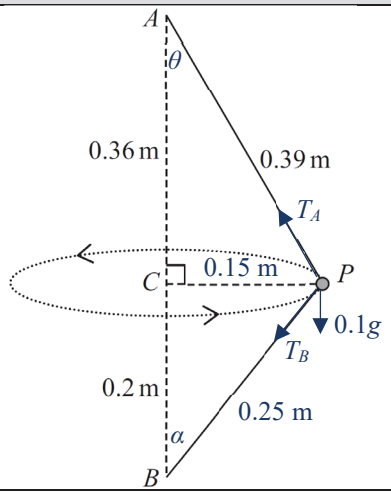
Question Number	Answer	Mark	Additional Guidance
1a	Use of $a = v\frac{\mathrm{d}v}{\mathrm{d}x}$ or $a = \frac{\mathrm{d}}{\mathrm{d}x}\left(\frac{1}{2}v^2\right)$	M1	Use correct substituted form for a using given function (not just stating $a = v\frac{\mathrm{d}v}{\mathrm{d}x}$ oe).
	$a = \frac{qx}{\left(x^2+4\right)^3}$ condone $a = \frac{p}{\left(x^2+4\right)^3}$	M1	Power going down by 1 but condone error in chain rule if x is lost from numerator. M0 for just differentiating v wrt x.
	$a = \frac{-72x}{\left(x^2+4\right)^3}$	A1	Or equivalent unsimplified. Allow for evaluation of correct expressions of v and $\frac{\mathrm{d}v}{\mathrm{d}x}$ and attempt to multiply.
	Deceleration $= \frac{216}{2197} = 0.098...\left(\mathrm{m\,s^{-2}}\right)$	A1	2 sf or better. Must be positive.
		(4)	
1b	$\frac{\mathrm{d}x}{\mathrm{d}t} = \frac{6}{x^2+4}$	M1	Form differential equation in x and t using given v
	$\int x^2+4\,\mathrm{d}x = \int 6\,\mathrm{d}t$	M1	Separate variables to get polynomials and attempt to integrate (at least one power increasing). 6 could be on either side
	$\frac{1}{3}x^3 + 4x = 6t\,(+C)$	A1	Or equivalent. Condone missing constant of integration
	Use $x = 3, t = 0$ $(\Rightarrow C = 21)$	DM1	Correct use of limits to find constant of integration and use of $x = 6$ to find T (or as limits in a definite integral) E.g. $c = \frac{7}{2}$ with 6 on other side Dependent on both previous M marks.
	$T = 12.5$	A1	Accept $t = 13$
		(5)	
		(9)	

Question Number	Answer	Mark	Additional Guidance
2a	M(A)	M1	Or equivalent to obtain an equation in T. Dimensionally correct. Condone sin/cos confusion
	$T \times 3a\sin\theta° = Mg \times \frac{3a}{2}\cos(2\theta°)$	A1	Correct unsimplified equation. Allow consistently cancelled a
	$\Rightarrow \text{tension} = \frac{Mg\cos(2\theta°)}{2\sin\theta°}$ *	A1*	Obtain **given answer** from correct working. Withold if length a never seen in working.
		(3)	
2b	Extension in the string $= 2 \times 3a\cos\theta°$	B1	Or for finding BC E.g. $\sqrt{18a^2(1+\cos 2\theta°)}$ E.g. $\frac{3a\sin 2\theta°}{\sin\theta°}$
	$T = \frac{\frac{2}{5}Mg \times "6a\cos\theta°"}{3a}$	M1	Correct use of Hooke's Law for their extension in terms of a and $\theta/2\theta$ (must be an extension: $BC \pm 3a$ is M0)
	Form an equation in either 2θ or θ	M1	e.g. $\frac{4}{5}Mg \times \sin(2\theta°) = Mg\cos(2\theta°)$
	$\tan 2\theta° = \frac{5}{4}$ *	A1*	Obtain **given answer** from correct working. Condone missing degrees symbol.
		(4)	
		(7)	

