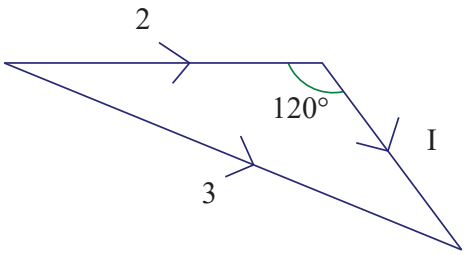
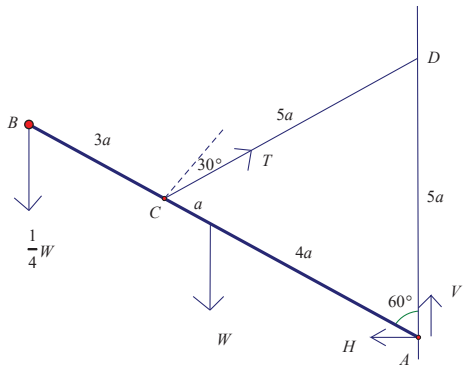
Question	Scheme	Mark	Notes
1	Accept column vectors throughout this question		
1a	Differentiate **r** (both components)	M1	In each component at least one power going down by 1
	$\mathbf{v}=\left(4t^3-16t\right)\mathbf{i}+\left(12t-3\sqrt{t}\right)\mathbf{j}$	A1	Accept as two separate components
	Equate **i** component of **v** to zero and solve for t	DM1	Dependent on the first M1. Must start with a component of the vector for **v** Can have more than one value at this stage.
	Obtain $\left(24-3\sqrt{2}\right)\mathbf{j}\ \left(\text{m s}^{-1}\right)$	A1	Accept $20\mathbf{j}\left(\text{m s}^{-1}\right)$ or better. (19.757359…) Correct answer only Answer must be a vector
		[4]	
1b	Differentiate **v** (both components)	M1	For differentiating their **v**, even if the method for obtaining it was incorrect. Their **v** must be a vector. In each component at least one power going down by 1
	Obtain $\mathbf{a}=\left(12t^2-16\right)\mathbf{i}+\left(12-\frac{3}{2}t^{-\frac{1}{2}}\right)\mathbf{j}$	A1	Any equivalent form for acceleration
	Obtain $176\mathbf{i}+\frac{45}{4}\mathbf{j}\left(\text{m s}^{-2}\right)$	A1	Accept $180\mathbf{i}+11\mathbf{j}\left(\text{m s}^{-2}\right)$ or better ISW
		[3]	
		(7)	

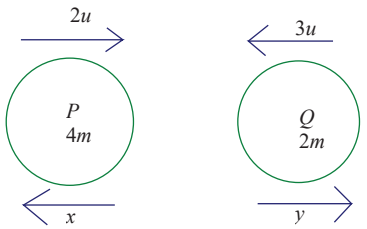
Question	Scheme	Mark	Notes
2a	<table><tr><td></td><td>$PQUY$</td><td>$RSTU$</td><td>$VWXY$</td></tr><tr><td>Mass</td><td>$16a^2$</td><td>$2\times4a^2$</td><td>$2\times4a^2$</td></tr><tr><td>From PX</td><td>$2a$</td><td>$5a$</td><td>a</td></tr></table>	B1 B1	Correct mass ratios (accept 2:1:1) Correct vertical distances
	Moments about PX or a parallel axis	M1	Dimensionally correct equation. All terms required Allow for an equation within a vector equation.
	$16a^2\times2a+8a^2\times5a+8a^2\times a=32a^2d$ $\left(=(16+8+8)a^2\times d\right)$ or equivalent for a parallel axis	A1	Correct unsimplified equation Allow for an equation within a vector equation. Could have y for d here o.e.
