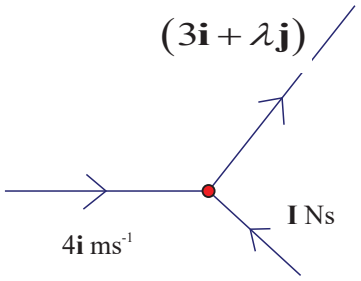
Question Number		Mark	Note
	Use the mass to determine which part of the system is being considered.		
1a	Equation of motion for the car and trailer or for each **with** T eliminated	M1	Need all terms. Dimensionally correct. M0 if they use power as a force. Condone sign errors.
	$F-350-200=(500+150)a$	A1	Correct unsimplified equation in F and a
	Use of $(F=)\ \frac{10500}{14}\ (=750)$ seen	M1	Independent M0 for just $14F = 10500$, with no subsequent working.
	$a=\frac{4}{13}$	A1	Accept 0.31 or better. 0.30769……
		[4]	
1b	Equation of motion for the car or the trailer to give an equation in T and a only.	M1	Need all relevant terms. Dimensionally correct. M0 if they use power as a force. Condone sign errors.
	$T-200=150\times\ '\frac{4}{13}'$ or $750-350-T=500\times\ '\frac{4}{13}'$	A1**ft**	Correct unsimplified equation, follow their a.
	$T=\frac{3200}{13}$	A1	Accept 250 or better 246.15338…….
		[3]	
		(7)	

Question Number		Mark	Note
2a			
	Impulse momentum equation	M1	Must be subtracting but condone subtraction in the wrong order Condone poor notation e.g. $\sqrt{29}=2(3\mathbf{i}+\lambda\mathbf{j})-2(4\mathbf{i})\left(=2(-\mathbf{i}+\lambda\mathbf{j})\right)$
	$(\mathbf{I}=)\ 2(3\mathbf{i}+\lambda\mathbf{j})-2(4\mathbf{i})\left(=2(-\mathbf{i}+\lambda\mathbf{j})\right)$	A1	Correct unsimplified expression for **I** Accept $2(\mathbf{i}-\lambda\mathbf{j})$
	Correct use of magnitude for their impulse e.g. $29=4(1+\lambda^2)$	M1	Allow with square roots on both sides
	$\lambda=2.5$	A1	Or equivalent. Must be positive.
		[4]	
2b	Correct use of trig or scalar product to find ratio for a relevant angle, for $4\mathbf{i}$ and their **I** e.g. $\tan\theta=\pm\frac{2}{2\lambda}$ or $\pm\frac{2\lambda}{2}$ or equivalent sin or cos equation.	M1	M0 if they use $(3\mathbf{i}+\lambda\mathbf{j})$ M0 for $\tan^{-1}\frac{2}{5}-\tan^{-1}4$ or similar
	Correct ratio for a relevant angle e.g. $\tan\theta=\pm\frac{2}{5}$ or $\pm\frac{5}{2}$ or equivalent sin or cos equation e.g. $\cos\theta=\frac{-2}{\sqrt{29}}$	A1ft	Follow their λ
	$111.801409...°$ or 1.9513027…. radians	A1	Accept $110°$ or 2, 2.0 radians or better
		[3]	
		(7)	

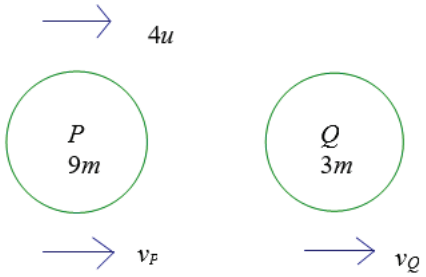
Question Number		Mark	Note
	Accept column vectors throughout apart from in the answer to part (b).		
3a	Use of $\mathbf{a}=\frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t}$ $\left(\mathbf{a}=2\mathbf{i}+(2t-5)\mathbf{j}\right)$	M1	At least two powers of t going down by 1.
	$t=4\Rightarrow\mathbf{a}=2\mathbf{i}+3\mathbf{j}\left(\mathrm{m\,s^{-2}}\right)$	A1	Isw if they find the magnitude.
		[2]	
3b	Use $\mathbf{r}=\int\mathbf{v}\,\mathrm{d}t$	M1	At least two powers of t going up by 1
	$\mathbf{r}=\left(t^2+3t+A\right)\mathbf{i}+\left(\frac{1}{3}t^3-\frac{5}{2}t^2-15t+B\right)\mathbf{j}$	A1	Allow without constant of integration
	Use of $t=1$, $\mathbf{r}=6\mathbf{i}-2\mathbf{j}$ to **find** the (vector) constant of integration	M1	$\left(1+3+A=6,\quad \frac{1}{3}-\frac{5}{2}-15+B=-2\right)$ Must find A and B.
	$\left(t^2+3t+2\right)\mathbf{i}+\left(\frac{1}{3}t^3-\frac{5}{2}t^2-15t+\frac{91}{6}\right)\mathbf{j}$	A1	Cao (exact)
		[4]	
3c	Use the velocity and the direction to form an equation in T.	M1	Condone if 5 and -3 on the wrong sides of the equation.
	$-3\times(2T+3)=5\times\left(T^2-5T-15\right)$ oe	A1	Correct unsimplified equation in T or t
	$5T^2-19T-66=0\quad\left((5T+11)(T-6)=0\right)$ $\Rightarrow\quad T=6$	**D**M1	Simplify and solve for T, dependent on M1.
	Use of Pythagoras with their T: $\left(v=\sqrt{(2\times6+3)^2+\left(6^2-5\times6-15\right)^2}\right)$	M1	Independent but not available if they have more than one positive T value.
	$v=\sqrt{306}\left(=3\sqrt{34}\right)\left(\mathrm{m\,s^{-1}}\right)$	A1	Must be exact, accept either. Isw if they go on to give a decimal.
		[5]	
		(11)	

