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EDEXCEL A LEVEL FURTHER MATHEMATICS: QUESTIONS BY TOPIC

Momentum and Impulse (1)

Further Mechanics 1 · Topic 1

14 questions · 129 marks · Mark schemes included

Pearson Edexcel A Level Further Mathematics (9FM0), June 2019 - June 2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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5.2 OBLIQUE IMPACTS WITH WALLS AND PLANES		1 Qs · 12 marks	47
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QUESTIONS

14 questions · 129 marks · 4 sub-topics



SUB-TOPIC 1.1

CONSERVATION OF MOMENTUM

Sub-topic 1.1 · 4 questions · 46 marks · lowest tariff first



1. A particle A of mass $3m$ and a particle B of mass m are moving along the same straight line on a smooth horizontal surface. The particles are moving in opposite directions towards each other when they collide directly.

Immediately before the collision, the speed of A is ku and the speed of B is u .

Immediately after the collision, the speed of A is v and the speed of B is $2v$.

The magnitude of the impulse received by B in the collision is $\frac{3}{2}mu$.

- (a) Find v in terms of u only.

(3)

- (b) Find the two possible values of k .

(5)





Question 1 continued

Lined area for writing the answer to Question 1 continued.

(Total for Question 1 is 8 marks)



(Total for Question 1 is 9 marks)







Question 2 continued

(Total for Question 2 is 14 marks)





Question 4 continued



SUB-TOPIC 1.2

IMPULSE IN VECTOR FORM

Sub-topic 1.2 · 6 questions · 41 marks · lowest tariff first



Question 3 continued

(Total for Question 3 is 5 marks)



Question 1 continued

(Total for Question 1 is 6 marks)



Question 1 continued

(Total for Question 1 is 7 marks)

4. A particle P has mass 0.5 kg . It is moving in the xy plane with velocity $8\mathbf{i} \text{ m s}^{-1}$ when it receives an impulse $\lambda(-\mathbf{i} + \mathbf{j}) \text{ N s}$, where λ is a positive constant.

The angle between the direction of motion of P immediately before receiving the impulse and the direction of motion of P immediately after receiving the impulse is θ°

Immediately after receiving the impulse, P is moving with speed $4\sqrt{10} \text{ m s}^{-1}$

Find (i) the value of λ

(ii) the value of θ

(8)



Question 4 continued

(Total for Question 4 is 8 marks)



Question 3 continued



(Total for Question 3 is 9 marks)



SUB-TOPIC 5.1

OBLIQUE IMPACTS BETWEEN SPHERES

Sub-topic 5.1 · 3 questions · 30 marks · lowest tariff first



4.

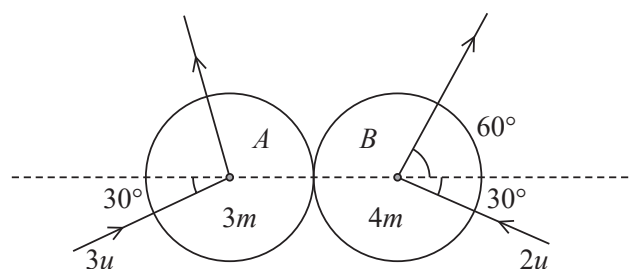


Figure 3

Two smooth uniform spheres, A and B , have equal radii. The mass of A is $3m$ and the mass of B is $4m$. The spheres are moving on a smooth horizontal plane when they collide obliquely. Immediately before they collide, A is moving with speed $3u$ at 30° to the line of centres of the spheres and B is moving with speed $2u$ at 30° to the line of centres of the spheres. The direction of motion of B is turned through an angle of 90° by the collision, as shown in Figure 3.

- Find the size of the angle through which the direction of motion of A is turned as a result of the collision.
- Find, in terms of m and u , the magnitude of the impulse received by B in the collision.

(9)

Question 4 continued

Lined area for writing the answer to Question 4 continued.



