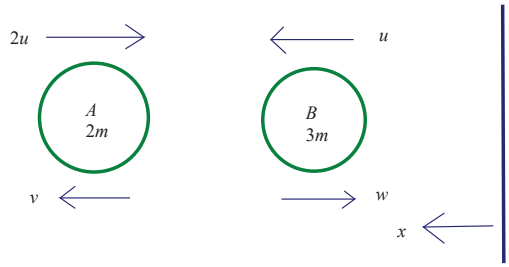
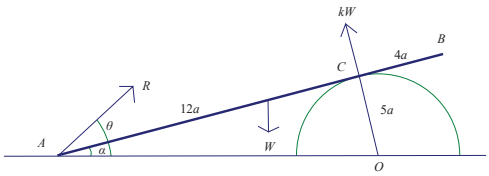
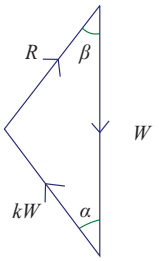
1a	Use of $\mathbf{I} = m\mathbf{v} - m\mathbf{u}$	M1	Condone subtraction in the wrong order.
	$\begin{pmatrix}-4\\6\end{pmatrix} = \frac{1}{2}\begin{pmatrix}x-2\\y-4\end{pmatrix}$	A1	Correct unsimplified equation Any equivalent form. Allow with **v**
	$\mathbf{v} = -6\mathbf{i} + 16\mathbf{j}\left(\text{m s}^{-1}\right)$	A1	Correct only. Seen or implied SR: Allow 3/3 if stop at $\mathbf{v} = 6\mathbf{i} - 16\mathbf{j}\left(\text{m s}^{-1}\right)$
	$\lvert\mathbf{v}\rvert = \sqrt{(-6)^2 + 16^2}$	M1	Correct use of Pythagoras with their **v**
	$= \sqrt{292}\ \left(= 2\sqrt{73}\right)\left(\text{m s}^{-1}\right)$	A1	Correct simplified value. 17 or better (17.088……)
			Allow 5/5 if working from the negative of the velocity.
		[5]	
1b	Correct use of trigonometry to find 2 relevant angles - as values or in inverse tangent form	M1	For their **v** e.g. $\pm 69.44..°, 63.43..°$ or $\pm 1.212..., 0.4636..$
	$\theta = \left(180° - \tan^{-1}\frac{16}{6}\right) - \tan^{-1}\frac{4}{2}$	A1ft	Correct unsimplified expression for θ Any equivalent form
	$= 47°$	A1	$47°$ or better (47.121..) $312.9°$ Accept radians (0.8224..)
		[3]	
1b alt	Use of scalar product with two relevant vectors	M1	For their **v**
	$\theta = \cos^{-1}\left(\frac{-12+64}{\sqrt{20}\sqrt{292}}\right)$	A1ft	Correct unsimplified expression for $\cos\theta$ or equivalent
	$= 47°$	A1	$47°$ or better (47.121..) $312.9°$ Accept radians (0.8224..)
		[3]	
		(8)	

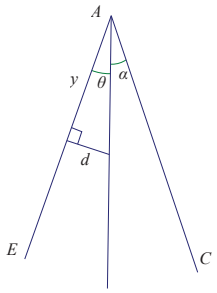
2.a	Equation of motion for car and trailer	M1	Need all terms. Dimensionally correct. Condone sin/cos confusion and sign errors.
	$F-300-150-\frac{200g}{20}-\frac{600g}{20}=0$ $\left(F-842=0\right)$	A1 A1	Unsimplified equation in P or F with at most one error Correct unsimplified equation in P or F Missing g is one accuracy error
	$\frac{1000P}{15}\left(-450-98-294=0\right)$	M1	Use of $P=Fv$ Allow with P or $1000P$
	$P=12.6$ or $P=13$	A1	3 s.f. or 2 s.f. only A final answer of 12600 (13000) scores 4/5 Condone 12600=12.6 (correct thinking without stating the units)
		[5]	
2b	KE lost = gain in GPE + WD against resistance	M1	Must be using work-energy principle for trailer only. Dimensionally correct. Correct terms and no extras. Condone sign errors and sin / cos confusion.
	$\frac{1}{2}\times 200\times 400=\frac{200}{20}gd+300d\left(=398d\right)$	A1 A1	Correct unsimplified equation in one variable with at most one error Correct unsimplified equation in one variable.
	$XY=d=101\ \left(100\right)$ (m)	A1	3 s.f. or 2 s.f. only
		[4]	
		(9)	