	$80a=32d\Rightarrow d=\frac{5}{2}a$ *	A1*	Obtain given answer from correct working. At least one stage of simplifying the moments equation is required. e.g. $32a^3+40a^3+8a^3$ seen, or they might have simplified the mass ratios at the start. Must get to $d=\ldots$ in the final line
		[5]	
2b	Moments about PQ or a parallel axis	M1	Dimensionally correct equation. All terms required
	$16a^2\times2a+8a^2\times3a+8a^2\times5a$ $=(16+8+8)a^2\times h$ or equivalent for a parallel axis	A1ft A1	Unsimplified equation with at most one error. Follow their mass ratios. Correct unsimplified equation
	$\Rightarrow h=3a$ from PQ	A1	a from YT, $3a$ from XW
	The working for the first 4 marks must be seen or used in part (b)		
	Correct use of trig. to find the tangent of a relevant angle.	M1	With *their* $3a$ e.g. $\tan\theta=\frac{3}{4-\frac{5}{2}}$
	$\tan\theta=2$	A1	Correct only
		[6]	
2c	Complete method to obtain an equation in M and F	M1	e.g. *M*oments about Q Dimensionally correct equation.
	$3a\times Mg=4a\times F$	A1	Correct unsimplified equation Condone if a missing throughout
	$F=\frac{3}{4}Mg$	A1	Correct only
		[3]	
		(14)	

Question	Scheme	Mark	Notes
3	Form impulse-momentum equation	M1	Dimensionally correct. Accept answers in "vector" form, or as separate components. Condone sine / cosine confusion.
	One correct equation	A1	e.g. one correct component of $\begin{pmatrix} I\cos 60° \\ I\sin 60° \end{pmatrix} = \frac{1}{4}\left[\begin{pmatrix} 12\cos\alpha \\ 12\sin\alpha \end{pmatrix} - \begin{pmatrix} 8 \\ 0 \end{pmatrix}\right]$ or $\left(= \begin{pmatrix} 3\cos\alpha - 2 \\ 3\sin\alpha \end{pmatrix}\right)$ $\begin{pmatrix} I\cos 60° \\ I\sin 60° \end{pmatrix} = \frac{1}{4}\left[\begin{pmatrix} v_x \\ v_y \end{pmatrix} - \begin{pmatrix} 8 \\ 0 \end{pmatrix}\right]$ $\left(= \begin{pmatrix} 3\cos\alpha - 2 \\ 3\sin\alpha \end{pmatrix}\right)$ if working parallel and perpendicular to the initial direction or one of $8\sin 60° = 12\cos(30° + \alpha)$ or $I = 0.25(12\sin(30° + \alpha) - 8\cos 60°)$ if working parallel and perpendicular to the impulse
	Form a second impulse-momentum equation	M1	
	correct second equation	A1	
	Complete method to solve for I	DM1	Dependent on the two preceding M marks. e.g. from $36 = (I+4)^2 + 3I^2 \quad (4I^2 + 8I - 20 = 0)$
	$I = \sqrt{6} - 1$ (or 1.45 or 1.4)	A1	
		[6]	
3 alt		**M1**	Use of $I = mv - mu$ to draw a vector triangle. Dimensionally consistent.
		A1	Correct diagram
	Form an equation in I	**M1**	e.g. by using cosine rule
	$4 + I^2 - 4I\cos 120° = 9$	**A1**	Correct unsimplified equation A correct cosine rule equation can imply the first M1A1 if no diagram seen
	Solve for I	**DM1**	Dependent on the 2 preceding M marks $I^2 + 2I - 5 = 0$
	$I = \sqrt{6} - 1$ (or 1.45 or 1.4)	**A1**	
		(6)	

Question	Scheme	Mark	Notes
4a	$4-gT_1=0$ or $T_1=\dfrac{\sqrt{32}\sin 45°}{g}$	M1	Complete method using *suvat*
	$T_1=0.408\,(0.41)$	A1	3 sf or 2 sf only. Not $\frac{20}{49}$
		[2]	
4b	Height of Q above P:	M1	Complete method using *suvat* and 7 and 4 for the initial vertical components
	$h=\left(7T_1-\frac{1}{2}gT_1^2\right)-\left(4T_1-\frac{1}{2}gT_1^2\right)\quad(=3T_1)$	A1	Correct unsimplified expression in T_1 or their T_1 They do not need to have substituted for T_1 (2.0408… - 0.8163…)
	$h=1.2$ (m)	A1ft	2 sf only $\left(3\times \textit{their}\ T_1\right)$
		[3]	
4c	Correct time for P to reach B. ($\frac{40}{49}$, 0.816, or $\frac{8}{g}$ or better)	B1	Seen or implied.
