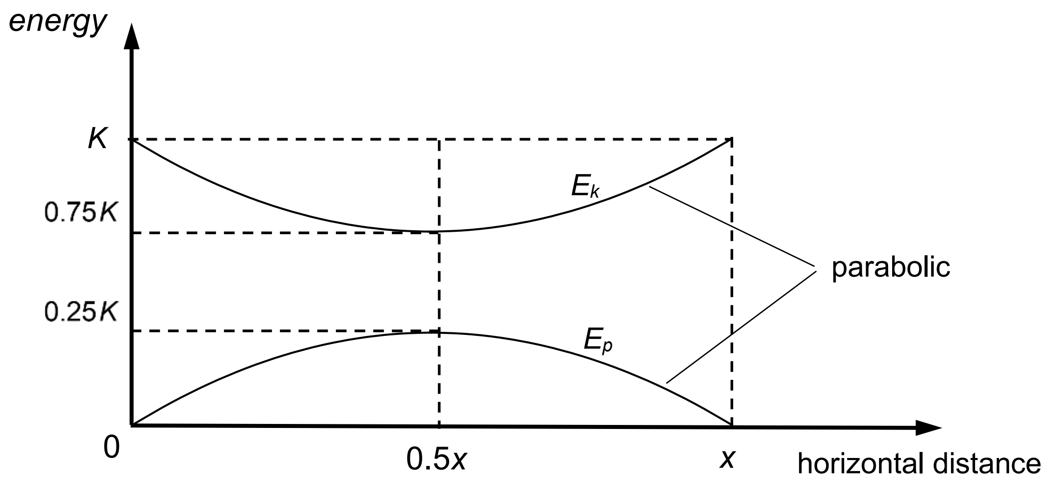
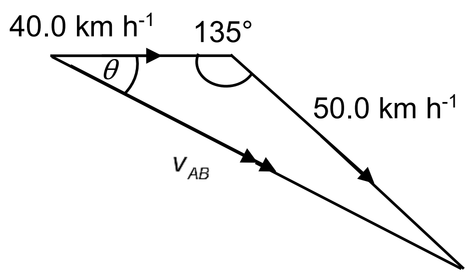
HCI H2 Physics 9749
2025 C2 Preliminary Examination
Paper 3 Suggested Solutions

Q1			
(a)	**(i)**	Vertical component of the ball's initial velocity, $u_y = u \sin \theta$ $= 25 \sin 30°$ $= 12.5 \text{ m s}^{-1}$ $= 13 \text{ m s}^{-1}$	
	(ii)	Considering the vertical component motion, At maximum height, the vertical component of the ball's velocity will decrease to zero. Using $v_y^2 = u_y^2 + 2a_y s_y$ and taking upwards direction as positive, $0 = (12.5)^2 + 2(-9.81)s_y$ Vertical displacement (i.e. max height reached), $s_y = 7.96 = 8.0$ m	
	(iii)	Initial total energy = $K = \frac{1}{2}mu^2$ At maximum height of 8.0 m, ball's vertical component velocity, $v_y = 0$. Its velocity will be its horizontal component velocity, $v_x = u \cos 30° = \frac{\sqrt{3}}{2}u$ kinetic energy at 8.0 m = $\frac{1}{2}m\left(\frac{\sqrt{3}}{2}u\right)^2 = \frac{3}{4}\left(\frac{1}{2}mu^2\right) = 0.75K$ Gain in potential energy of system = Loss in kinetic energy of ball Potential energy at 8.0 m = $K - \frac{3}{4}K = 0.25K$ OR: Initial total energy $K = \frac{1}{2}mu^2 \Rightarrow m = \frac{2K}{u^2}$ at 8.0 m, $PE = mgh = \frac{2K}{u^2}gh = \frac{2(9.81)(8.0)}{(25)^2}K = 0.25K\,(2 \text{ s.f.})$ $KE = K - PE = K - 0.25K = 0.75K\,(2 \text{ d.p.})$	

(b)	**(i)**	 **Fig. 1.2** *Correct graph* E_p parabolic curve starts from zero, peaks at $K/4$ at the middle, ends at zero. E_k parabolic curve starts from K, decreases to $3K/4$ at the middle, ends at K. Correct labels, clear markings, symmetry	`

