidates drew accurate sine waves in general, but often the beginning and end of their sketch graph was that of a 'rectified' rather than sinusoidal shape.

(iii) The correct answer was shown by most candidates. The most common error was to include $\sqrt{2}$ in the calculation.

(c) Stronger candidates were able to describe the independence of power from the current direction across all values of voltage or current, or to indicate the manifestation of that in identical power–time graphs.

4(a)	combined capacitance of parallel capacitors = 30 (μF)	**C1**
	total capacitance $= (1 / 45 + 1 / 30)^{-1}$ $= 18\ \mu\text{F}$	**A1**

4(b)	$E = ½CV^2$	**C1**
	$\Delta E = ½ \times 45 \times 10^{-6}\ (9.6^2 - 8.0^2)$ $= 6.3 \times 10^{-4}\ \text{J}$	**A1**

4(c)(i)	gaps in circuit closed and correct symbol for capacitor shown in parallel with load resistor	**B1**

4(c)(ii)	two correct pairs of values of t and V read off from within same discharge cycle, e.g. (5.0, 4.0) and (13.0, 3.2)	**C1**
	correct substitution of values of V, V_0 and Δt into $V = V_0 \exp(-\Delta t / \tau)$ e.g. $3.2 = 4.0 \exp(-8.0 / \tau)$	**C1**
	$\tau = 36$ ms	**A1**

4(d)(i)	8.0 W	**A1**

4(d)(ii)	4.0 W	**A1**

NOT FOUND:

9702_m24_qp_42 EXAMINER REPORT (Qu 4)

4(a)(i)	amplitude $= \frac{1}{2} \times 7.2 \times 10^{-15}$ $= 3.6 \times 10^{-15}$ m	A1

4(a)(ii)	$\omega = 2\pi / (0.20 \times 10^{-6})$ $= 3.1 \times 10^{7}$ rad s^{-1}	A1

4(a)(iii)	$v_0 = \omega x_0$	C1
	$v_0 = 3.1 \times 10^{7} \times 3.6 \times 10^{-15} = 1.1 \times 10^{-7}$ m s^{-1}	A1

4(b)(i)	$I_0 = nAv_0e$ $= 8.5 \times 10^{28} \times 4.3 \times 10^{-4} \times 1.1 \times 10^{-7} \times 1.60 \times 10^{-19}$	C1
	$= 0.64$ A	A1

4(b)(ii)	sketch: two cycles of sinusoidal curve of amplitude I_0 and period 0.20 μs	B1
	correct phase, with $I = +I_0$ at $t = 0$	B1

4(b)(iii)	equation of form $I = I_0 \cos \omega t$	M1
	value of I_0 used matches answer to **(b)(i)** and value of ω used matches answer to **(a)(ii)** [if **(a)(ii)** and **(b)(i)** correct then $I = 0.64 \cos (3.1 \times 10^{7}\ t)$]	A1

4(b)(iv)	$I_{r.m.s.} = I_0 / \sqrt{2}$ $= 0.64 / \sqrt{2}$ $= 0.45$ A	**A1**

Question 4

(a) (i) This question was generally well answered. Among candidates that did not give the correct answer, the most common mistakes were misreading the scale, omission of the 10^{-15} factor, or forgetting to halve the peak–trough height.

(ii) There was some confusion among weaker candidates between frequency and angular frequency, but otherwise this question was well answered.

(iii) Most candidates knew or were able to deduce the correct relationship between maximum speed and amplitude for simple harmonic motion.

(b) (i) Most candidates realised that a substitution into $I = nAvq$ was required. The common mistake among the more able candidates was a power-of-ten error in the unit conversion for the area. Some of the weaker candidates attempted to square the area, and a small number did not know that the value of q required was the elementary charge.

(ii) Most candidates realised that a sinusoidal curve was required with an amplitude I_0 and a period of 0.20 μs. Many candidates found it difficult to draw the curve with the correct curvature in the different parts of the graph. The stronger candidates were generally able to deduce that the current has the largest magnitude when the electrons are moving with the fastest speed and therefore draw a curve with the correct phase.

(iii) Many candidates found this question difficult. Partial credit was awarded to candidates who substituted their values from **(a)(ii)** and **(b)(i)** into $I = I_0 \sin \omega t$ but, as with **(b)(ii)**, it was generally only the stronger candidates that realised it was a cosine rather than sine equation that was required here.

(iv) This question was generally well answered.

7(a)(i)	$P = I_0^2R$	**A1**

7(a)(ii)	$P = 4I_0^2R$	**A1**

7(b)	sketch: square wave of period T, with P always non-zero	**B1**
	horizontal lines, from 0 to 0.5T and from 1.0T to 1.5T, all at the same level that the scale indicates to be I_0^2R	**B1**
	horizontal lines, from 0.5T to 1.0T and from 1.5T to 2.0T, at a level that is four times higher than the lower lines	**B1**

7(c)(i)	$<P> = (5/2)I_0^2R$	**A1**

7(c)(ii)	$<P> = I_{\text{r.m.s.}}^2R$	**C1**
	$I_{\text{r.m.s.}}^2R = (5/2)I_0^2R$ $I_{\text{r.m.s.}} = \sqrt{(5/2)}\ I_0$	**A1**

NOT FOUND:

9702_w23_qp_41 EXAMINER REPORT (Qu 7)