	Vertical component of speed $=7-g\times 2T_1\quad(=-1)$	M1	Complete method using *suvat* with $2T_1$ or their t for the time at B M0 if not using 7
	$\tan\alpha=\pm\dfrac{\textit{their}\ 1}{5}$	M1	Correct use of *their* 1 and 5 to find an equation in a relevant angle (e.g. 90 – α)
	$\alpha=11$	A1	11 or better (e.g. 11.3)
	If they use T_1 in place of $2T_1$ can score B0M0M1A0		
		[4]	
4d	Form an equation in T_2 only	M1	Complete method using *suvat* and perpendicular gradients. e.g. $\begin{pmatrix}5\\7\end{pmatrix}\cdot\begin{pmatrix}5\\7-gT_2\end{pmatrix}=0$ Condone sign errors (Vertical component of speed $=\pm\frac{25}{7}$) (perpendicular direction is downwards at 35.5° to the horizontal)
	$-\dfrac{25}{7}=7-gT_2$	A1	Correct unsimplified equation
	$T_2=1.08$ or $T_2=1.1$	A1	3 sf or 2 sf only
		[3]	
		(12)	

Question	Scheme	Mark	Notes
5a	Use of $P = Fv$ $\left(F = \frac{500}{6}\right)$	M1	
	Equation of motion	M1	Dimensionally correct. Required terms and no extras
	$F - 60 = 80a$	A1	Correct unsimplified equation in F
	$a = \frac{7}{24}\left(\text{m s}^{-2}\right)$	A1	0.29 or better (0.291666666..)
		[4]	
5b	Gain in KE = $\frac{1}{2} \times 80 \times 8^2 \text{(J)} \left(= 2560\text{(J)}\right)$ Gain in GPE = $80 \times 9.8 \times 300 \text{ (J)} \left(= 235200\text{(J)}\right)$ Work done against resistance $= 20\,000 \times 60$	B1 B1	Any one correct (seen or implied) A second term correct (seen or implied) (KE gain + GPE gain = 237760 J)
	Use of *suvat* and $F = ma$ is M0A0A0		
	expression for combined work and energy	M1	All terms required and no double counting. Mass replaced with 80. Condone sign errors. Dimensionally correct. Condone error in zeros in $20\,000$
	Total work done $= 40 \times 64 + 80 \times 9.8 \times 300 + 20\,000 \times 60$	A1	Correct unsimplified expression for the work done
	$1440\left(\text{kJ}\right)$ or $1400\left(\text{kJ}\right)$	A1	Accept answers in joules. 3 sf or 2 sf (1437760)
		[5]	
5c	Equation of motion	M1	Dimensionally correct. Required terms and no extras
	$F - 60 - 80g \times \sin\alpha = 0$ $\frac{P}{7} - 60 - 80g \times \frac{1}{20} = 0$	A1 A1	Unsimplified equation in P or F with at most one error Correct unsimplified equation in P
	$P = 694$ or $P = 690$	A1	3sf or 2 sf only
		[4]	
		(13)	

Question	Scheme	Mark	Notes
6a			
	Moments about A: **M0 if there is no resolving**	M1	Need all terms and no extras. Dimensionally consistent. Condone sign errors and sine/cosine confusion.