Q2		
(a)	$F_d = \frac{1}{2}\rho C_d A v^2$ $= \frac{1}{2}(1.20)(0.30)(2.50)\left(\frac{108\times1000}{60\times60}\right)^2$ $= 405$ N $\frac{\Delta F_d}{F_d} = \frac{\Delta\rho}{\rho} + \frac{\Delta C_d}{C_d} + \frac{\Delta A}{A} + \frac{2\Delta v}{v}$ $\frac{\Delta F_d}{405} = \frac{0.05}{1.20} + \frac{0.02}{0.30} + \frac{0.05}{2.50} + \frac{2(2)}{108}$ $\Delta F_d = 70$ N (1s.f.) $F_d \pm \Delta F_d = 410 \pm 70$ N	
(b)	velocity of car A relative to car B, $v_{AB} = v_A - v_B$  By Cosine Rule, $v_{AB} = \sqrt{40.0^2 + 50.0^2 - 2(40.0)(50.0)\cos 135°}$ $= 83.2$ km h^{-1} By Sine Rule, $\frac{\sin\theta}{50.0} = \frac{\sin 135°}{83.2}$, hence $\theta = 25.1°$ direction: bearing = 90.0° + 25.1° = 115.1°	

Q3		
(a)	Let mass of Planet Z be M, mass of argon molecules be m, Consider an argon molecule escapes from the planet's surface to infinity. By conservation of energy, Loss in KE = Gain in GPE $KE_{surface} - KE_{\infty} = U_{\infty} - U_{surface}$ $\frac{1}{2}mv^2 - 0 = 0 - \left(-\frac{GMm}{r}\right)$ $v = \sqrt{\frac{2GM}{r}}$ $= \sqrt{\frac{2G\left(\frac{4}{3}\pi r^3 \rho\right)}{r}}$ $= \sqrt{\frac{8}{3}G\pi r^2 \rho} \quad (shown)$	
(b)	$v = \sqrt{\frac{8}{3}G\pi r^2 \rho}$ $= \sqrt{\frac{8}{3}(6.67 \times 10^{-11})\pi(413 \times 10^3)^2(5500)}$ $= 724 \text{ m s}^{-1}$	
(c)	Assume that escape velocity v is equal to the root-mean-square speed c_{rms} of the argon molecules. By Kinetic Theory, average KE of one argon molecule = 3/2 kT Average KE of one mole of monatomic gas is therefore 3/2 RT. $\frac{1}{2}M_r c_{rms}^2 = \frac{3}{2}RT_{\max}$ where is M_r the molar mass of argon. $T_{\max} = \frac{M_r c_{rms}^2}{3R}$ $= \frac{(40 \times 10^{-3})(724)^2}{3 \times 8.31}$ $= 841 \text{K}$	
(d)	The root-mean-square speed of argon molecules will be less than escape velocity when temperature decreases. However, due to the random distribution of speeds, some molecules will have speeds greater than the escape velocity and would be able to escape.	