Question Number	Answer	Mark	Additional Guidance
3a			
	Resolve vertically	M1	Dimensionally correct. Condone sine / cosine confusion but angles and tensions must be different (allow same letter only if recovered).
	$T_A \cos\theta = 0.1g + T_B \cos\alpha$ $\left(\frac{12}{13}T_A = 0.1g + \frac{4}{5}T_B\right)$	A1	Correct unsimplified equation.
	Circular motion	M1	Dimensionally correct. Condone sine / cosine confusion but angles and tensions must be different (allow same letter only if recovered).
	$0.1r\omega^2 = T_A \sin\theta + T_B \sin\alpha$ $\left(0.675 = \frac{5}{13}T_A + \frac{3}{5}T_B\right)$	A1 A1	Unsimplified equation with at most one error Correct unsimplified equation
	Substitute for trig and ω and solve for T_B	DM1	Dependent on the two previous M marks
	T_B = tension = 0.29 or 0.286 (N)	A1	2 sf or 3 sf only (only penalise over-accurate "correct" answer once per whole question)
		(7)	
3b	Resolve horizontally **and** vertically	M1	Dimensionally correct. Condone sine / cosine confusion. Must be using $T_B = 0$ but allow inequality in working.
	$T_A \cos\theta = 0.1g$	A1	Correct unsimplified equation

	$0.1\times 0.15\omega^2 = T_A \sin\theta$	A1	Correct unsimplified equation
	$\omega = 5.2$ or 5.22	A1	2 sf or 3 sf only (only penalise over-accurate "correct" answer once per whole question)
		(4)	
		(11)	

Question Number	Answer	Mark	Additional Guidance
4a	Use of $\pi\int xy^2\mathrm{d}x\left(=\pi\int 25x-x\left(x+3\right)^2\mathrm{d}x\right)$ for moments about the y-axis	M1	Condone if π is missing. There must be some attempt to use the function in the question, not just quoting the general formula. E.g. $\pi\left(\int 16x-6x^2-x^3\right)\mathrm{d}x$
	Integrate as far as $\pi\left[\frac{25}{2}x^2-\frac{x}{3}\left(x+3\right)^3+\int\frac{1}{3}\left(x+3\right)^3\,\mathrm{d}x\right]$	M1	Or equivalent. Condone sign slips and slips in coefficients. Condone if π is missing
	Obtain $\pi\left[\frac{25}{2}x^2-\frac{x}{3}\left(x+3\right)^3+\frac{1}{12}\left(x+3\right)^4\right]$	A1	Or equivalent e.g. $\pi\left[8x^2-2x^3-\frac{1}{4}x^4\right]$
	$=\pi\left\{50-\frac{2}{3}\times125+\frac{1}{12}\times625-\frac{1}{12}\times81\right\}$ $\left(=12\pi\right)$	M1	Correct use of limits 0 and 2. Must see at least 12 or 12π. Condone if π is missing
	Complete method for centre of mass	M1	Using their moment and the given volume (if they try to work out the volume it must be correct including correct sign). Allow the π to be missing from the given volume for the M mark.
	$=12\pi\times\frac{3}{52\pi}=\frac{9}{13}$ *	A1*	Obtain **given answer** from full and correct working but allow missing dx throughout.
	If π is missing from the moments integral, can score M marks only unless they have also worked out the volume and explicitly shown that π cancels.		
		(6)	
4b	Use of $\frac{3r}{8}=\frac{3}{2}$	B1	Correct distance for c of m of hemisphere seen or implied.
	Moments about AB	M1	Or equivalent. Dimensionally correct
	$\frac{3}{2}\times\frac{128}{3}\pi-\frac{9}{13}\times\frac{52}{3}\pi=d\times\left(\frac{128}{3}-\frac{52}{3}\right)\pi$	A1	Correct unsimplified equation in d
	$d=\frac{39}{19}$ *	A1*	Obtain given answer from correct working. Allow with $\bar{x}$ etc. in place of d
			π is a common factor.