	$4a\cos 30°\times W+8a\cos 30°\times\frac{W}{4}$ $=5a\cos 30°\times T$	A1	Correct unsimplified equation
	$6W=5T\Rightarrow T=\frac{6}{5}W$ *	A1*	Obtain **given answer** from correct working, e.g. show cancelling of the common factors or some simplification of the moments equation
		[3]	
6b	They need 2 equations. Award M1A1 for the first correct equation seen and M1A1 for the second correct equation. Common alternatives: $M(B)$: $T\cos 30°\times 3a+V\cos 30°\times 8a=W\cos 30°\times 4a+H\cos 60°\times 8a$ $M(C)$: $W\cos 30°\times a+H\cos 60°\times 5a=\frac{1}{4}W\cos 30°\times 3a+V\cos 30°\times 5a$ Perpendicular to rod: $\frac{1}{4}W\cos 30°+W\cos 30°+H\cos 60°=T\cos 30°+V\cos 30°$ Parallel to rod: $\frac{1}{4}W\cos 60°+T\cos 60°+W\cos 60°=V\cos 60°+H\cos 30°$		
	First equation dimensionally correct. Condone sine/cosine confusion and sign errors	M1	e.g. Resolve horizontally
	Correct unsimplified equation	A1	$H=T\cos 30°\quad\left(H=\frac{3\sqrt{3}}{5}W\right)$
	Second equation dimensionally correct. Condone sine/cosine confusion and sign errors	M1	e.g. resolve vertically
	Correct unsimplified equation	A1	$V+T\cos 60°=W+\frac{W}{4}\quad\left(V=\frac{13}{20}W\right)$
	$\lvert R\rvert=\sqrt{V^2+H^2}$ or $\lvert R\rvert^2=V^2+H^2$	DM1	Correct use of Pythagoras Dependent on two preceding M marks.
	$\lvert R\rvert=\frac{W}{20}\sqrt{3\times 144+169}=\frac{\sqrt{601}}{20}W$	A1	$1.2W$ or better (1.22576…)
		[6]	
		(9)	

Question	Scheme	Mark	Notes
7a			
	Equation for CLM	M1	Dimensionally correct. All terms required. Condone sign errors.
	$8mu-6mu=2my-4mx$ $(u=y-2x)$	A1	Correct unsimplified equation
	Equation for kinetic energy $(\frac{1}{2}$ or 2 must be used$)$	M1	Dimensionally correct. Correct masses paired with correct velocities. All terms required. No sign errors. Condone 2 on the wrong side.
	$2mx^2+my^2=\frac{1}{2}(2m\times4u^2+m\times9u^2)$ $(17u^2=4x^2+2y^2)$	A1	Correct unsimplified equation
	Solve for y: $17u^2=2y^2+(y-u)^2$ $\Rightarrow 3y^2-2yu-16u^2=0$	DM1	Some working must be shown to obtain the quadratic in y (and u). Dependent on the preceding M marks $((3y-8u)(y+2u)=0)$
	$\Rightarrow y=\frac{8}{3}u$ *	A1*	Obtain given answer from correct working
		[6]	
7b	Use of Impact Law: $x+y=e\times5u$	M1	Condone sign errors but must be used the right way round.
	$e=\dfrac{\frac{1}{2}\left(\frac{8}{3}u-u\right)+\frac{8}{3}u}{5u}$	A1	Correct unsimplified equation. $\left(x=\dfrac{5u}{6}\right)$
	$=\dfrac{7}{10}$	A1	Correct only
		[3]	
7c	Velocity of Q after impact $=f\times\dfrac{8}{3}u$	B1	Allow $\pm$
	No collision if $f\times\frac{8}{3}u\le\frac{5}{6}u$ i.e. speed of $P\ge$ speed of Q	M1	Correct inequality with their values Accept strict inequality. Dimensionally correct.
	$\Rightarrow 0<f\le\frac{5}{16}$	A1	Both ends required. $(0<f\le0.3125)$
		[3]	
7d	Use of $I=\pm2m\left(y-\left(-\dfrac{1}{4}y\right)\right)$	M1	Subtraction seen or implied with *their* $\frac{1}{4}y$ Requires correct mass Requires correct impact law
	$\lvert I\rvert=\dfrac{20}{3}mu$	A1	Or equivalent. Must be positive $6.7mu$ or better Condone $-\dfrac{20}{3}mu\rightarrow\dfrac{20}{3}mu$ with no explanation
		[2]	
		(14)	