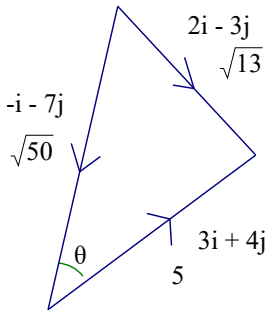
Question Number	Scheme	Marks	Notes
1(a)	Use of Impulse = change in momentum	M1	Dimensionally correct. Condone subtraction in the wrong order.
	$2((2\mathbf{i} - 3\mathbf{j}) - (3\mathbf{i} + 4\mathbf{j})) = \mathbf{I}$	A1	Correct unsimplified. Allow ±
	$= -2\mathbf{i} - 14\mathbf{j}$	A1	Allow ±
	Use of Pythagoras	M1	For *their* impulse
	$\lvert\mathbf{I}\rvert = \sqrt{2^3 + 14^2} = \sqrt{200} = 10\sqrt{2}$ (Nm)	A1	14(Ns) or better. (14.142…..) From correct working (i.e. only from $\pm\mathbf{I}$)
		5	
1(b)	Correct use of trigonometry to find the required angle	M1	For $3\mathbf{i} + 4\mathbf{j}$ and *their* impulse
	$\tan^{-1}\frac{4}{3} + \frac{\pi}{2} + \tan^{-1}\frac{1}{7}$	A1	Correct unsimplified
	$\theta = 2.64$ (radians)	A1	or 150° or better (151.2602…..) Accept 209° or better: (208.739…)and 3.64 radians
		(3)	
Alt1 1(b)	Using scalar product to find the required angle:	M1	For $3\mathbf{i} + 4\mathbf{j}$ and *their* impulse
	$\cos\theta = \frac{-3 - 28}{5 \times \sqrt{50}}$	A1	Correct unsimplified equation in $\cos\theta$
	$\theta = 151°$	A1	Accept 150° or better (151.2602…..), or 2.6(4) radians Accept 209° (208.739…) and 3.64 radians
		(3)	
Alt2 1(b)			
	Complete method to find the required angle e.g. use of correct cosine rule to find the obtuse angle	M1	For $3\mathbf{i} + 4\mathbf{j}$ and *their* impulse
	$\cos\theta = \frac{50 + 25 - 13}{2 \times 5 \times \sqrt{50}}$	A1	Correct unsimplified equation in $\cos\theta$
	required angle $(= 180° - \theta) = 151°$	A1	Accept 150° or better (151.2602…..), or 2.6(4) radians Accept 209° (208.739…)and 3.64 radians
		(3)	

Question Number	Scheme	Marks	Notes
	NB: If they are working with an incorrect impulse e.g. $2\mathbf{i}+14\mathbf{j}$ from (a) then M1A0A0 can be scored in (b)		
		8	

2(a)	Use of $P=Fv$:	M1	$F=\frac{280}{2}\left(=140\right)$(N) Seen or implied
	Equation of motion: $F-75g\sin\theta=R$	M1	Need all terms, condone trig confusion and sign errors Accept $\frac{P}{v}-75g\sin\theta=R$
	$140-75g\sin\theta=R$ $\left(140-75\times9.8\times\frac{1}{21}=R\right)$	A1	Correct substituted equation in R (and θ)
	$R=105$ (or 110)	A1	3 sf or 2 sf only.
		(4)	
2(b)	Equation of motion:	M1	Need all terms, condone trig confusion and sign errors. Must be using $v=3.5$ and $m=75$ unless there is a clear consistent misread
	$75g\sin\theta+\frac{280}{3.5}-60=75a$ $\left(75g\sin\theta+80-60=75a\right)$	A1 A1	Unsimplified equation in g, θ and $\pm a$ with at most one error Correct unsimplified equation in g, θ and $\pm a$
	$a=0.73$ (m s^{-2}) (0.733)	A1	a must be positive 2 sf or 3 sf only A0 for $\frac{11}{15}$
		(4)	
	SC: A candidate who uses $F=Pv$ can score M0M1A0A0 in (a) and 0/4 in (b)		
		8	