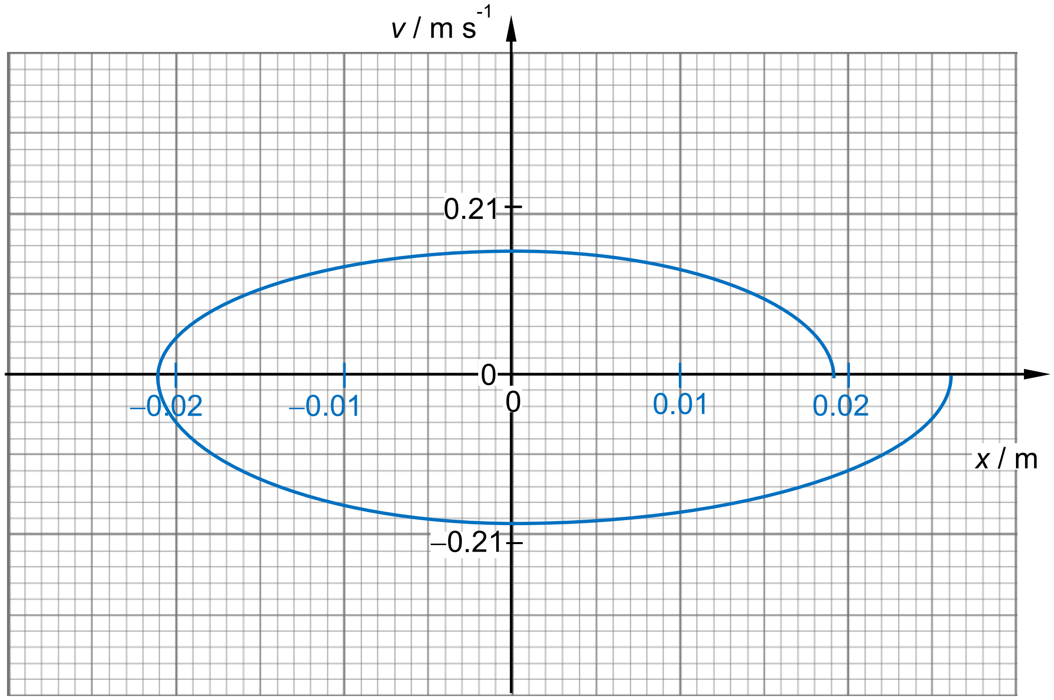
Q4		
(a)	From Fig. 4.2, 5 mm corresponds to 3 fringe separations. $3\Delta y = 5.0 \Rightarrow \Delta y = 5.0 \div 3 = 1.67$ mm $\Delta y = \frac{L\lambda}{d}$ $1.67 \times 10^{-3} = \frac{0.980(633 \times 10^{-9})}{d}$ $d = 3.7 \times 10^{-4}$ m	
(b)	Let θ be the angle made by 1st order minimum of the single slit diffraction envelope from the principle axis. From Fig. 4.1 and Fig 4.2, $\tan\theta_{min} = \frac{10.0 \times 10^{-3}}{0.980} = 0.0102$ $\sin\theta_{min} = \frac{\lambda}{b}$ $b = \frac{\lambda}{\sin\theta}; \frac{\lambda}{\theta}$ (Applying small angle approximation) $= \frac{633 \times 10^{-9}}{0.0102}$ $= 6.2 \times 10^{-5}$ m <u>Alternative Method</u> From Fig. 4.2, the first minimum for single slit diffraction envelope coincides with the 6th maximum for double slit interference (missing order). Single slit diffraction: $b\sin\theta_1 = 1\lambda$ Double slit interference: $d\sin\theta_6 = 6\lambda$ Since $\theta_1 = \theta_6$, $\frac{b}{d} = \frac{1}{6}$ $b = \frac{d}{6} = \frac{3.7 \times 10^{-4}}{6}$ $= 6.2 \times 10^{-5}$ m	
(c)(i)	Increase slit separation *d*. From $\Delta y = \frac{\lambda L}{d}$, a smaller *d* makes the fringe separation Δy wider, spreading the interference pattern.	
(c)(ii)	Make the slits narrower. Narrower slits produce a much wider single-slit diffraction envelope with lower overall intensity, so the bright fringes vary less in intensity.	