3a	Use of $\mathbf{a}=\dfrac{\mathrm{d}\mathbf{v}}{\mathrm{d}t}$ $\left(\mathbf{a}=18\cos 3t\,\mathbf{i}-2\sin t\,\mathbf{j}\right)$	M1	Differentiate to obtain $\mathbf{a}=\lambda\cos 3t\,\mathbf{i}+\mu\sin t\,\mathbf{j}$
	Use of $\mathbf{F}=m\mathbf{a}$: $\mathbf{F}=\dfrac{1}{4}\mathbf{a}$	M1	Must be working in vectors
	$\mathbf{F}=\dfrac{9}{2}\cos 3t\,\mathbf{i}-\dfrac{1}{2}\sin t\,\mathbf{j}$	A1	Or equivalent. e.g. as a column vector
		[3]	
3b	$2\cos t+1=0$	M1	Set **j** component of **v** = 0 and solve for t
	$\Rightarrow t=\dfrac{2\pi}{3}$	A1	ISW if correct answer seen. Only answer $120°$ scores A0 here and the final A0
	Use of $\mathbf{v}=\dfrac{\mathrm{d}\mathbf{r}}{\mathrm{d}t}$ $\left(\mathbf{r}=-2\cos 3t\,\mathbf{i}+\left(t+2\sin t\right)\mathbf{j}\left(+\mathbf{C}\right)\right)$	M1	Integrate **v** with respect to t to obtain $\mathbf{r}=p\cos 3t\,\mathbf{i}+\left(t+q\sin t\right)\mathbf{j}\left(+\mathbf{C}\right)$ Condone if there is no constant of integration.
	$t=0,\quad \mathbf{r}=\left(4\mathbf{i}-\sqrt{3}\mathbf{j}\right)\mathrm{m}$ $\mathbf{r}=\left(-2\cos 3t+6\right)\mathbf{i}+\left(t+2\sin t-\sqrt{3}\right)\mathbf{j}$	M1	Correct use of boundary condition to find their **C**. Could be part of a definite integral e.g. $4\mathbf{i}-\sqrt{3}\mathbf{j}+\int_0^t 6\sin 3t\mathbf{i}+\left(1+2\cos t\right)\mathbf{j}\mathrm{d}t$ for their upper limit
	$=4\mathbf{i}+\dfrac{2\pi}{3}\mathbf{j}\quad(\mathrm{m})$	A1 A1	Accept $4\mathbf{i}+2.1\mathbf{j}$ or better one component correct both components correct ISW if they also offer $4\mathbf{i}+120\mathbf{j}$ "correct" components after an M0 are fortuitous – A0
		[6]	
		(9)	

4a			
	Use of CLM	M1	Need all terms, dimensionally correct. Condone sign errors.
	$4mu-3mu=3mw-2mv$ $(u=3w-2v)$	A1	Correct unsimplified equation
	Use of impact law	M1	Used correctly. Condone sign errors
	$v+w=3eu$	A1	Correct unsimplified equation. Signs consistent with their CLM equation
	$\begin{cases} u=3w-2v \\ 6eu=2w+2v \end{cases}$	DM1	Dependent on both preceding M marks. Solve to find speed of B.
	$\Rightarrow 5w=u+6eu, \quad w=\frac{1}{5}u(1+6e)$ *	A1*	Obtain **given answer** from correct working
		[6]	
4b	$v=3eu-w=\frac{u}{5}(9e-1)$	B1	Check their diagram / directions and allow $v=\frac{u}{5}(1-9e)$ if correct for their working. Any equivalent form. Must be seen or used in (b)
	$x=\frac{u}{7}(1+6e)$	B1	Seen or implied. Accept $\pm$
	Second collision if $\frac{u}{7}(1+6e)>\frac{u}{5}(9e-1)$	M1	Correct inequality to find the upper limit for e, using their v and x
	$(0<)e<\frac{4}{11}$	A1	Final answer. Or equivalent Do not need to mention the lower limit, but if they do it must be stated correctly (strict inequality).
		[4]	

