1(i)	$x = \text{PB}$	M1	May be implied	
	$x = \sqrt{a^2 + y^2}$	A1		
	$V = \frac{1}{2}kx^2 - mgy$	M1	EPE term	
		M1	GPE term	
	$= \frac{1}{2}k\left(a^2 + y^2\right) - mgy$	A1	cao	
				5
(ii)	$\frac{dV}{dy} = ky - mg$	M1	Differentiate their V	
	equilibrium $\Rightarrow \frac{dV}{dy} = 0$	B1	Seen or implied	
	$\Rightarrow y = \frac{mg}{k}$	A1	cao	
	$\frac{d^2V}{dy^2} = k > 0$	M1	Consider sign of V'' (or V' either side)	
	$\Rightarrow$ stable	E1	Complete argument	
				5
(iii)	$R = T\sin P\hat{B}A = k \cdot PB \cdot \frac{a}{PB}$	M1	Use Hooke's law and resolve	
	$= ka$	A1		
				2
2(i)	$\frac{d}{dt}(mv) = 0 \Rightarrow mv$ constant	M1	Or no external forces $\Rightarrow$ momentum conserved, or attempt using δ terms.	
	hence $mv = m_0u$	A1		
	$\frac{dm}{dt} = k$	B1	$\frac{dm}{dt} = k$ seen	
	$\Rightarrow m = m_0 + kt$	B1	$m_0 + kt$ stated or clearly used as mass	
	$v = \frac{m_0u}{m} = \frac{m_0u}{m_0 + kt}$	E1	Complete argument (dependent on all previous marks and $m_0 + kt$ derived, not just stated)	
	$x = \int \frac{m_0u}{m_0 + kt}\,dt$	M1	Integrate v	
	$= \frac{m_0u}{k}\ln\left(m_0 + kt\right) + A$	A1	cao	
	$x = 0, t = 0 \Rightarrow A = -\frac{m_0u}{k}\ln m_0$	M1	Use condition	
	$x = \frac{m_0u}{k}\ln\left(\frac{m_0 + kt}{m_0}\right)$	A1	cao	
				9
(ii)	$v = \frac{1}{2}u \Rightarrow m_0 + kt = 2m_0$	M1	Attempt to calculate value of m or t	
	$\Rightarrow x = \frac{m_0u}{k}\ln\left(\frac{2m_0}{m_0}\right)$	M1	Substitute their m or t into x	
	$\Rightarrow x = \frac{m_0u}{k}\ln 2$	F1	$t = \frac{m_0}{k}$ or $m = 2m_0$ in their x	
				3

3(i)	$I = \int_{-a}^{a} \rho x^2 \, dx$	M1 A1	Set up integral Or equivalent	
	$\rho = \dfrac{m}{2a}$	M1	Use mass per unit length in integral or I	
	$I = \dfrac{m}{2a}\left[\frac{1}{3}x^3\right]_{-a}^{a}$	M1	Integrate	
	$= \frac{1}{6}ma^2 - -\frac{1}{6}ma^2$	M1	Use limits	
	$\frac{1}{3}ma^2$	E1	Complete argument	
				6
(ii)	$I_{\text{rod}} = \frac{1}{3}\times 1.2\times 0.4^2 + 1.2\times 0.4^2$	M1 A1	Use $\frac{1}{3}ma^2$ or $\frac{4}{3}ma^2$ Rod term(s) all correct	
	$I_{\text{sphere}} = \frac{2}{5}\times 2\times 0.1^2 + 2\times 0.9^2$	M1 M1 A1	Use formula for sphere Use parallel axis theorem Sphere terms all correct	
	$I = I_{\text{rod}} + I_{\text{sphere}} = 1.884$	M1 A1	Add moment of inertia for rod and sphere cao	
				7