			Allow full marks if not seen.
		(4)	
4c	$\tan\theta^\circ = \frac{39}{19} \div 4 \quad \left(= \frac{39}{76}\right)$	M1	Correct use of trig to find a relevant angle. Allow for reciprocal.
	$\theta = 27$	A1	Or better 27.1649…. Must be in degrees.
		(2)	
		(12)	

Question Number	Answer	Mark	Additional Guidance
5a	Use of $EPE = \dfrac{\lambda x^2}{2a}$	B1	Correct form seen at least once
	Energy equation	M1	Dimensionally correct. Need all 3 terms
	$\dfrac{\lambda \times (2a)^2}{2a} = mg \times \dfrac{5}{2}a + \dfrac{\lambda\left(\frac{a}{2}\right)^2}{2a}$	A1	Correct unsimplified equation
	$\dfrac{15\lambda a}{8} = \dfrac{5mga}{2} \quad \Rightarrow \lambda = \dfrac{4}{3}mg$ *	A1*	Obtain **given answer** from full and correct working. Must see at least one line of working e.g. combining epe terms.
		(4)	
5b	Conservation of energy	M1	Dimensionally correct. Need all 3 terms
	$\dfrac{1}{2}mv^2 + mg \times 2a = \dfrac{4}{3}mg \times \dfrac{(2a)^2}{2a}$	A1 A1	Unsimplified equation with at most one error Correct unsimplified equation
	$\Rightarrow v = \sqrt{\dfrac{4ag}{3}}$	A1	Any equivalent form Eg. $\dfrac{2\sqrt{3ag}}{3}$ Accept $1.2\sqrt{ag}$ or better
		(4)	
5c	At max speed $T = mg$	M1	Form equation for equilibrium
	$\Rightarrow mg = \dfrac{4mg}{3} \times \dfrac{x}{a}$	A1	Correct unsimplified equation
	$\Rightarrow x = \dfrac{3}{4}a, \quad AE = x + a = \dfrac{7}{4}a$ *	A1*	Obtain **given answer** from full and correct working with no errors. Allow without "$AE =$"
		(3)	
5c Alt1	Form equation using energy when extension is x and maximise v.		Forms equation for energy at an arbitrary point **and** then tries to find the value of their x which maximise v or v^2 (e.g. completing the square or differentiating). Note their "x" could be any

			consistently used position e.g. AP or DP.
	$\frac{4mg(2a)^2}{3\times 2a}=\frac{4mg(x)^2}{3\times 2a}+mg(2a-x)+\frac{1}{2}mv^2$ $v^2=-\frac{4g}{3a}x^2+2gx+\frac{4}{3}ag$		Correct unsimplified equation
	$v_{\max}$ when $x=\frac{3}{4}a\Rightarrow AE=\frac{7}{4}a$ *		Obtain **given answer** from full and correct working with no errors. Allow without "$AE=$"
5c Alt2	Max speed at equilibrium position and as this is a spring that position is halfway between the positions where $v = 0$	M1	Observes that max speed occurs at equilibrium position and justifies use of midpoint by stating either: - it is a spring / never slack **or** - P moves with SHM **and** attempts to find midpoint
	$AE=\frac{\frac{1}{2}a+3a}{2}$	A1	Correct unsimplified equation
	$AE=\frac{7}{4}a$ *	A1*	Obtain **given answer** from full and correct working with no errors. Allow without "$AE=$"
		(3)	
5d	Equation of motion	M1	Must be using distance from E
	$m\ddot{y}=mg-\frac{\frac{4mg}{3}\left(y+\frac{3}{4}a\right)}{a}$	A1	Correct unsimplified equation using distance from E (condone if using x again; allow "a" etc. for acceleration for this mark).
	$\Rightarrow m\ddot{y}=-\frac{4mg}{3a}y,\quad \ddot{y}=-\frac{4g}{3a}y$ Of the form $\ddot{y}=-\omega^2 y$ so SHM *	A1*	Obtain **given answer** from full and correct working. Requires a conclusion mentioning "SHM" and acceleration must be second derivative of displacement from E wrt t.
		(3)	
		(14)	