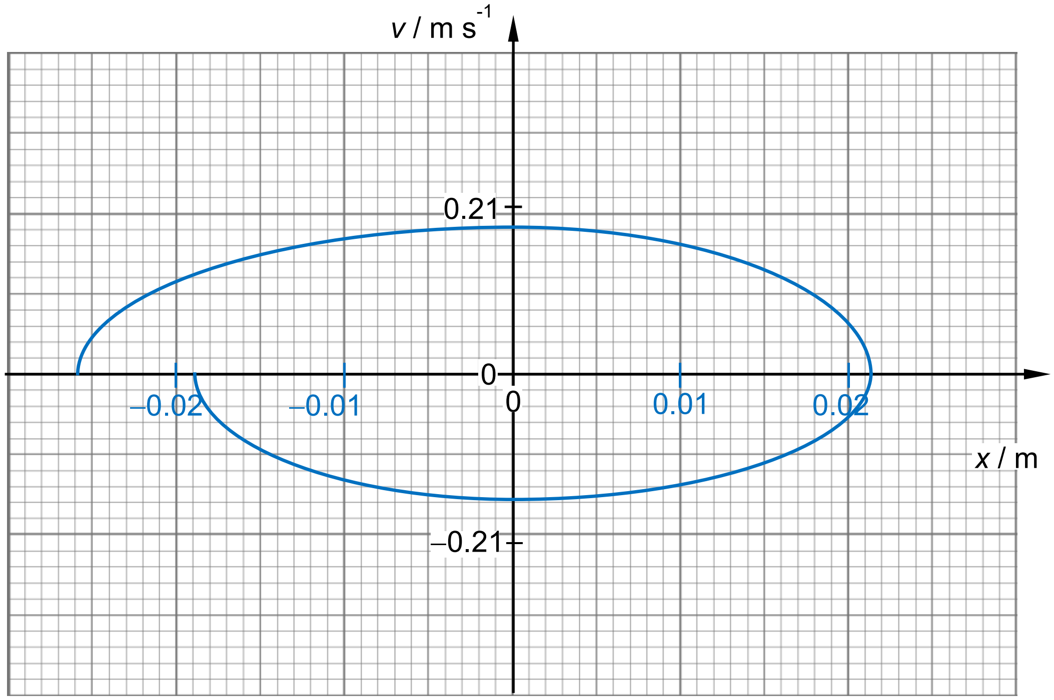
Q5		
(a)(i)	The component of velocity perpendicular to the magnetic field results in a magnetic force on the electron, which is always perpendicular to the motion. Hence, the electron rotates in a circular path. The component of velocity parallel to the magnetic field remains constant. Hence, the electron travels at constant velocity along the direction of magnetic field. The combination of both components of velocity of the electron results in a helical path.	
(a)(ii)	$F_B = Bqv_\perp = Bqv\sin 20^\circ$ $v = \dfrac{F_B}{Bq\sin 20^\circ} = \dfrac{4.3\times 10^{-14}}{0.088(1.60\times 10^{-19})\sin 20^\circ}$ $v = 8.93\times 10^{6}$ m s^{-1}	
(a)(iii)	Magnetic force provides centripetal force to the electron's component of velocity perpendicular to the magnetic field. Find period *T*: $F_B = Bqv_\perp = \dfrac{mv_\perp^2}{r} \Rightarrow v_\perp = \dfrac{Bqr}{m}$ $v_\perp = \omega r = \dfrac{2\pi}{T} r$ $T = \dfrac{2\pi r}{v_\perp} = \dfrac{2\pi rm}{Bqr} = \dfrac{2\pi m}{Bq}$ Pitch:\` $p = v_P T$ $= v\cos 20^\circ \left(\dfrac{2\pi m}{Bq}\right)$ $= \dfrac{(8.93\times 10^{6})\cos 20^\circ (2\pi)(9.11\times 10^{-31})}{(0.088)(1.60\times 10^{-19})}$ $= 3.4\times 10^{-3}$ m	
(b)	The pair of forces generate a torque. The maximum output torque is *F* x *d* $\text{Torque} = \tau = Fd = (NBIl)d = NBIA$ $B = \dfrac{\tau}{NIA} = \dfrac{395}{(1200)(96)(6.1\times 10^{-3})}$ $B = 0.562$ T	

Q6		
(a)(i)	For any given metal, electrons are emitted only when the frequency of incident light is above some minimum value. This frequency is known as the threshold frequency.	
(a)(ii)	At threshold frequency, energy of photon matches the work function. Hence, $\Phi = \frac{hc}{\lambda_o}$ $E_{MAX} = hf - \Phi = \frac{hc}{\lambda} - \frac{hc}{\lambda_o} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right)$	
(b)(i)	Extend line to the x-axis. The x-intercept is $\frac{1}{\lambda_o}$ $\frac{1}{\lambda_o} = 2.3 \times 10^{6}$ $\lambda_o = 4.35 \times 10^{-7}$ m	
(b)(ii)	Gradient of graph = *hc* $\frac{(3.1 - 1.0) \times 10^{-19}}{(3.85 - 2.8) \times 10^{6}} = h\left(3.00 \times 10^{8}\right)$ $h = 6.7 \times 10^{-34}$ Js	
(c)	Same gradient Higher y-intercept, x-intercept more to the left.	
(d)	As electrons escape the surface, the sphere becomes more positively charged and the potential at the surface increases. It comes to a point when the electrons with maximum kinetic energy lose all the energy at almost infinite distance and they are attracted back to the surface due to the electric field. The system is finally in dynamic equilibrium. The rate of return is equal to the rate of emission, keeping the total charge constant at the surface. Thus, electric potential energy gained by an electron at infinity = E_{MAX} lost $U_{\infty} - U_{surface} = E_{MAX}$ $0 - \frac{Q(-e)}{4\pi\varepsilon_o r} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right)$ $Q = \frac{4hc\pi\varepsilon_o r}{e}\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right)$	