Question 4 continued

Question 4 continued

(Total for Question 4 is 9 marks)

Question 7 continued

Question 7 continued



Question 7 continued

(Total for Question 7 is 9 marks)



Question 6 continued



Question 6 continued



Question 6 continued

(Total for Question 6 is 12 marks)



SUB-TOPIC 5.2

OBLIQUE IMPACTS WITH WALLS AND PLANES

Sub-topic 5.2 · 1 question · 12 marks · lowest tariff first



6. A particle P of mass m is falling vertically when it strikes a fixed smooth inclined plane. The plane is inclined to the horizontal at an angle α , where $0 < \alpha \leq 45^\circ$

At the instant immediately before the impact, the speed of P is u .

At the instant immediately after the impact, P is moving horizontally with speed v .

- (a) Show that the magnitude of the impulse exerted on the plane by P is $mu \sec \alpha$ (5)

The coefficient of restitution between P and the plane is e , where $e > 0$

- (b) Show that $v^2 = u^2(\sin^2 \alpha + e^2 \cos^2 \alpha)$ (3)

- (c) Show that the kinetic energy lost by P in the impact is

$$\frac{1}{2} \mu u^2 (1 - e^2) \cos^2 \alpha \quad (2)$$

- (d) Hence find, in terms of m , u and e **only**, the kinetic energy lost by P in the impact. **(2)**



Question 6 continued

Question 6 continued



Question 6 continued

(Total for Question 6 is 12 marks)



MARK SCHEMES

official mark schemes



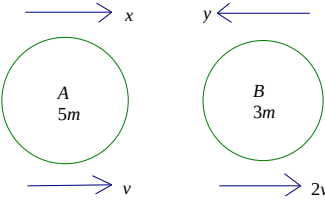
Question	Scheme	Marks	AOs
1a	$ku \rightarrow$ $\leftarrow u$ either $v \rightarrow$ $\rightarrow 2v$ or $v \leftarrow$ $\rightarrow 2v$		
	Note that if they start with their $2v$ to the left this creates an impossible situation (the particles need to pass through each other). The maximum score is M1M1M1.		
	Impulse received by B :	M1	3.4
	$\frac{3}{2}mu = m(2v - (-u))$	A1	1.1b
	$v = \frac{u}{4}$	A1	1.1b
		(3)	

1b	Use of CLM or Impulse-momentum for one option for A:	M1	3.4
	$3kmu - mu = 2mv + 3mv \left(= \frac{5mu}{4} \right)$ or $3m(v - ku) = -\frac{3mu}{2} \left(3mu \left(\frac{1}{4} + \frac{1}{2} \right) = 3mku \right)$	A1ft	1.1b
	$k = \frac{3}{4}$	A1	1.1b
	Form a second equation in k $\left(3mku - mu = 2mv - 3mv \left(= -\frac{mu}{4} \right) \text{ or } 3m(v + ku) = \frac{3mu}{2} \right)$	M1	3.1a
	$k = \frac{1}{4}$	A1	1.1b
		(5)	
(T0tal 8 Marks)			
Notes			
(a)M1	Form impulse-momentum equation for B (or A). May be expressed as either $\mathbf{I} = m\mathbf{v} - m\mathbf{u}$ or $\mathbf{I} + m\mathbf{u} = m\mathbf{v}$. Dimensionally correct. Must be considering difference in velocities Must have a correct combination of mass and velocity: pairing velocity of one with the mass of the other scores M0 Allow for subtraction the wrong way round or impulse in the wrong direction. Assuming that you have not seen an incorrect formula stated, allow for $2v + u$ without overt evidence of subtraction. Allow if the common factor of m is not seen		
A1	Correct unsimplified equation for B (or A). Allow without m		
A1	Correct answer only		
(b) M1	Correct method to form an equation in k . Must be dimensionally correct Condone sign errors in CLM. Allows marks for CLM equation here if seen in (a) and used correctly to find k here. Rules for impulse-momentum as above. M1 is available if they have not reversed the direction of the impulse. An equation which allows for the change in direction by using $\mathbf{u} - \mathbf{v}$ can score full marks. Could be working with either option for the direction of motion of A		
A1ft	Correct unsimplified equation in u , v or their v		
A1	One correct solution Be aware that a sign error in the impulse-momentum equation for A can lead to a fortuitous answer. A fortuitous answer scores A0 (5) If the incorrect answer was 57 and 11		
M1	Correct method to form a second equation in k (reversing the direction of motion of A)		
A1	Second correct solution		