7(a)(i)	full-wave (rectification)	**B1**
7(a)(ii)	lower left diode shown pointing left	**B1**
	lower right and upper left diodes shown pointing left	**B1**
7(a)(iii)	arrow indicating current direction in resistor to the right	**B1**
7(b)(i)	sketch: periodic line showing minimum $V_{OUT} = 0$ and maximum $V_{OUT} = +V_0$	**B1**
	line showing peak V_{OUT} at $t = 0$, $0.5T$, $1.0T$, $1.5T$ and $2.0T$, with V_{OUT} going to zero half-way in between each peak	**B1**
	line showing correct modulated sine shape	**B1**
7(b)(ii)	sketch: sinusoidal curve with troughs sitting on the time axis	**B1**
	<u>peak</u> power at $t = 0$, $0.5T$, $1.0T$, $1.5T$ and $2.0T$ and zero power half-way in between each peak	**B1**
7(b)(iii)	same power-time graph with or without rectification, so same V_{rms} **or** V^2-time graph is same for both V_{OUT} and V_{IN}, so same V_{rms} **or** power does not depend on sign of V, so same V_{rms}	**B1**

Question 7

(a) (i) Most candidates were able to identify the circuit as producing full-wave rectification.

(ii) A variety of different responses was seen, but most candidates were able to deduce that all three additional diodes must point in the same direction as the one printed in the diagram.

(iii) More candidates responded correctly than incorrectly, although a significant number of candidates offered no response to this question.

(b) (i) Many correct graphs were seen, with the award of full credit being common among the stronger candidates. Many of the weaker candidates drew graphs that showed no rectification.

(ii) The difference between the rectified voltage–time graph and the power–time graph is not understood by many candidates. Many candidates drew graphs that had the same shape as the answer to **(b)(i)**. Candidates cannot appreciate the reason why the mean power is half the peak power for sinusoidal a.c. without knowing the correct shape for the power–time graph.

(iii) Candidates found this a very challenging question. Whilst many candidates did correctly conclude that the r.m.s. voltages are equal, most found it difficult to adequately articulate the reason why this is the case.

5(a)(i)	correct circuit symbol for a diode shown correctly connected in series with the wires leading into and out of the dotted box	**B1**

5(a)(ii)	smoothing / V_{OUT} is smoothed	**B1**

5(b)(i)	frequency = 1 / 0.04 = 25 Hz	**A1**

5(b)(ii)	$V = V_0 \exp(-t/RC)$ **and** $\tau = RC$ **or** $V = V_0 \exp(-t/\tau)$	**C1**
	$3.25 = 5.50 \exp(-0.020/\tau)$ leading to $\tau = 0.038$ s	**A1**

5(b)(iii)	$\tau = RC$	**C1**
	capacitance = 0.038 / 14000 $= 2.7 \times 10^{-6}$ F	**A1**

5(c)	V_{IN} has constant magnitude in both positive and negative directions	**B1**
	(so) V_{OUT} is (now) constant / V_{OUT} does not vary with time	**B1**

Question 5

(a) (i) The majority of the candidates knew that the component was a diode and correctly drew the symbol. There were a few other components drawn, such as cells. There was some confusion between a NOT gate (which is not a symbol required by the syllabus) and a diode.

(ii) Whilst most candidates knew that the purpose of the capacitor was to smooth the output voltage, some were under the impression that the capacitor would decrease the output voltage. This may have come from thinking about the exponential curve seen for the discharge of a capacitor. In fact the capacitor increases the average V_{OUT}.

(b) (i) Most candidates correctly determined the frequency of the supply.

(ii) Many candidates were able to use the exponential formula to show the value of the time constant. Some used the total time elapsed (0.04 s) rather than the time interval (0.02 s). Some attempted to use $\tau = RC$, but not enough information was known at this stage for this equation to be helpful.

(iii) There were many correct answers for the capacitance.

(c) Many candidates realised that the output voltage would now be constant. Candidates found it more difficult to explain that this was due to the magnitudes of the positive and negative parts of the input voltage being equal.

7(a)(i)	peak voltage = $4.2 \times \sqrt{2}$ (= 5.9 V)	**B1**
	power = V^2 / R = $5.9^2 / 760$ = 0.046 W or 46 mW	**A1**

7(a)(ii)	sketch shows peak(s) in power at 46 mW	**B1**
	correct shape (sinusoidal wave sitting on *t*-axis)	**B1**
	four cycles of repeating pattern shown, with $P = 0$ at 0, 10, 20, 30, 40 μs	**B1**

7(a)(iii)	line is symmetrical about 23 mW	**B1**

7(b)(i)	(alternating p.d. makes) the crystal vibrate	**B1**
	vibrations (of crystal) causes air to vibrate	**B1**
	frequency is in ultrasound range	**B1**

7(b)(ii)	(air makes) crystal vibrate, which causes an e.m.f. to be generated across the (second) crystal	**B1**

Question 7

(a) (i) A small number of candidates used the r.m.s. potential difference rather than the peak voltage here. However, there were many answers that correctly and clearly showed the maximum power dissipated.

(ii) The most common misconception here was with the shape of the line drawn. The modulus of a sine wave was drawn rather than a $\sin^2$ shape. There were only a few problems with the value of the peak power values and the period of the shape.

(iii) The majority of answers here did not refer to the line but just said that the mean power was half of the peak power. The fact the line was symmetrical about this value was not often known, and candidates who had drawn an incorrect shape of line without the relevant symmetry found it difficult to use their line to answer this question.

(b) (i) Candidates need to make it clear in their answers when one phenomenon causes something else. Here, the vibration of the crystal causing the air to vibrate was often missed.

(ii) Many candidates did not realise that the second crystal would be acting as a receiver. Some stated that the second crystal would vibrate but few went on the add that this would cause an e.m.f. to be generated.