Q7		
(a)	The binding energy E of a nucleus is the energy required to separate the nucleus into its constituent free neutrons and protons. It is related to the mass defect Δm by the formula, $E = \Delta mc^2$.	
(b)(i)	The energy equivalent of 1.00 u is given by, $= 1.00uc^2$ $= (1.66 \times 10^{-27})(3.00 \times 10^{8})^2$ J $= \dfrac{(1.66 \times 10^{-27})(3.00 \times 10^{8})^2}{(1.60 \times 10^{-19})(10^6)}$ MeV $= 933.75$ MeV $= 934$ MeV	
(b)(ii)	For Nitrogen-14, Binding energy $E = (7(1.007276) + 7(1.008665) - 14.003074)uc^2$ $= 0.108513(934 \text{ MeV}) = 101.35$ MeV Binding energy per nucleon $= \dfrac{101.35}{14} = 7.24$ MeV per nucleon	
(c)(i)	The energy released in the reaction = final binding energy – initial binding energy $= 17(7.530) - [14(7.24) + 4(6.836)]$ $= 128.01 - 128.70$ $= -0.694$ MeV Hence there is actually a gain of mass in this reaction and 0.694 MeV of energy needs to be provided.	
(c)(ii)	We need at least 0.694 MeV of energy from the kinetic energy of the alpha particles as the oxygen nucleus and proton may also have kinetic energy after the reaction. Since the kinetic energy of the alpha particle is only 0.300 MeV, it is clearly insufficient and hence the reaction cannot proceed.	

Q8			
(a)	The net external force acting on a body is zero and the net moment on the body about any point is zero.		
(b)	(i)	$T\sin\theta = kx$ $k = \dfrac{T\sin\theta}{x} = \dfrac{2.50\sin 36^{o}}{0.050}$ $= 29.389$ $= 29.4\ \text{N m}^{-1}$ or $29\ \text{N m}^{-1}$ (to 2 s.f.)	
	(ii)	$T\cos\theta = mg$ $m = \dfrac{T\cos\theta}{g} = \dfrac{2.50\cos 36^{o}}{9.81}$ $= 0.206$ kg or 0.21 kg (to 2 s.f.)	
	(iii)	$\text{EPE} = \dfrac{1}{2}kx^{2} = \dfrac{1}{2}(29.4)(0.050)^{2}$ $= 0.0368$ $= 0.037$ J	
(c)	(i)	Simple harmonic motion is a periodic motion in which the acceleration of the body is directly proportional to the displacement from its equilibrium point, and is always in the opposite direction to the displacement (or always directed to equilibrium position.)	
	(ii)1.	By conservation of energy, Loss in GPE = Gain in KE $mgh = \dfrac{1}{2}mv_{max}^{2}$ $v_{max} = \sqrt{2gh} = \sqrt{2g(L - L\cos\theta)}$ $= \sqrt{2(9.81)\left(0.150 - 0.150\cos 10^{\circ}\right)}$ $= 0.21145$ $= 0.21\ \text{m s}^{-1}$	
	(ii)2.	*T* will be greater than *W* because, in addition to supporting the bob's weight, the string must provide the necessary centripetal force to keep the bob moving in its circular path. OR The vector sum of the weight and tension must provide the centripetal force for circular motion pointing upwards at the bottom.	

	(ii)3.	T – W provides the centripetal force for the bob to move in its circular arc $T - W = \dfrac{mv^2}{r}$ $T = \dfrac{mv^2}{r} + mg = \dfrac{0.206(0.211^2)}{0.15} + 0.206(9.81)$ $= 2.082\text{ N}$ $= 2.1\text{ N}$	
(d)	**(i)**	Correct shape starting at 0.026 m (reasonable smooth spiral) Correct labelling of v_{max} and x_o $x_o = L\sin\theta = 0.15\sin 10^o = 0.02604 = 0.026$ m  OR	