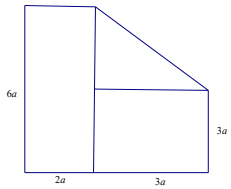
<table>
<tr><th>Q</th><th>Scheme</th><th>Marks</th><th>Notes</th></tr>
<tr><td>3(a)</td><td>
<table>
<tr><td></td><td>square</td><td>triangle</td><td>template</td></tr>
<tr><td>Area</td><td>$36a^2(6)$</td><td>$6a^2(1)$</td><td>$30a^2(5)$</td></tr>
<tr><td>From OD</td><td>$3a$</td><td>$\frac{14a}{3}$</td><td>$\bar{x}$</td></tr>
<tr><td>From OA</td><td>$3a$</td><td>$5a$</td><td>$\bar{y}$</td></tr>
</table>
</td><td>B1

B1

B1</td><td>Correct area ratio

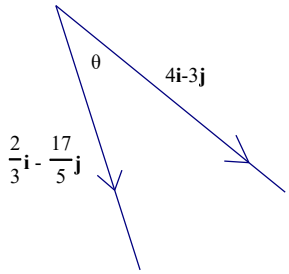
Correct horizontal distances

Correct vertical distances

Be aware of other possible splits e.g.</td></tr>
<tr><td></td><td></td><td colspan="3">


<table>
<tr><td></td><td>Tall rectangle</td><td>triangle</td><td>Lower rectangle</td><td>template</td></tr>
<tr><td>Area</td><td>$12a^2(2)$</td><td>$6a^2(1)$</td><td>$12a^2(2)$</td><td>$30a^2(5)$</td></tr>
<tr><td>From OD</td><td>a</td><td>$\frac{10a}{3}$</td><td>$4a$</td><td>$\bar{x}$</td></tr>
<tr><td>From OA</td><td>$3a$</td><td>$4a$</td><td>$\frac{3}{2}a$</td><td>$\bar{y}$</td></tr>
</table>
</td></tr>
<tr><td colspan="4">If they do not give you a diagram allow their values to imply a correct table / split
No diagram and incorrect values can score at most M1 for a dimensionally correct moments equation
If they use a non-standard shape (e.g. trapezium) they must show full working for the centre of mass.</td></tr>
<tr><td>(i)</td><td>$6\times3a-1\times\frac{14a}{3}=5\bar{x}$</td><td>M1</td><td>moments equation about OD or a parallel axis OR a moments equation about OA or a parallel axis.
Moments equation must be dimensionally consistent.
Condone sign errors.
SC Allow M1 for work on a framework with 5 sections</td></tr>
<tr><td></td><td>$\Rightarrow \bar{x}=\frac{8a}{3}$ ISW</td><td>A1</td><td>Allow $2.6\dot{a}$ but not an approximate value e.g. $2.67a$</td></tr>
<tr><td>(ii)</td><td>$6\times3a-1\times5a=5\bar{y}\Rightarrow\bar{y}=\frac{13a}{5}$</td><td>A1</td><td>Accept $2.6a$</td></tr>
<tr><td></td><td></td><td>(6)</td><td></td></tr>
<tr><td>3(b)</td><td>Use of trig to find a relevant angle</td><td>M1</td><td>e.g. $\alpha, 180°-\alpha$ or $90°-\alpha$.
Need correct pairing of angles i.e. do not accept $\frac{3}{4}$ vs $\frac{4}{3}$ confusion in their equation for α</td></tr>
<tr><td></td><td>$\alpha=\arctan\left(\frac{6a-\bar{y}}{\bar{x}-2a}\right)-\arctan\left(\frac{3}{4}\right)$</td><td>A1ft