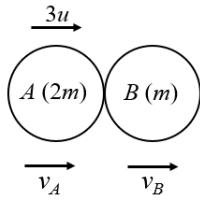


Question	Scheme	Marks	AOs
1(a)	Form an expression for total KE	M1	3.1a
	$\frac{1}{2} \times 3 \times (3^2 + (-1)^2) + \frac{1}{2} \times 2 \times ((-6)^2 + 2^2)$	A1	1.1b
	= 55 (J)	A1	1.1b
		(3)	
1(b)	Use of change in momentum	M1	3.1a
	$3 \left((-2\mathbf{i} + \frac{2}{3}\mathbf{j}) - (3\mathbf{i} - \mathbf{j}) \right)$	A1	1.1b
	= (-15i + 5j) (N s)	A1	1.1b
		(3)	
1(c)	Either: Use impulse on B to form equation	M1	3.1a
	$(15\mathbf{i} - 5\mathbf{j}) = 2(\mathbf{v}_B - (-6\mathbf{i} + 2\mathbf{j}))$	A1	1.1b
	$\mathbf{v}_B = (1.5\mathbf{i} - 0.5\mathbf{j}) \text{ (m s}^{-1}\text{)}$	A1	1.1b
	Or: Use CLM to form equation	M1	3.1a
	$3(3\mathbf{i} - \mathbf{j}) + 2(-6\mathbf{i} + 2\mathbf{j}) = 3(-2\mathbf{i} + \frac{2}{3}\mathbf{j}) + 2\mathbf{v}_B$	A1	1.1b
	$\mathbf{v}_B = (1.5\mathbf{i} - 0.5\mathbf{j}) \text{ (m s}^{-1}\text{)}$	A1	1.1b
		(3)	
(9 marks)			
Notes: Ignore units in final answers			
(a)			
M1	Form an expression for total KE, correct number of terms and dimensionally correct. Must add 2 KE terms of the correct structure. Allow missing minus signs on components when squaring. M0 for use of $(3\mathbf{i} - \mathbf{j})^2$ unless recovered. M0 if KE terms are never added together. M0 for using $\frac{1}{2}mv$ unless the correct KE formula is also stated. (Note that $\frac{1}{2}mv$ is not dimensionally correct)		
A1	Correct unsimplified expression for the total KE. If the 2 KE terms are incorrect when the total is formed, this is A0.		
A1	Cao		
(b)	N.B. Only penalise use of column vectors in final answers once across (b) and (c). Penalise the first occurrence. Allow column vectors throughout working in (b) and (c).		

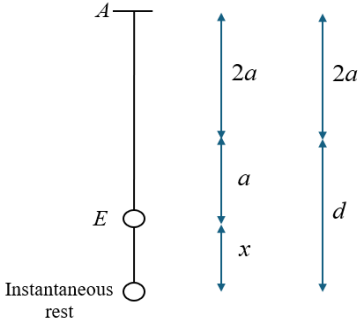
M1	Use of change in momentum, dimensionally correct (mass $\times$ velocity). Must subtract momenta but condone in wrong order. Must use mass of 3kg with velocities of A or mass of 2kg with velocities of B. M0 if speeds are used.
A1	Correct unsimplified expression for impulse
A1	Correct answer in i and j form. Penalise first occurrence if answer is given as a column vector. ISW if they continue and find the magnitude.
(c)	
M1	Either: Use of impulse-momentum equation with their Impulse. Must subtract momenta (mass $\times$ velocity) but condone in wrong order. Condone sign error on LHS.
A1	Correct unsimplified equation
A1	Correct answer in i and j form. Penalise first occurrence if answer is given as a column vector.
M1	Or: Use of CLM equation with correct number of terms, condone sign errors. Masses and velocities must be paired correctly. M0 if speeds are used.
A1	Correct unsimplified equation
A1	Correct answer in i and j form. Penalise first occurrence if answer is given as a column vector.