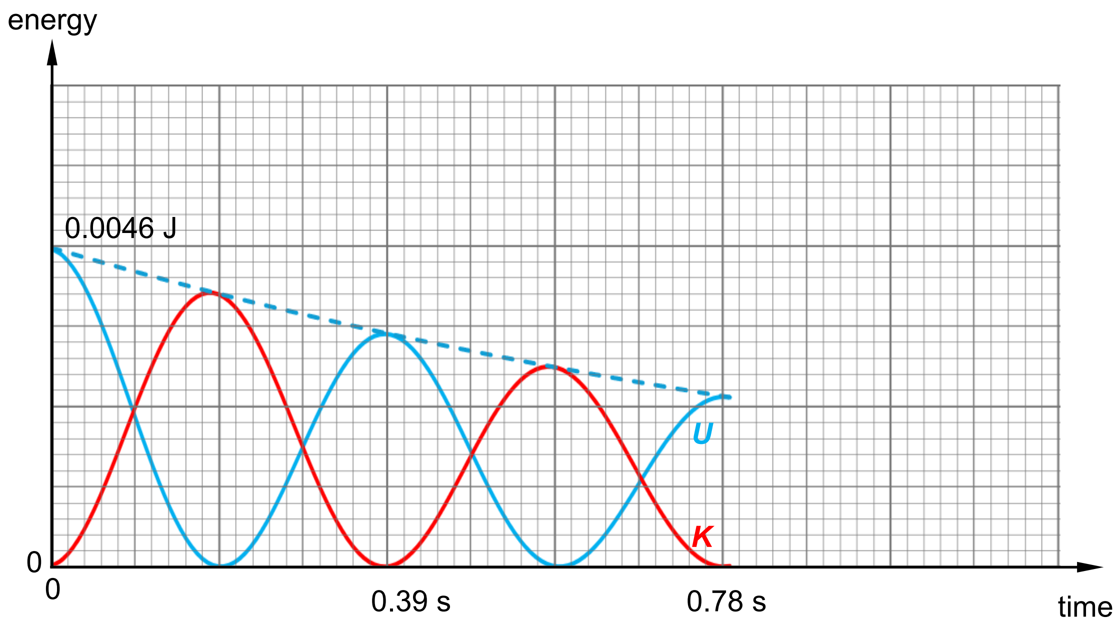


(ii)

$$v = \omega x_0 = \left(\frac{2\pi}{T}\right) x_0$$

$$T = \frac{2\pi x_0}{v} = \frac{2\pi(0.026)}{0.21} = 0.78 \text{ s}$$

Total initial energy $= \frac{1}{2}mv^2 = \frac{1}{2}(0.21)(0.21)^2 = 0.0046$ J



Correct period labelled (2 cycles)
Correct shape of *U*
Correct shape of *K*

Q9			
(a)	(i)	As the coil rotates at constant angular speed ω, the component of magnetic flux density B perpendicular to the cross-sectional area A of the coil varies sinusoidally. Since the magnetic flux linkage Φ varies sinusoidally, the rate of change of flux linkage will be sinusoidal. For instance, if $\Phi = NBA\sin\omega t$, then $d\Phi/dt = NBA\omega\cos\omega t$. By Faraday's law, the magnitude of the induced emf is directly proportional to the rate of change of magnetic flux linkage. Thus emf induced in the coil will be sinusoidal.	
	(ii)	1. $(6.8\text{ cm} \times 0.050\text{ V cm}^{-1})/2$ $= 0.17$ V 2. T = 5 cm × 8.0 ms = 40 ms $f = 1/(40 \times 10^{-3}) = 25$ Hz	
	(iii)	The plane of the rectangular coil is perpendicular to the plane of the paper (i.e. minimum flux linkage), when maximum e.m.f. is induced in the coil. OR coil rotated 90°	
	(iv)	$E_0 = NBA\omega$ $0.17 = 120 \times B \times 0.0013 \times 2\pi(25)$ $B = 6.94 \times 10^{-3}$ T	
(b)	(i)	The root-mean-square value of an alternating current is the equivalent constant direct current that will dissipate the same amount of heat per unit time in a given resistive load.	
	(ii)	$\omega = 2\pi f = 377$ $f = \dfrac{377}{2\pi} = 60.0$ Hz	
	(iii)	$V_{rms} = \dfrac{V_o}{\sqrt{2}} = \dfrac{240}{\sqrt{2}}$ Power dissipated in heater, $\langle P \rangle = \dfrac{(V_{rms})^2}{R}$ $= \left(\dfrac{240}{\sqrt{2}}\right)^2 \left(\dfrac{1}{38}\right)$ $= 758$ W	

	(iv)	The peak power, P_o = $(240)^2/38$ = 1516 W