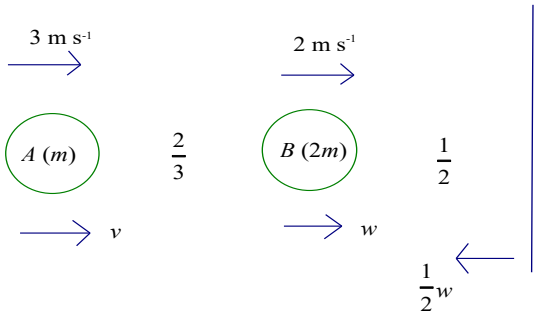
A1ft</td><td>Unsimplified expression with at most one error. For their $\bar{x}$, $\bar{y}$ (need not be substituted)</td></tr>
</table>

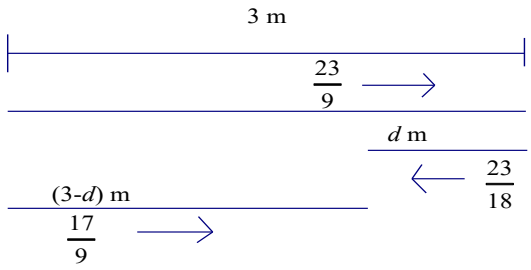
	Or equivalent e.g. $\tan^{-1}\frac{4}{3}-\tan^{-1}\frac{\overline{x}-2a}{6a-\overline{y}}\left(=\tan^{-1}\frac{4}{3}-\tan^{-1}\frac{10}{51}\right)$		Correct unsimplified expression. For *their* $\overline{x}$, $\overline{y}$ (need not be substituted)
	$=42^\circ$	A1	Accept $138°$, but not 42.0° The Q asks for the nearest degree
		(4)	
3b alt			
	Correct statement for scalar product to find a relevant angle	M1	Correct vector for their $\overline{x}$ and $\overline{y}$
	$\cos\theta=\frac{4\times\frac{2}{3}+3\times\frac{17}{5}}{5\times\sqrt{\frac{2701}{225}}}\left(=0.742\right)$	A1ft A1ft	Unsimplified expression with scalar product expanded and at most one error Correct unsimplified expression with scalar product expanded
	$\left(\theta=\right)42^\circ$	A1	Accept $138°$ but not 42.0° The Q asks for the nearest degree
		(4)	
		10	

Q	Scheme	Marks	Notes
4(a)	Accept working in column vectors throughout this question		
	Differentiate **r** to obtain **v**	M1	Powers going down by 1. M0 if clearly dividing by t Condone one slip. Seen or implied
	$\mathbf{v}=\left(3t^2-9t-24\right)\mathbf{i}+\left(-3t^2+6t+12\right)\mathbf{j}$	A1	Correct only. Seen or implied
	$3T^2-9T-24=-3T^2+6T+12$ $\Rightarrow 6T^2-15T-36=0$	M1	Equate coefficients of **i** and **j** from their **v** to obtain a 3-term quadratic in t or T
	Solve for T: e.g. $3\left(2T+3\right)\left(T-4\right)=0$	DM1	Ignore $T=-\frac{3}{2}$ if seen. Can be implied by correct roots of an incorrect quadratic. Allow if they solve a quadratic resulting from a slip in simplifying Dependent on the previous M1
	$\left(T=\right)4$	A1	Only
		(5)	
4(b)	Differentiate *their* **v** to obtain **a**:	M1	Powers going down by 1. M0 if clearly dividing by t Condone one slip. Seen or implied
	$\mathbf{a}=\left(6t-9\right)\mathbf{i}+\left(-6t+6\right)\mathbf{j}$	A1ft	Follow their **v.** Seen or implied
	$\mathbf{a}=\left(6T-9\right)\mathbf{i}+\left(-6T+6\right)\mathbf{j}=15\mathbf{i}-18\mathbf{j}$	DM1	substitute *their* positive T Dependent on the previous M1 Seen or implied
	Use Pythagoras	DM1	Correct method for the magnitude: $\left\|\mathbf{a}\right\|=\sqrt{15^2+18^2}$ Dependent on the previous DM1
	$\left\|\mathbf{a}\right\|=\sqrt{549}=23.4\,(\text{m s}^{-2})$	A1	23 or better e.g. $3\sqrt{61}$
		(5)	
		10	