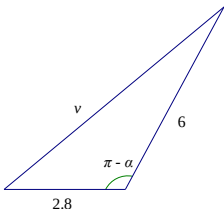
Question	Scheme	Marks	AOs
2(a)			
	Use of CLM	M1	3.1a
	$5mv + 6mv (= 11mv) = 5mx - 3my \quad (11v = 5x - 3y)$	A1	1.1b
	Use of impact law	M1	3.1a
	$v = e(x + y)$	A1	1.1b
	$\begin{cases} 11ev = 5ex - 3ey \\ 3v = 3ex - 3ey \end{cases} \Rightarrow x = \frac{v}{8e}(11e + 3)$	M1	3.1a
	$y = \frac{v}{8e}(5 - 11e)$	A1	1.1b
	$e > 0 \quad (\Rightarrow x > 0) \Rightarrow 5 - 11e > 0$	M1	3.4
	$\Rightarrow 0 < e < \frac{5}{11}$	A1	2.2a
	(8)		
(b)	Form equation for KE	M1	2.1
	$\frac{1}{2} \times 5m \times v^2 = \frac{16}{100} \times \frac{1}{2} \times 5m \times \frac{v^2}{64e^2} (11e + 3)^2$	A1ft	1.1b
	$(4(11e + 3) = (\pm)80e) \quad e = \frac{1}{3}$	A1	1.1b
	Impulse = $-5m(v - x)$	M1	3.1a
	$= -5m \left(v - \frac{11v}{8} - \frac{3v}{8e} \right)$ Or: $3m \left(2v + \frac{5v}{8e} - \frac{11v}{8} \right)$	A1ft	1.1b
	Magnitude = $\frac{15}{2}mv$	A1	2.2a
	(6)		
Alt(b)	Form equation for KE	M1	2.1
	$\frac{1}{2} \times 5m \times v^2 = \frac{16}{100} \times \frac{1}{2} \times 5m \times x^2$	A1	1.1b
	$\Rightarrow x = \frac{5v}{10} \quad v = \frac{v}{2} \quad \Rightarrow e = \frac{1}{2}$	A1	1.1b

	Impulse = $-5m(v - x)$	M1	3.1a
	$= -5m\left(v - \frac{5v}{2}\right)$ Or: $3m\left(2v + \frac{v}{2}\right)$	A1	1,16
	Magnitude = $\frac{15}{2}mv$	A1	2.2a
		(6)	
(14 marks)			
Notes:			
(a)M1	All terms required. Dimensionally correct. Condone sign errors		
A1	Correct unsimplified equation		
M1	Used correctly. Condone sign errors		
A1	Correct unsimplified equation		
M1	Use their correctly formed equations to solve for v or w or a multiple of v or w		
A1	Both velocities correct		
M1	Use their velocities (in general form – not by considering one specific value) to form inequality for both moving in the same direction.		
A1	Correct only.		
(b)M1	Dimensionally correct. Condone 16% on wrong side Allow M or $5m$		
A1ft	Or equivalent. Correct unsimplified equation. Follow their x Allow M or $5m$		
A1	Correct answer only Allow M or $5m$		
M1	Correct use of $I = mv - mu$. Must be subtracting.		
A1ft	Accept $\pm$ Follow their x, y, e		
A1	Correct only. Must be positive.		