(iii)	$\frac{1}{2}I\dot{\theta}^2 - 1.2g\times 0.4\cos\theta - 2g\times 0.9\cos\theta$ $= -1.2g\times 0.4\cos\alpha - 2g\times 0.9\cos\alpha$	M1 M1 M1 A1	Use energy KE term Reasonable attempt at GPE terms All terms correct (but ignore signs)	
	$\dot{\theta}^2 = \dfrac{4.56g}{1.884}(\cos\theta - \cos\alpha)$	M1 F1	Rearrange Only follow an incorrect I	
				6
(iv)	$2\dot{\theta}\ddot{\theta} = \dfrac{4.56g}{1.884}(-\sin\theta\,\dot{\theta})$ or $I\ddot{\theta} = -1.2g\times 0.4\sin\theta - 2g\times 0.9\sin\theta$	M1	Differentiate, or use moment $= I\ddot{\theta}$	
		F1	Equation for $\ddot{\theta}$ (only follow their I or $\dot{\theta}^2$)	
	$\sin\theta \approx \theta \Rightarrow \ddot{\theta} = -11.86\theta$	M1	Use small angle approximation (in terms of θ)	
	i.e. SHM	E1	All correct (for their I) and make conclusion	
	$T \approx \dfrac{2\pi}{\sqrt{11.86}} \approx 1.82$	F1	$\dfrac{2\pi}{\text{their } \omega}$	
				5

4(i)	$2v\dfrac{dv}{dx} = 2 - 8v^2$	M1 A1	N2L	
	$\int \dfrac{v}{1-4v^2}\,dv = \int dx$	M1	Separate	
	$-\frac{1}{8}\ln\left\|1-4v^2\right\| = x + c_1$	A1	LHS	
	$x = 0, v = 0 \Rightarrow c_1 = 0$	M1	Use condition	
	$1-4v^2 = e^{-8x}$	M1	Rearrange	
	$v^2 = \frac{1}{4}\left(1-e^{-8x}\right)$	E1	Complete argument	
				7
(ii)	$F = 2-8v^2 = 2-2\left(1-e^{-8x}\right)$	M1	Substitute given v^2 into F	
	$= 2e^{-8x}$	A1	cao	
	Work done = $\int_0^2 F\,dx$	M1	Set up integral of F	
	$= \int_0^2 2e^{-8x}\,dx$	A1	cao	
	$= \left[-\frac{1}{4}e^{-8x}\right]_0^2$	M1	Integrate	
	$= \frac{1}{4}\left(1-e^{-16}\right)$	A1	Accept $\frac{1}{4}$ or 0.25 from correct working	
				6
(iii)	$2\dfrac{dv}{dt} = 2-8v^2$	M1	N2L	
	$\frac{1}{4}\int \dfrac{1}{\frac{1}{4}-v^2}\,dv = \int dt$	M1	Separate	
	$\frac{1}{4}\ln\left\|\dfrac{\frac{1}{2}+v}{\frac{1}{2}-v}\right\| = t + c_2$	A1	LHS	
	$t = 0, v = 0 \Rightarrow c_2 = 0$	M1	Use condition	
	$\dfrac{\frac{1}{2}+v}{\frac{1}{2}-v} = e^{4t}$	M1	Rearrange (remove log)	
	$1+2v = e^{4t}(1-2v)$			
	$2v\left(1+e^{4t}\right) = e^{4t}-1$	M1	Rearrange (v in terms of t)	
	$v = \frac{1}{2}\left(\dfrac{e^{4t}-1}{e^{4t}+1}\right) = \frac{1}{2}\left(\dfrac{1-e^{-4t}}{1+e^{-4t}}\right)$	E1	Complete argument	
				7
(v)	$t = 1 \Rightarrow v = 0.4820$	B1		
	$t = 2 \Rightarrow v = 0.4997$	B1		
	Impulse $= mv_2 - mv_1$	M1	Use impulse-momentum equation	
	= 0.0353	A1	Accept anything in interval [0.035, 0.036]	
				4