Q	Solution	Marks	Notes
5(a)	Moments about A:	M1	Or equivalent to obtain an equation for F e.g. moments about another point and vertical resolution. Requires all terms and dimensionally correct. Condone sign errors and sine / cosine confusion. Allow $\cos\theta = \frac{4}{5}$ used without comment.
	$F \times \frac{5a}{4} = mga\cos\theta + 2kmga\cos\theta$	A1 A1	Unsimplified equation with at most one error. Consistent trig confusion counts as 1 error. g missing in both terms is a single error Correct unsimplified equation
	$F = \frac{4mg\cos\theta}{5}(1+2k) = \frac{16}{25}mg(1+2k)$ *	A1*	Obtain **given answer** from full and correct working
			SC allow M1A1A1A0 if a missing throughout
		(4)	
5(b)	resolve horizontally: $H = F\sin\theta$	M1	Condone sine / cosine confusion
	$H = \frac{48}{125}mg(1+2k)$	A1	Or equivalent with trig substituted
	resolve vertically	M1	Requires all three terms. Condone sine/cosine confusion and sign errors.
	$\pm V = mg(1+k) - F\cos\theta$	A1	Correct unsimplified equation
	$= mg(1+k) - \frac{64}{125}mg(1+2k)$ $\left(= mg\left(\frac{61}{125} - \frac{3k}{125}\right)\right)$	A1	Or equivalent with trig substituted Allow for V acting downwards here ISW if they had a correct expression and make an error in simplifying it.
	Either of the above equations could be replaced with an alternative e.g. Resolve parallel to the rod: $\frac{4}{5}H + \frac{3}{5}V = \frac{3}{5}mg + \frac{3}{5}kmg$ Resolve perpendicular to the rod: $\frac{3}{5}H + \frac{4}{5}mg + \frac{4}{5}kmg = \frac{4}{5}V + F$ Moments about C: $\frac{5}{4}a \times \frac{4}{5}V + \frac{3}{4}a \times \frac{4}{5}kmg = \frac{5}{4}a \times \frac{3}{5}H + \frac{1}{4}a \times \frac{4}{5}mg$ NB: the names H and V are not given in the question so they might be using their own alternatives.		
	SC: If they have confused horizontal and vertical, obtain correct values for the two components but name them incorrectly then allow M1M1 (2/5)		
		(5)	

5(c)	Use $H = V$ to form equation in k	M1	For their H, $\pm V$
	Obtain $\frac{48}{125}mg(1+2k) = mg(1+k) - \frac{64}{125}mg(1+2k)$	A1ft	Must now be using V acting vertically upwards. Or equivalent e.g. $48(1+2k) = (61-128k)$ Follow their H and V upwards
	$k = \frac{13}{99}$	A1	Accept 0.13 or better
		(3)	
		[12]	

Q	Solution	Marks	Notes
6a			
	Equation for CLM	M1	Need all terms. Dimensionally consistent. Condone sign errors.
	$3m + 4m = mv + 2mw$	A1	Or equivalent e.g. $7 = v + 2w$
	Equation for Impact Law	M1	Must be used the right way round. Condone sign errors
	$w - v = \frac{2}{3}(3-2)$	A1	Or equivalent e.g. $3w - 3v = 2$
	Solve for w or v e.g. $w - \frac{2}{3} + 2w = 7$	DM1	Dependent on both previous M marks Must have both equations. Not available if all they have is CLM and then work back from the given answer
	$3w = \frac{23}{3}$, $w = \frac{23}{9}$ *	A1*	Obtain **given answer** with no incorrect working seen
	$\frac{23}{9} - v = \frac{6}{9}$, $v = \frac{17}{9}$	A1	Correct only
		(7)	