Question	Scheme		Marks	AOs
4(a)				
	CLM:		M1	3.1a
	$2m \times 3u = 2mv_A + mv_B$ $(6u = 2v_A + v_B)$	$2m \times 3u = -2mv_A + mv_B$ $(6u = -2v_A + v_B)$	A1	1.1b
	Impact Law:		M1	3.4
	$3ue = -v_A + v_B$	$3ue = v_A + v_B$	A1	1.1b
	Solve for v_B		M1	2.1
	$(v_B =) 2u(1+e) *$		A1*	2.2a
			(6)	
4(b)	Solve for v_A		M1	3.1a
	$v_A = u(2-e)$	$v_A = u(e-2)$	A1	1.1b
	Complete and correct explanation: $0 \leq e \leq 1 \Rightarrow v_A > 0$ $\Rightarrow A$ continues to move towards the wall $\Rightarrow A$ will collide again with B .	Complete and correct explanation: $0 \leq e \leq 1 \Rightarrow v_A < 0$ $\Rightarrow A$ continues to move towards the wall $\Rightarrow A$ will collide again with B .	A1	2.4
			(3)	
4(c)	Rebound speed or velocity of $B = \pm \frac{1}{2} \times 2u(1+e)$		B1	3.4
	$\pm m[-u(1+e) - 2u(1+e)]$		M1	3.1a
	$3(1+e)mu$		A1	1.1b
			(3)	
4(d)	Attempt at KE loss of B		M1	3.4
	$\frac{1}{2}m[(2u(1+e))^2 - (u(1+e))^2]$		A1	3.1a
	$\frac{3mu^2(1+e)^2}{2}$		A1	1.1b
			(3)	
	(15 marks)			
	Notes:			

(a)	
M1	Use of CLM, all terms required, dimensionally correct (mass $\times$ velocity in each term). Mass and velocity paired correctly. Condone sign errors on velocities. Condone consistent extra g and/or consistent missing m (in every term).
A1	Correct unsimplified equation.
M1	Correct use of Impact Law, dimensionally correct, condone sign errors on velocity. M0 if separation and approach are on the wrong sides.
A1	Correct unsimplified equation, the direction of A must be consistent with their CLM.
M1	Use their <i>correctly formed</i> equations to solve for v_B
A1*	Given answer correctly obtained and exactly as printed. Working should include an equation in v_B only <i>before</i> reaching the given answer.
(b)	
M1	Use given answer in (a) to solve for v_A . If seen in (a) it must be used in (b) to earn this mark.
A1	Correct expression seen for velocity of A after impact.
A1*	Correct and complete explanation with no incorrect statements. Must include all of: $0 < e \leq 1$ or $0 \leq e \leq 1$ or $0 \leq e < 1$ or 'for all e' $v_A > 0$ or $v_A < 0$ (must be correct for their v_A) - Must refer to the wall. - A continues to move with unchanged direction or towards the wall (eg do not accept descriptions for direction of travel as 'to the right' or similar) - Conclude second collision between A and B Note: A0* for explanations that rely on comparing speed of v_B and v_A
(c)	
B1	Correct unsimplified expression for rebound speed or velocity of B, may be seen on diagram or elsewhere in working. Accept positive or negative.
M1	Attempt to find difference in momenta, dimensionally correct (mass $\times$ velocity). Must use given answer from (a) for V_b . Condone use of e or e' in place of $\frac{1}{2}$
A1	Correct answer, must be positive. Accept any equivalent form that is either factorised or reduced to 2 terms eg $3(1+e)mu$, $3mu + 3emu$
(d)	
M1	Attempt at KE loss of B: clear attempt at a difference in KE of B before and after impact with the wall. Must use velocity of B from (a). Condone use of e or e' in place of $\frac{1}{2}$. Dimensionally correct, condone subtraction either way round.
A1	Correct unsimplified expression for KE loss of B
A1	Any equivalent factorised form eg $\frac{3mu^2(1+e)^2}{2}$, $\frac{3mu^2(1+2e+e^2)}{2}$, or

Question	Scheme	Marks	AOs
	 The diagram shows a vertical line representing a string or rod suspended from a point labeled A. A particle is attached to the end of the string. The distance from A to the particle is labeled $2a$. The particle is at an "Instantaneous rest" position. The distance from the particle to the lowest point of its path is labeled x. The distance from the lowest point to the instantaneous rest position is labeled d. The distance from the particle to the lowest point is also labeled a.		