Question Number		Mark	Note
4a	<table><tr><td></td><td>*ABDE*</td><td>*BCD*</td><td>*PQR*</td><td>template</td></tr><tr><td>Mass</td><td>16</td><td>8π</td><td>2π</td><td>$6\pi+16$</td></tr><tr><td>From *BD*</td><td>$-a$</td><td>$\frac{16a}{3\pi}$</td><td>$\frac{8a}{3\pi}$</td><td>(*d*)</td></tr></table>	B1 B1	Correct mass ratios Correct distances from *BD* or from a parallel axis (Condone sign error)
	Moments about *BD*, using their table **N.B**. c of m of 'RH part' = $\frac{112a}{18\pi}$ then $\left(\frac{112a}{18\pi}\times 6\pi\right)-16a=(6\pi+16)d$	M1	Allow use of a parallel axis. Dimensionally consistent terms. All terms required. Correct pairings Condone sign error(s)
	$-16a+8\pi\times\frac{16a}{3\pi}-2\pi\times\frac{8a}{3\pi}=(6\pi+16)d$	A1	Correct unsimplified equation for their parallel axis.
	$d=\frac{64a}{3(16+6\pi)}=\frac{32a}{3(8+3\pi)}$ *	A1*	Obtain **given answer** from full and correct working. Need *d* = not $\bar{x}$
		[5]	
4b	Vertical distance of c of m from *B* = 4*a*	B1	Seen or implied
	Use of trigonometry to obtain a relevant angle $\tan\phi=\frac{32a}{3(8+3\pi)\times 4a}$ e.g. $\left(=\frac{8}{3(8+3\pi)}\right)\ (=0.153....)$	M1	M0 if they don't use 4*a*
	$\phi=8.7$	A1	8.7 or better (8.700966...)
		[3]	
4c	Moments about *B* or any other complete method to obtain in equation in *k*, *W* and *a* only. e.g. resolve horizontally (*X* = *W*) and	M1	All terms required. Terms dimensionally consistent. Condone sign

	vertically ($Y = (15 + k)W$) and Moments about another point.		errors.
	$\frac{32}{3(8+3\pi)}a \times 15W - 2akW = 8a \times W$	A1 A1	Unsimplified equation with at most one error Correct unsimplified equation
	$(k) = \frac{48-12\pi}{8+3\pi}$ or equivalent single fraction	A1	0.59 or better (0.59116…..)
		[4]	
		(12)	

Question Number		Mark	Note
5a	Correct use of Pythagoras e.g. $AC = \sqrt{(25a)^2 - (7a)^2} = 24a$ *	B1*	Allow quotation of the Pythagorean triple without detailed working. Need '*AC* =' B0 if error(s) in working e.g. $\sqrt{576a}$
		[1]	
5b	Moments about *A* or equivalent complete method.	M1	Dimensionally consistent. Condone sine/cosine confusion. Allow M1A0A0 if *a*'s never appear. M0 if they use 25*a* instead of 24*a*
	$W \times 15a \times \cos\theta = 24aN$	A1	Correct unsimplified equation
	$N = \frac{15}{25}W = \frac{3}{5}W$ *	A1*	Obtain **given answer** from correct working. Must see use of $(\cos\theta =)\frac{24}{25}$
		[3]	
5c	Resolve vertically:	M1	First equation (enter first on ePEN). Condone sine/cosine confusion. Condone sign error.
	$R_A + N\cos\theta = W \left(R_A = \frac{53}{125}W \right)$	A1	Correct unsimplified equation
	Resolve horizontally:	M1	Second equation (enter second on ePEN). Condone sine/cosine confusion. Condone sign error.
	$F_A = N\sin\theta \left(= \frac{21}{125}W \right)$	A1	Correct unsimplified equation
	Alternatives for either of the above equations: Resolve perpendicular to the rod: $N + R_A\cos\theta = W\cos\theta + F_A\sin\theta$ Resolve parallel to the rod: $W\sin\theta = F_A\cos\theta + R_A\sin\theta$ M(C): $9a \times W\cos\theta + 24a \times F_A\sin\theta = 24a \times R_A\cos\theta$		

