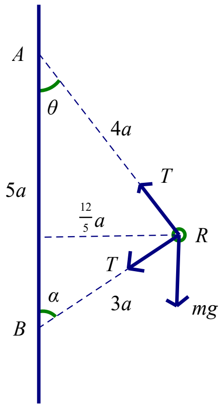
Question	Scheme	Marks	AOs
1			
	$\updownarrow\ mg + T\cos\alpha = T\cos\theta$	M1	3.3
	$mg + \frac{3}{5}T = \frac{4}{5}T \quad (T = 5mg)$	A1	1.1b
	$\leftrightarrow\ T\sin\theta + T\sin\alpha = m \times \frac{12a}{5} \times \omega^2$	M1	3.3
	$\frac{3}{5}T + \frac{4}{5}T = \frac{12ma\omega^2}{5} \quad (7T = 12ma\omega^2)$	A1	1.1b
	Complete strategy	M1	3.1b
	$\Rightarrow 35mg = 12ma\omega^2, \quad \omega = \sqrt{\frac{35g}{12a}}$	A1	1.1b
		(6)	
			(6 marks)

Notes:

1	M1	Resolve vertically. All terms needed. Condone sign errors. Condone sin/cos confusion
	A1	Correct substituted equation
	M1	Circular motion. All terms needed. Condone sign errors. Condone sin/cos confusion
	A1	Correct substituted equation
	M1	Complete strategy: formed sufficient equations and solving for ω.
	A1	Eliminate T to obtain ω. Accept exact equivalent

Question	Scheme	Marks	AOs
2(a)	Area of $L = 36a^2 - \frac{9}{2}a^2\left(=\frac{63}{2}a^2\right)$	B1	1.2
	Moments equation to find the distance	M1	2.1
	$36a^2 \times 3a - \frac{9}{2}a^2 \times a\left(=\frac{207}{2}a^3\right) = \frac{63}{2}a^2 \times \bar{x}$	A1ft	1.1b
	$\Rightarrow \bar{x} = \frac{207}{63}a = \frac{23}{7}a$ *	A1*	2.2a
		(4)	
(b)	Mass ratios $63:27:90$	B1	1.1b
	Complete strategy to find the centre of mass	M1	3.1b
	$\frac{23}{7}a \times \frac{63}{2}a^2M + a \times \frac{9}{2}a^2 \times 3M = d \times a^2M\left(\frac{63}{2} + 3 \times \frac{9}{2}\right)$ $\left(117a^3 = d \times 45a^2\right)$	A1ft	1.1b
	$d = \frac{13}{5}a$	A1	1.1b
	$\tan\theta = \frac{6a - d}{d}\left(=\frac{17}{13}\right)$	M1	3.1b
	$\theta = 52.6$ (53 or better)	A1	1.1b
		(6)	
			(10 marks)

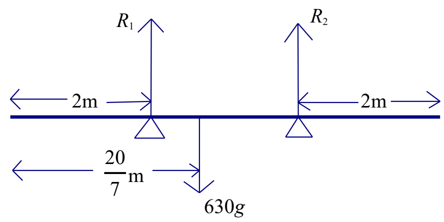
Notes:

(a)	B1	Correct area of L seen or implied
	M1	moments about EF or a parallel axis. Condone slips but needs to be dimensionally correct and a clear attempt to combine elements correctly.
	A1ft	Correct unsimplified moments equation. Follow their $\frac{63}{2}a^2$
	A1*	Obtain given result from correct working
(b)	B1	Correct mass ratios – any equivalent form
	M1	Complete strategy: use moments to find distance of centre of mass of template from any side
	A1ft	Correct unsimplified equation. Follow their mass ratios
	A1	Correct distance: $d = \frac{13}{5}a$ from AE or AC, $d = \frac{17}{5}a$ from CD or DE
	M1	Complete strategy: use of their distances to find a relevant angle. For their d. Condone reciprocal
	A1	2 s.f. or better 52.59464....