Question	Scheme	Marks	AOs
3	Impulse momentum equation(s)	M1	3.1a
	$\begin{pmatrix} 3 \times \cos \alpha \\ 3 \times \sin \alpha \end{pmatrix} = \frac{1}{2} \begin{pmatrix} v_x - 2.8 \\ v_y \end{pmatrix} \quad \left(v_x = \frac{32}{5}, \quad v_y = \frac{24}{5} \right)$	A1 A1	1.1b 1.1b
	$v = \frac{1}{5} \sqrt{32^2 + 24^2}$	M1	1.1b
	$= 8 \text{ (ms}^{-1}\text{)}$	A1	1.1b
	Alternative working parallel and perpendicular to the impulse: $\begin{pmatrix} 3 \\ 0 \end{pmatrix} = \frac{1}{2} \begin{pmatrix} v_1 - 2.8 \times \cos \alpha \\ v_2 \pm 2.8 \times \sin \alpha \end{pmatrix} \quad v_1 = 7.68, v_2 = \pm 2.24$ $v = \sqrt{7.68^2 + 2.24^2} = 8 \text{ (ms}^{-1}\text{)}$		
		(5)	
3alt			
	Using cosine rule:	M1	
	$v^2 = 2.8^2 + 6^2 - 2 \times 2.8 \times 6 \cos(\pi - \alpha)$	A1 A1	
	Solve for v	M1	
	$v = 8 \text{ (ms}^{-1}\text{)}$	A1	
		(5)	
(Total 5 marks)			
Notes			
M1	Use of $\mathbf{I} = m\mathbf{v} - m\mathbf{u}$ in two dimensions. (i.e. resolving used) Dimensionally correct. Allow for a combined equation in vector format or for just one component. Condone sin/cos confusion. Allow if m seen but not substituted.		
A1 A1	Equation for one component correct unsimplified Equations for both components correct unsimplified Allow A1A1 for a correct unsimplified vector equation Allow A marks if in terms of m and α		
M1	Correct use of Pythagoras for their components to obtain the numerical value of the speed This may be seen or implied: an alert candidate might spot the 3, 4, 5 triangle.		

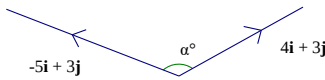
A1	Correct only
Alt	
M1	Correct use of cosine rule in a dimensionally correct triangle. The lengths of the sides must be consistent, i.e. v , 2.8 and 6 or $\frac{1}{2}v$, 1.4 and 3 and it must be a correct vector triangle (vectors combined correctly)
A1	Unsimplified equation with at most one error
A1	Correct unsimplified equation
M1	Substitute for trig. and solve for v
A1	Correct only



Question	Scheme	Marks	AOs
1(a)	Impulse-momentum:	M1	3.1a
	$(-6\mathbf{i} + 42\mathbf{j}) = 2\{\mathbf{v} - (-4\mathbf{i} + 3\mathbf{j})\}$	A1	1.1b
	Find magnitude of their $\mathbf{v}$: $\sqrt{(-7)^2 + 24^2}$	M1	1.1b
	25 (m s ⁻¹)	A1	1.1b
		(4)	
1(b)	Use scalar product $\cos \alpha = \frac{(-4 \times -7) + (3 \times 24)}{\sqrt{(-4)^2 + 3^2} \times \sqrt{(-7)^2 + 24^2}}$	M1	3.1a
	$\alpha = 37$ or better	A1	1.1b
		(2)	
1(b)alt 1	Use cosine rule in a vector triangle: $\cos \alpha = \frac{\{(-4)^2 + 3^2\} + \{(-7)^2 + 24^2\} - (3^2 + (-21)^2)}{2 \times 5 \times \sqrt{(-7)^2 + 24^2}}$	M1	3.1a
	$\alpha = 37$ or better	A1	1.1b
		(2)	
1(b)alt 2	Use inverse tan: Eg $\alpha = \tan^{-1}\left(\frac{24}{7}\right) - \tan^{-1}\left(\frac{3}{4}\right)$ $\alpha = 90 - \tan^{-1}\left(\frac{7}{24}\right) - \tan^{-1}\left(\frac{3}{4}\right)$	M1	3.1a
	$\alpha = 37$ or better	A1	1.1b
		(2)	
(6 marks)			
Notes:			
(a)			
M1	Dimensionally correct, mass $\times$ velocity. Must be subtracting momenta but condone subtracting in the wrong order. M0 if g is included.		
A1	Correct unsimplified equation.		
M1	Correct application of Pythagoras to find the magnitude of their $\mathbf{v}$. M0 for an incorrect speed if there is no evidence of Pythagoras being used on their velocity.		
A1	Correct answer following the correct velocity.		
(b)			