	M(*B*): $6aN + 30a \times R_A \cos\theta = 30a \times F_A \sin\theta + 15a \times W \cos\theta$ M(*G*): $15a \times F_A \sin\theta + 9aN = 15a \times R_A \cos\theta$		
	Use $F_A = \mu R_A$ to obtain an equation in μ only.	**D**M1	Substitute their values correctly, dependent on both M's, to obtain an equation in μ only. This mark is only available if they use the equations for which they have been awarded marks.
	$\mu = \frac{21}{53}$ or an equivalent fraction	A1	Accept 0.4, 0.40 or better (0.39622….)
		[6]	
		(10)	

Question Number		Mark	Note
6a			
	Use of CLM	M1	Need all terms. Dimensionally consistent Must be using the correct masses.
	$9m\times 4u = 9mv_P + 3mv_Q$	A1	Correct unsimplified equation
	Impact Law	M1	Used the correct way round $\left(v_{\text{sep}} = e\times v_{\text{app}}\right)$
	$v_Q - v_P = 4ue$	A1	Correct unsimplified equation
	Obtain $\left(v_Q\right) = 3u\left(1+e\right)$ *	A1*	Obtain given answer correctly with at least one line of intermediate working.
		[5]	
6b	$v_P = u\left(3-e\right)\left(=\frac{7}{3}u\right)$ or negative of these	B1	Seen or implied
	KE lost $=\frac{1}{2}.9m.\left(4u\right)^2 - \frac{1}{2}.9m.\left(v_P\right)^2 - \frac{1}{2}.3m.\left(v_Q\right)^2$	M1	Correct form for KE. Need all terms. Condone subtraction the wrong way round i.e. all signs reversed.
	$=\frac{1}{2}.9m.\left(4u\right)^2 - \frac{1}{2}.9m.\left(\frac{7u}{3}\right)^2 - \frac{1}{2}.3m.\left(5u\right)^2$ $(=72mu^2 - 24.5mu^2 - 37.5mu^2)$ $(=18mu^2(1-e^2))$	A1ft	Correct unsimplified expression in *m* and *u* only Follow their v_P
	$(k=)10$	A1	cao
		[4]	

6c	$w = 5uf$ or $-5uf$	B1	Or equivalent. Seen or implied Condone a sign error here.
	$21mu = 3m \times 5u - 3m \times w$ $(w = -2u)$	M1	Impulse momentum equation. Dimensionally correct. Must be using $3m$. Condone sign error and in terms of e.
	$(f =) \frac{2}{5}$ oe	A1**cso**	
		[3]	
		(12)	

Question Number		Mark	Note
7a	$F_{\max} = \frac{1}{3} \times 0.5g \times \frac{12}{13}$	M1	Use of $F = \mu R$. Allow $\cos\alpha$ Condone sine/cosine confusion
	Work done $= F_{\max} \times 5$	DM1	For their $F_{\max}$ Dependent on previous M1
	Work done = 7.5 (J)	A1	7.5(J) or 7.54 (J) or $\frac{10g}{13}$ Not $\frac{98}{13}$ (follows substitution for g).
		[3]	
7b	Work-energy equation	M1	Need all terms. Condone sign errors and sine/cosine confusion.
	$\frac{1}{4}U^2 = \frac{1}{4}.26^2 + \frac{1}{2}g.5\sin\alpha + their\ \text{WD}$	A1ft A1ft	Unsimplified equation with at most one error Correct unsimplified equation
	(U =) 27	A1	27 or 27.3 (2 sf or 3 sf)
		[4]	
7c	Use of $v = u + at$	M1	Complete method using *suvat*
	$-26\sin\alpha = 26\sin\alpha - gT \quad (20 = gT)$ **OR** $0 = 26\sin\alpha \times T - \frac{1}{2}gT^2$ **OR** $T = 2 \times \frac{26\sin\alpha}{g}$	A1	Correct unsimplified equation in T or t.
	(T =) 2.0	A1	2, 2.0 or 2.04 (2sf or 3sf)
		[3]	
7d	Use of $s = ut + \frac{1}{2}gt^2$	M1	Complete method for time to ground using *suvat*
	$-5\sin\alpha = 26\sin\alpha t - \frac{1}{2}gt^2$	A1	Unsimplified equation with at most one error

	$(t = 2.2177...)$	A1	Correct unsimplified equation
	ALT 1: time up + time down	M1	Complete method using *suvat*
	$\frac{26\sin\alpha}{g} + \frac{2}{g}\sqrt{\left(\frac{(26\sin\alpha)^2}{2g} + 5\sin\alpha\right)}$ =(1.0204 + 1.1973)	A1 A1	Unsimplified equation with at most one error Correct unsimplified equation
	Horizontal distance, $X = 26\cos\alpha \times t$ (53.22)	**D**M1	Use of $u\cos\alpha t$ or equivalent, dependent on M1.
	Total distance $= 5\cos\alpha + 26\cos\alpha \times t$	M1	Use of: their $X + 5\cos\alpha$
	$= 58\ (\text{m})$	A1	58 or 57.8 (2sf or 3sf)
		[6]	
		(16)	