Question	Scheme	Marks	AOs
3(a)	Max speed $= a\omega = 1.2$, Max acceleration $= a\omega^2 = 4.8$	B1	3.4
	Solve for a or ω	M1	1.1b
	$a = 0.3$ (m)	A1	1.1b
	$T = \dfrac{2\pi}{\omega}$	M1	3.4
	$(\omega = 4,)\ T = \dfrac{\pi}{2}$(s)	A1	1.1b
		(5)	
(b)	$v^2 = 16(0.09 - 0.01)$	M1	3.4
	$v = \dfrac{4\sqrt{2}}{5}$ m s^{-1} $(1.13$ m s$^{-1})$	A1ft	1.1b
		(2)	
(c)	$x = 0.3\sin 4t$	B1ft	2.2a
	$\sin 4t = \dfrac{1}{3}$ Required time $= 4t$	M1	3.1a
	$= 0.340$ (s)	A1	1.1b
		(3)	
			(10 marks)

Notes:

(a)	B1	Use the model to form simultaneous equations
	M1	Solve for one unknown
	A1	a correct
	M1	Use the model to find T
	A1	T correct
(b)	M1	Use the model to find v
	A1ft	Follow their $a > 0.1$ and ω
(c)	B1ft	Use values to deduce correct expression for x. Follow their $a > 0.1$ and ω
	M1	Complete strategy to find required time
	A1	2 s.f or better (0.3398…)

Question	Scheme	Marks	AOs
4(a)	Total mass $=\int_0^6 k\left(2-\frac{x}{12}\right)\mathrm{d}x = k\left[2x-\frac{x^2}{24}\right]_0^6$	M1	2.1
	$630 = k\left(12-\frac{3}{2}\right)$	M1	1.1b
	$630 = k\left(\frac{21}{2}\right) \Rightarrow k = 630\times\frac{2}{21} = 60$ *	A1*	1.1b
		(3)	
(b)	Taking moments about the base: $\int_0^6 60x\left(2-\frac{x}{12}\right)\mathrm{d}x$	M1	3.4
	$=60\int_0^6\left(2x-\frac{x^2}{12}\right)\mathrm{d}x = 60\left[x^2-\frac{x^3}{36}\right]_0^6 (=1800)$	A1	1.1b
	$\Rightarrow 630d = 1800$	M1	3.4
	$d=\frac{1800}{630}=\frac{20}{7}$ (m)	A1	1.1b
			
	Form sufficient equations to solve for R_1 and R_2 :	M1	3.1b
	(using LH support) $630g\times\frac{6}{7} = R_2\times 2$ or (using RH support) $630g\times\frac{8}{7} = R_1\times 2$	A1ft	1.1b
	Second moments equation or ↕ $R_1 + R_2 = 630g$	A1ft	1.1b
	Reactions: 3500 (N) and 2600 (N)	A1	1.1b
		(8)	
			(11 marks)

Notes:		
(a)	M1	Use integration (usual rules)
	M1	Use limits and given mass to solve for k
	A1*	Show sufficient working to justify given answer
(b)	M1	Use the model to find the moment about the base (usual rules for integration)
	A1	Correct integration
	M1	Use the model to complete the moments equation. Require their 1800 and 630 used correctly
	A1	Any equivalent form (2.86 or better)
	M1	Use moments and / or vertical resolution to form sufficient equations to solve for required forces. Dimensionally correct and all terms included
	A1ft	First correct unsimplified equation. Follow their $d \neq 3$
	A1ft	Second correct unsimplified equation. Follow their $d \neq 3$
	A1	3530 (N), 2650 (N), $360g$ and $270g$