6(b)			
	Velocity of B after hitting wall $= \frac{23}{18}$ (m s^{-1})	B1	Or equivalent: $\frac{1}{2}\times\frac{23}{9}$ (both values given) Allow +/-
	Time for B to get to the 2nd collision	M1	Using time $= \frac{\text{distance}}{\text{speed}}$
	$=3\times\frac{9}{23}+d\times\frac{18}{23}$	A1	Or equivalent e.g, $\frac{27+18d}{23}$
	Time for A to get to the 2nd collision $=(3-d)\frac{9}{17}$	B1ft	Follow their v: $\frac{3-d}{v}$
	Equation in d	M1	Using time between collisions for their "correct" times
	$17(27+18d)=9\times23(3-d)$	A1	Or equivalent e.g. $\frac{27+18d}{23}=\frac{9}{17}(3-d)$
	$d=\frac{162}{513}\left(=\frac{6}{19}\right)$	A1	Accept 0.32 or better. ISW
		(7)	
6(b) Alt1	Velocity of B after hitting wall $= \frac{23}{18}$ (m s^{-1})	B1	Or equivalent: $\frac{1}{2}\times\frac{23}{9}$ (both values given) Allow +/-
	Time for B to reach wall $\frac{3}{w}=3\times\frac{9}{23}=\frac{27}{23}$ (s)	M1	
	Distance travelled by A in this time $=\frac{17}{9}\times\frac{27}{23}=\frac{51}{23}$ (m)	A1ft	Follow *their v*: $\frac{27}{23}\times$ *their v*
	Distance between A and B now $=3-\frac{51}{23}=\frac{18}{23}$ (m)	A1	
	Gap closing at $\frac{23}{18}+\frac{17}{9}=\frac{19}{6}$ (m s^{-1})	M1	Relative velocity
	Time to meet $=\frac{18}{23}\div\frac{19}{6}=\frac{18}{23}\times\frac{6}{19}\left(=\frac{108}{437}\right)$	A1	Using time $= \frac{\text{distance}}{\text{speed}}$
	$d=\frac{18}{23}\times\frac{6}{19}\times\frac{23}{18}=\frac{6}{19}$	A1	Accept 0.32 or better ISW
		(7)	

6balt2	Velocity of B after hitting wall = $\frac{23}{18}$ (m s^{-1})	B1	Or equivalent: $\frac{1}{2}\times\frac{23}{9}$ (both values given) Allow +/-
	Time for B to reach wall $\frac{3}{w}=3\times\frac{9}{23}=\frac{27}{23}$ (s)	M1	
	Distance travelled by A in this time $=\frac{17}{9}\times\frac{27}{23}=\frac{51}{23}$ (m)	A1ft	Follow *their v*: $\frac{27}{23}\times$ *their v*
	Total additional distance in time t between B hitting the wall and A & B colliding again $=\frac{23}{18}t+\frac{17}{9}t$	A1	
	$\Rightarrow\frac{17}{9}\times\frac{27}{23}+\frac{17}{9}t+\frac{23}{18}t=3$	M1	Add these two distances to form an equation in t
	$t=\frac{108}{437}$	A1	Seen or implied
	$d=\frac{23}{18}t=\frac{6}{19}$	A1	ISW
		(7)	
		14	