Question Number	Answer	Mark	Additional Guidance
6a	Conservation of energy P to Q	M1	Dimensionally correct. Required terms and no others.
	$\frac{1}{2}mv^2 = mg \times 1.5 \quad (\Rightarrow v^2 = 3g)$	A1	Correct unsimplified equation. No need to substitute the value for m.
	Circular motion at Q:	M1	Dimensionally correct. Required terms and no others
	$R - mg = \frac{mv^2}{1.5}$	A1	Correct unsimplified equation.
	$(\Rightarrow R = mg + 2mg)$ $R = 5.9$ or 5.88 (N)	A1	2 sf or 3 sf only. Accept $0.6g$
		(5)	
6b	Conservation of energy e.g. from P to R: $\frac{1}{2}mv^2 = mg \times 0.75$	M1	Dimensionally correct. Required terms and no others. Q to R: $\frac{1}{2}mv^2 + mg \times 0.75 = \frac{1}{2}m(3g)$
	$v^2 = 1.5g \Rightarrow v = \sqrt{1.5g}$	A1	oe
	Equation for time from R to S	M1	Complete method using *suvat* Condone sin/cos confusion.
	e.g. $-0.75 = \sqrt{1.5g}\sin 60°t - 4.9t^2$	A1	Correct unsimplified equation
	$t = 0.856$	A1	0.86 or better seen or used $\left(\frac{\sqrt{210} + 3\sqrt{10}}{28} = 0.85636...\right)$
	Equation in terms of t for the horizontal distance after leaving R	M1	e.g. $\sqrt{1.5g}\cos 60°t$ Condone sin/cos confusion.
	Complete method for distance QS	M1	e.g. $1.5\sin 60° + \sqrt{1.5g}\cos 60°t$ or equivalent. Condone sin/cos confusion.
	$QS = 2.9$ or 2.94 (m)	A1	2 sf or 3 sf only
		(8)	
		(13)	
	Some useful values:		Other useful times: R to top of parabola: $\frac{3\sqrt{10}}{28} = 0.33881...$ Top of parabola to S: $\frac{\sqrt{210}}{28} = 0.51754...$

	$\sqrt{3g} = \frac{7\sqrt{15}}{5} = 5.42217...$ $\sqrt{1.5g} = \frac{7\sqrt{30}}{10} = 3.83405...$ $v_y = \frac{21\sqrt{10}}{20} = 3.32039...$ $v_x = \frac{7\sqrt{30}}{20} = 1.91702...$ $RS_{\text{horizontal}} = \frac{3\sqrt{7}+3\sqrt{3}}{8} = 1.64167...$		

Question Number	Answer	Mark	Additional Guidance
7a	Max speed: $a\omega = 12$	B1	Seen or implied
	$\left(4\sqrt{5}\right)^2 = \omega^2\left(a^2 - 2^2\right)$	B1	Correct use of $v^2 = \omega^2\left(a^2 - x^2\right)$
	Solve for a	M1	(N.B. $\omega = 4$)
	$a = 3$	A1	
		(4)	
7b	$A = a\omega^2 = 48$	B1ft	Follow their a, ω. May use $\frac{v_{\max}^2}{a}$. Do not need to see "A="
		(1)	
7c	Use $\ddot{x} = -A\cos\omega t$ or $\ddot{x} = -A\sin\omega t$ $\left(\frac{1}{2}A = \pm A\cos\omega t \text{ or } \frac{1}{2}A = \pm A\sin\omega t\right)$	M1	Or equivalent e.g. $x = a\cos\omega t$ and $\frac{1}{2}A = -\omega^2 x$ (N.B. $x = \pm\frac{3}{2}$)
	$4t = \cos^{-1}\frac{1}{2} \Rightarrow t = \frac{\pi}{12}$ or $4t = \sin^{-1}\frac{1}{2} \Rightarrow t = \frac{\pi}{24}$	A1	Obtain a relevant value of t (allow for an inequality)
	$\frac{2\pi}{\omega} - 4\times\frac{\pi}{12}$ or $4\times\frac{\pi}{24}$	M1	Complete method to obtain the required time
	$\frac{\pi}{6}$ (s)	A1	0.52 (s) or better (0.52359 …)
		(4)	
		(9)	