Question	Scheme	Marks	AOs
5(a)	Form differential equation in x and v and integrate: $\frac{d}{dx}\left(\frac{1}{2}v^2\right)=\frac{10}{x^2}-\frac{4}{x^3}$	M1	2.1
	$\Rightarrow \frac{1}{2}v^2=\int\frac{10}{x^2}-\frac{4}{x^3}dx=-\frac{10}{x}+\frac{2}{x^2}(+C)$	A1	1.1b
	$x=1, v=3 \Rightarrow \frac{9}{2}=-10+2+C \Rightarrow C=12\frac{1}{2}$	M1	2.1
	$v^2=25-\frac{20}{x}+\frac{4}{x^2}=\left(\left(5-\frac{2}{x}\right)^2\right)$	A1	1.1b
	$\Rightarrow v=5-\frac{2}{x}=\frac{5x-2}{x}$ *	A1*	1.1b
	Require positive root for $x=1, v=3$	B1	2.4
		(6)	
(b)	$\frac{dx}{dt}=\frac{5x-2}{x} \Rightarrow \int\frac{x}{5x-2}dx=\int 1dt$	M1	2.5
	$=\frac{1}{5}\int\frac{5x-2+2}{5x-2}dx=\frac{1}{5}\int 1+\frac{2}{5x-2}dx$	M1	2.1
	$\Rightarrow t=\frac{1}{5}x+\frac{2}{25}\ln(5x-2)(+C)$	A1 A1	1.1b 1.1b
	$[t]_0^T=\left[\frac{1}{5}x+\frac{2}{25}\ln(5x-2)\right]_1^4$	M1	2.1
	$T=\frac{4}{5}-\frac{1}{5}+\frac{2}{25}\ln\left(\frac{20-2}{5-2}\right)=\frac{3}{5}+\frac{2}{25}\ln 6$ *	A1*	2.2a
		(6)	
			(12 marks)

Notes:		
(a)	M1	Accept equivalent forms e.g. $v\frac{\mathrm{d}v}{\mathrm{d}x}=....$
	A1	Correct integration. Condone missing constant of integration.
	M1	Use boundary conditions to evaluate constant of integration
	A1	Correct expression for v^2. Any equivalent form.
	A1*	Obtain given answer correctly
	B1	Justify choice of positive root.
		A candidate who starts with the given answer and shows that it fits the differential equation can score M1A1 for correct unsimplified $v\frac{\mathrm{d}v}{\mathrm{d}x}$ or equivalent M1A1A1 for deducing the correct differential equation and checking that the boundary conditions fit the equation. They score no marks for making the choice between the positive and negative square root.
(b)		Condone no limits or incorrect limits on integrals for the first 4 marks
	M1	Form differential equation and separate variables
	M1	Rearrange to integrable form and attempt integration. NB: algebraic integration required - working towards a given answer.
	A1	One x term correct
	A1	All integration correct
	M1	Use limits correctly on definite integral (or to find C and hence) to find T
	A1*	Obtain given answer from correct working

Question	Scheme	Marks	AOs
6(a)	$\int \pi x^2 y \mathrm{d}y = \pi \int 2y^2 \mathrm{d}y$	M1	2.1
	$= \frac{2}{3}\pi \left[y^3 \right]_{\frac{1}{2}}^{2}$	M1	1.1b
	$\frac{2}{3}\pi \left(8 - \frac{1}{8} \right) = \frac{21}{4}\pi$	A1	1.1b
	Complete strategy	M1	3.1a
	$\bar{y} = \frac{21}{4}\pi \Big/ \frac{15}{4}\pi = \frac{21}{15}\left(= \frac{7}{5} \right) = 1.4 \text{ (cm)}$ *	A1*	2.2a
		(5)	
(b)	Use moments to find c of m of composite body	M1	3.1a
	$\frac{15}{4}\pi \times 0.9 + \frac{2}{3}\pi \times 8 \times \left(\frac{3}{8} \times 2 + 1.5 \right) = \left(\frac{45+64}{12} \right)\pi d$	A1 A1	1.1b 1.1b
	$d = \frac{369}{218}$ (1.69…..)	A1	1.1b
	Complete strategy to find α	M1	3.1b
	$\tan\alpha = \frac{1}{\text{their } d}$	A1ft	1.1b
	$\alpha = 30.6$ (31 or better)	A1	2.2a
		(7)	
			(12 marks)