Q	scheme	Marks	Notes
	NB Penalise each type of accuracy error once and only once in any question (incorrect g, answers not to 2 sf or 3 sf)		
7(a)	Vertical speed = 0: $v = 9 - gt = 0$	M1	Complete method using *suvat*
	$t = 0.92\,(\text{s})$ 0.918	A1	2 sf or 3 sf only $\frac{9}{g}$ and $\frac{45}{49}$ score A0 ISW if go on to find the max height Clear use of 9.81 is A0.
		(2)	
7(b)	$x = 4t$	B1	
	$y = 9t - \frac{1}{2}gt^2$	B1	Correct use of *suvat*
	Use $y = x$ Or $4t = 9t - \frac{1}{2}gt^2$, $t = \frac{10}{g}$	M1	e.g. $t = \frac{x}{4} = \frac{k}{4}$, $k = 9 \times \frac{k}{4} - \frac{g}{2} \times \frac{k^2}{16}$, $\frac{5}{4}k = \frac{g}{32}k^2$
	$k = 4.1$ (4.08)	A1	2 sf or 3 sf only $\frac{40}{g}$ and $\frac{200}{49}$ are A0 unless previously penalised. ISW after an acceptable answer
		(4)	
7(c)	Using symmetry for the other point	M1	Time to $A = \frac{k}{4} = \frac{10}{g}$ (s)
	$t = \frac{9}{g} - \left(\frac{10}{g} - \frac{9}{g}\right) = \frac{8}{g}\left(= \frac{40}{49}\right)$	A1	Accept unsimplified e.g. $2 \times \frac{9}{g} - \frac{k}{4}$ Accept as a decimal (0.816…)
	$\mathbf{r} = \left(\frac{4}{5}k\right)\mathbf{i} + k\mathbf{j}$	A1	Accept decimal equivalent Accept column vector
7(c) Alt 1	Other point: $x = \frac{36}{g} - \left(k - \frac{36}{g}\right)$ or $x = \frac{72}{g} - k$	M1	At max ht $x = 4 \times \frac{9}{g} = \frac{36}{g}$
	$x = \frac{9}{5}k - k = \frac{4}{g}k$	A1	Accept unsimplified
	$\mathbf{r} = \left(\frac{4}{5}k\right)\mathbf{i} + k\mathbf{j}$	A1	Accept decimal equivalent Accept column vector

7(c) Alt 2	Same height: $\frac{40}{g} = 9t - \frac{1}{2}gt^2$	M1	Form an equation in t only and solve for t
	Obtain $(gt-10)(gt-8)=0$, $t=\frac{8}{g}$	A1	Accept 0.816 and $\frac{40}{49}$ Allow difference in final decimal place if working with 9.81 throughout and already penalised earlier. Must reject $\frac{10}{g}$ but can be implied by subsequent work
	$(\mathbf{r}=)\left(\frac{4}{5}k\right)\mathbf{i}+k\mathbf{j}$	A1	Accept decimal equivalent Accept column vector
	SC if they start with $k = 9t - \frac{1}{2}gt^2$ and stop they score 0/3, but if they solve the quadratic to get to $\frac{36-4\sqrt{81-19.6k}}{9.8}\mathbf{i}+k\mathbf{j}$ then allow 3/3		
	Allow an answer of $(\mathbf{r}=)\frac{32}{g}\mathbf{i}+k\mathbf{j}$ or $(\mathbf{r}=)\left(\frac{72}{g}-k\right)\mathbf{i}+k\mathbf{j}$ or $(\mathbf{r}=)3.3\mathbf{i}+k\mathbf{j}$ or $(\mathbf{r}=)(7.35-k)\mathbf{i}+k\mathbf{j}$ or equivalent Condone exact fractions and figures to more than 3 sf after substitution for g, but an answer of $(\mathbf{r}=)3.3\mathbf{i}+4.1\mathbf{j}$ or $(\mathbf{r}=)\frac{32}{g}\mathbf{i}+\frac{40}{g}\mathbf{j}$ scores M1A1A0 because k is not involved The Q asks for a vector. Should be in **i** and **j** or as a column vector. Coordinates can score M1A1A0		
		(3)	
7(d)	$4\mathbf{i} - n\mathbf{j}$ perpendicular to $4\mathbf{i} + 9\mathbf{j}$	M1	Use ratios or scalar product to find velocity
	$\frac{4}{n}=\frac{9}{4}$, $n=\frac{16}{9}$	A1	Accept 1.8 or better $(1.\dot{7})$ Accept $\pm$
	$-\frac{16}{9}=9-gT$	dM1	Form an equation in T (or t) only Correct signs. Dependent on the previous M1
	$(T=)1.1$ (1.10)	A1	2 sf or 3 sf $\frac{97}{9g}$ is A0 unless previously penalised
		(4)	
		[13]	