5a			
	Angle ACO is a right angle or state that AB is a tangent hence triangle is $5a$, $12a$, $13a$ *	B1*	Or equivalent **explanation** of **given answer.** They need to say why it is a 5, 12, 13 triangle. If they say nothing, check the diagram to see if there is a right angle marked.
		[1]	
5b	Moments about A:	M1	Dimensionally correct equation Condone sin / cos confusion
	$W \times 8a\cos\alpha = kW \times 12a$ $\left(W \times 8a \times \frac{12}{13} = kW \times 12a\right)$	A1	Correct unsimplified equation
	$k = \frac{8}{13}$ *	A1*	Obtain given answer from correct working. Need to see correct substitution for $\cos\alpha$ and correct final statement.
		[3]	
5c	$\leftrightarrow R_H = kW\sin\alpha$	M1	First equation e.g. resolve horizontally. Condone sin/cos confusion
	$= \frac{8W}{13} \times \frac{5}{13} = \frac{40W}{169}$	A1	Correct unsimplified expression for R_H
	$\updownarrow R_V + kW\cos\alpha = W$	M1	Second equation e.g. resolve vertically. Condone sin/cos confusion and sign errors.
	$R_V = W - \frac{8W}{13} \times \frac{12}{13} = \frac{73W}{169}$	A1	Correct unsimplified expression for R_V
	$\lvert R\rvert^2 = (R_V)^2 + (R_H)^2$	DM1	Dependent on the two preceding M marks. Method to obtain the magnitude, e.g.correct use of Pythagoras
	$\lvert R\rvert = \frac{W}{169}\sqrt{40^2 + 73^2}$ $= \frac{\sqrt{6929}}{169}W = \frac{\sqrt{41}}{13}W$	A1	Accept $0.49W$ or better Allow $\sqrt{\frac{41W^2}{169}}$ or correct unsimplified form. ISW
	$\tan\theta° = \frac{73}{40}$ $(=1.825)$	DM1	Dependent on the first 2 M marks. Method to obtain the angle, e.g.correct use of trigonometry to find a relevant angle $(\theta$ or $90-\theta)$
	$\theta = 61$ (61.3)	A1	61 or better (61.2796…)
		[8]	
	See overleaf for alternatives		
5c Alt 1	$P = W\sin\alpha$	M1	First equation e.g. resolve parallel to the rod. Condone sin/cos confusion.

	$=\frac{5W}{13}$	A1	Correct unsimplified expression for parallel component
	$Q+kW=W\cos\alpha$	M1	Second equation e.g. resolve perpendicular to the rod. Condone sin/cos confusion and sign errors.
	$Q=\frac{12}{13}W-\frac{8}{13}W=\frac{4W}{13}$	A1	Correct unsimplified expression for perpendicular component
	$\lvert R\rvert=\sqrt{P^2+Q^2}$	DM1	Dependent on the first 2 M marks. Correct use of Pythagoras
	$\lvert R\rvert=\frac{W}{13}\sqrt{4^2+5^2}=\frac{\sqrt{41}}{13}W$	A1	Accept $0.49W$ or better Allow correct unsimplified form
	$\theta°=\tan^{-1}\frac{5}{12}+\tan^{-1}\frac{4}{5}$	DM1	Dependent on the first 2 M marks. Correct use of trig to find the required angle
	$\theta=61\quad(61.3)$	A1	61 or better (61.2796…)
		[8]	
5c Alt2		M1 A1	Vector diagram showing the three forces acting Correctly configured
	Use of Cosine Rule:	M1	Correct use of cosine rule for their triangle
	$R^2=W^2+(kW)^2-2W(kW)\cos\alpha$	A1	Correct unsimplified equation.
	$R^2=W^2+\frac{64}{169}W^2-\frac{16}{13}\times\frac{12}{13}W^2\left(=\frac{41}{169}W^2\right)$	DM1	Solve for R. Dependent on the first 2 M marks
	$\lvert R\rvert=\frac{\sqrt{41}}{13}W$	A1	Accept $0.49W$ or better
	$\frac{R}{\sin\alpha}=\frac{kW}{\sin\beta}\quad\left(\sin\beta=\frac{8}{13}\times\frac{\sqrt{41}}{13}\times\frac{5}{13}\right)$	DM1	Dependent on the first M mark. Correct method to find a relevant angle e.g. by use of sine rule
	$\theta=90-28.7=61.3$	A1	61 or better (61.2796…)
		[8]	
		(12)	

6a	Mass ratio $24a : 25a : 7\pi a : 7a(7+\pi)$	B1	Correct ratio seen or implied
	Moments about AE	M1	Need all terms, with their masses and horizontal distances Allow use of a parallel axis.
	$25a \times \frac{7}{2}a + 7\pi a \times \frac{14a}{\pi}$ $= 7a(7+\pi)d$	A1	Correct unsimplified equation
	$\frac{371}{2}a^2 = 7a(7+\pi)d$ $\Rightarrow d = \frac{53}{2(7+\pi)}a$ *	A1*	Obtain **given answer** from correct working Condone if they call it $\overline{x}$
		[4]	
6b	Centre of mass of semicircle lies $7a$ "vertically below" A	B1	Seen or implied e.g. $17a$ above E
	Moments about "horizontal" axis through A:	M1	Or a parallel axis. Need all terms, with their masses and distances.
	$24a \times 12a + 25a \times 12a + 7\pi a \times 7a$ $= 7a(7+\pi)y$	A1	Correct unsimplified equation
	$y = \frac{49a(12+\pi)}{7(7+\pi)}\left(= \frac{7a(12+\pi)}{7+\pi}\right)$	A1	Any equivalent form. Accept $\frac{84+17\pi}{7+\pi}a$ from E
	NB: A candidate might have a vector equation in (a) which provides evidence for some or all or the first 4 marks in (b).		
			