Notes:		
(a)	M1	Attempt correct moments integral for rotation about y-axis (Algebraic integration required because question asks to demonstrate an exact answer.)
	M1	Correct use of correct limits for y
	A1	Any equivalent form
	M1	Complete strategy for $\bar{y}$ - integration and use of the given volume
	A1*	Obtain given answer from correct working
(b)	M1	Dimensionally correct. Condone use of 1.4 and 2.75
	A1	Unsimplified moments equation with at most one error. Condone use of 1.4 and 2.75
	A1	Correct unsimplified moments equation for distance of c of m from plane surface or distance of centre of mass from x-axis.
	A1	Correct distance $\left(\text{centre of mass } \frac{239}{109} \text{ from axis}\right)$ (2.19…..)
	M1	Complete strategy for α e.g using moments to find d and trig. to find a relevant angle
	A1ft	Correct trig for relevant angle (for their d)
	A1	Obtain correct angle. 3 s.f. or better $\alpha = 30.5739..$

Question	Scheme	Marks	AOs
7(a)	Equation for circular motion	M1	3.1b
	$mg\cos\theta(-R)=\dfrac{mv^2}{r}$	A1	1.1b
	$\cos\theta=\dfrac{5}{6}$	B1	1.2
	$(R=0)\ \Rightarrow\ \dfrac{5g}{6}=\dfrac{v^2}{r},\ v^2=\dfrac{5gr}{6}$ *	A1*	2.2a
		(4)	
(b)	At A, for the particle to be moving on the surface of the hemisphere require $R>0\ \Rightarrow\ R=mg-\dfrac{mu^2}{r}>0\ \Rightarrow\ u<\sqrt{gr}$	B1	2.4
		(1)	
(c)	Conservation of energy	M1	3.1a
	$\dfrac{1}{2}mv^2\left(=\dfrac{1}{2}mu^2+mgr(1-\cos\theta)\right)=\dfrac{1}{2}mu^2+mg\left(\dfrac{r}{6}\right)$	A1	1.1b
	$u^2=v^2-\dfrac{2gr}{6}\left(=\dfrac{gr}{2}\right)$	M1	1.1b
	$u=\sqrt{\dfrac{gr}{2}}$	A1	1.1b
		(4)	
(d)	Horizontal component $=\sqrt{\dfrac{5gr}{6}}\times\dfrac{5}{6}$	B1	3.1a
	Conservation of energy: $\dfrac{1}{2}mV^2=\dfrac{1}{2}m\dfrac{gr}{2}+mgr\left(=\dfrac{5mgr}{4}\right)$	M1	2.1
	$V=\sqrt{\dfrac{5gr}{2}}$	A1	1.1b
	Complete strategy to find the angle	M1	3.1a
	$\cos\alpha=\dfrac{5}{6\sqrt{3}},\ \alpha=61.2^\circ\ \Rightarrow$ downwards at 61.2° to the horizontal	A1	2.2a
		(5)	
		(14 marks)	

Notes:		
(a)	M1	Need all terms. Must be dimensionally correct. Condone sign errors and sin/cos confusion.
	A1	Correct unsimplified equation. Could be using $R = 0$.
	B1	Correct value for $\cos\theta$ seen or implied
	A1*	Set $R = 0$ and obtain given answer from correct working
(b)	B1	Correct justification of the restriction on u
(c)	M1	Dimensionally correct. Require all terms . Condone sign errors and sin/cos confusion.
	A1	Correct unsimplified equation. Allow marks if equation seen in (a) and used here.
	M1	Substitute to find u^2
	A1	Correct expression for u.
(d)	B1	Horizontal component correct
	M1	Use energy to find speed. Require all terms and dimensionally correct. Alt: find vertical component.
	A1	Correct component
	M1	Complete strategy to find the direction: e.g. any two sides of the velocity triangle and use of trig.
	A1	Correct angle to horizontal $61.2°$ or better (61.24……), or 1.0688….radians or equivalent