	$\theta° = \tan^{-1}\frac{d}{y} = \tan^{-1}\frac{53}{14(12+\pi)}\left(=14.037...°\right)$	DM1	Use trig to find relevant angle $\left(\theta \text{ or } 90-\theta\right)$ in a triangle with d and A (must now be working with vertical distance of C of M from A) Dependent on first M
	$\alpha° = \tan^{-1}\frac{7}{24} - \theta°$	DM1	Dependent on the previous M1. Complete method for the required angle
	$\alpha = 2.2$	A1	2.2 or better (2.22…)
		[7]	
		(11)	

7a	Horizontal distance	M1	Correct use of *suvat*
	$x = u\cos\alpha\, t$	A1	Correct equation
	Vertical distance	M1	Correct use of *suvat*
	$y = u\sin\alpha\, t - \frac{1}{2}gt^2$	A1	Correct equation. Correct signs. Condone if not using "y"
	$t = \frac{x}{u\cos\alpha} \Rightarrow$ $y = u\sin\alpha.\frac{x}{u\cos\alpha} - \frac{g}{2}\left(\frac{x}{u\cos\alpha}\right)^2$ $\left(= x\tan\alpha - \frac{gx^2}{2u^2}\sec^2\alpha\right)$	DM1	Dependent on the first 2 M marks. Substitute for t to obtain y in terms of x and α
	$y = x\tan\alpha - \frac{gx^2}{2u^2}\left(1+\tan^2\alpha\right)$ *	A1*	Obtain **given answer** from correct working (final step needs to be explained). Allow if $\sec^2\alpha$ seen. Must be "y" here
		[6]	
7b	$u = 20, x = 10, y > 2 \Rightarrow$ $2 = 10\tan\theta - \frac{100g}{800}\left(1+\tan^2\theta\right)$ $\left(\frac{g}{8}\tan^2\theta - 10\tan\theta + \left(2+\frac{g}{8}\right) = 0\right)$	M1	Use given values to form quadratic in $\tan\theta$ or equivalent equation in one trig function. Allow working with =, < or > 2
	Critical values: $\theta° = 18.6°$ or $\theta° = 82.7°$	A1	One correct value to 2 sf or better
	Range: $18.6 < \theta < 82.7$	A1	Accept < or $\leqslant$ $\left(19 \leq \theta \leq 82 \text{ or } 83\right)$ max 3 sf
		[3]	
7c	$y = 10\tan 40° - \frac{9.8\times 100}{2\times 400}\left(1+\tan^2 40°\right)$	M1	Use given formula to find vertical height
	$y = 6.3(03...)\,(\text{m})$	A1	Can be implied by correctly substituted formula
	Conservation of energy	DM1	Dependent on the first M1. Need all 3 terms. Dimensionally correct. Condone sign errors.
	$\frac{1}{2}mv^2 = \frac{1}{2}m\times 400 - mgy$	A1ft	Correct unsimplified equation in y or their y
	$v = 17 \quad (16.6)\left(\text{m s}^{-1}\right)$	A1	2sf or 3sf only
		[5]	
7c alt	$20\cos 40°\, t = 10$, $t = \frac{1}{2\cos 40°} = 0.653....$ $\updownarrow v_V = 20\sin 40° - gt$	M1	Complete method using *suvat* to vertical component of speed e.g. by finding time taken then use of $v = u - gt$ or finding vertical distance and using *suvat*
	$= 6.5 \quad (6.459...)$	A1	6.5 or better (not final answer so allow > 3sf or a correct unsimplified expression)
	$v^2 = \left(v_H\right)^2 + \left(v_V\right)^2$	DM1	Correct use of Pythagoras

			Dependent on preceding M mark
	$\leftrightarrow v_H = 20\cos 40° \left(= 15.3....\right)$	A1	Horizontal component of speed seen or implied
	$v = 17 \quad (16.6)\,(\mathrm{m\,s^{-1}})$	A1	2sf or 3sf only
		[5]	
7d	$0 = x\tan 40° - \dfrac{9.8x^2}{800}\left(1 + \tan^2 40°\right)$	M1	Complete method to solve for x.
	$x = 40\,(40.2)\,(\mathrm{m})$	A1	2sf or 3sf only
		[2]	
7d Alt1	$y = 0 \Rightarrow t = \dfrac{40\sin 40°}{g} \left(= 2.623...\right)$ $x = 20\cos 40° \times t$	M1	Complete method to solve for x.
	$x = 40\,(40.2)\,(\mathrm{m})$	A1	2sf or 3sf only
		[2]	
7d Alt2	$\text{Range} = \dfrac{20^2 \sin 80°}{g}$	M1	Complete method to solve for x.
	$= 40\,(40.2)\,(\mathrm{m})$	A1	2sf or 3sf only
		[2]	
		(16)	