M1	Complete method to find the required angle. Correct use of scalar product with their v . The formula must be correct, $\cos \alpha = \frac{\mathbf{u} \cdot \mathbf{v}}{ \mathbf{u} \mathbf{v} }$ M0 if the fraction is up the wrong way. Do not ISW.
A1	cao in degrees
(b)alt1	
M1	Complete method to find the required angle. Correct use of cosine rule on $(\mathbf{v} - \mathbf{u})$ or $(\mathbf{u} - \mathbf{v})$ vector triangle for their v . M0 if using $(\mathbf{v} + \mathbf{u})$. Do not ISW.
A1	cao in degrees
(b)alt2	
M1	Complete method to find the required angle. Correct use of inverse tan formulae for their v . Do not ISW. M0 for $\tan^{-1}\left(\frac{3}{4}\right)$ alone which also gives the value 36.869...
A1	cao in degrees

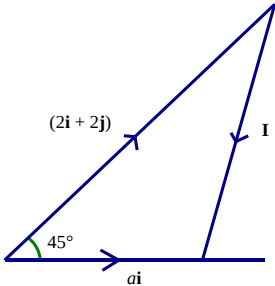


Question	Scheme	Marks	AOs
1a	Impulse-momentum equation	M1	3.1a
	$\mathbf{J} = 0.5(-\mathbf{i} + 6\mathbf{j} - 4\mathbf{i} - 3\mathbf{j})$ $(\mathbf{J} = 0.5(-5\mathbf{i} + 3\mathbf{j}))$	A1	1.1b
	Find magnitude of $\mathbf{J}$:	M1	1.1b
	$ \mathbf{J} ^2 = \frac{1}{4}(25 + 9), \quad \mathbf{J} = \frac{\sqrt{34}}{2} \text{ (N s)}$	A1	1.1b
		(4)	
1b			
	Correct use of trig	M1	3.1a
	$\alpha^\circ = 180^\circ - \tan^{-1} \frac{3}{4} - \tan^{-1} \frac{3}{5}$ or $\alpha^\circ = \tan^{-1} \frac{4}{3} + \tan^{-1} \frac{5}{3}$	A1ft	1.1b
	$\alpha = 112$	A1	1.1b
		(3)	
1balt	Use scalar product of $\mu\mathbf{J}$ and $4\mathbf{i} + 3\mathbf{j}$ to find the angle	M1	3.1a
	$\cos \alpha^\circ = \frac{-20 + 9}{\sqrt{34} \times 5}$	A1ft	1.1b
	$\alpha = 112$	A1	1.1b
		(3)	
1balt	Use of cosine rule in triangle of momenta or equivalent	M1	3.1a
	$\alpha^\circ = 180^\circ - \cos^{-1} \left(\frac{34 + 25 - 37}{2 \times 5 \times \sqrt{34}} \right)$	A1ft	1.1b
	$\alpha = 112$	A1	1.1b
		(3)	
(7 marks)			
Notes:			
(a)M1	Dimensionally correct. Must be subtracting, but condone subtracting in the wrong order.		
A1	Correct unsimplified equation		
M1	Correct application of Pythagoras to find the magnitude. (from $\pm\mathbf{J}$)		
A1	2.9 or better (2.9154....) (from $\pm\mathbf{J}$)		

(b)M1	Correct use of trig to find a relevant angle using $4\mathbf{i} + 3\mathbf{j}$ and their $\mathbf{J}$ i.e. α° or $180^\circ - \alpha^\circ$ Allow $\left \frac{\mathbf{a} \cdot \mathbf{b}}{ \mathbf{a} \mathbf{b} } \right$
A1ft	Correct unsimplified expression for the required angle. Follow their $\mathbf{J}$ A0 for $\left \frac{\mathbf{a} \cdot \mathbf{b}}{ \mathbf{a} \mathbf{b} } \right$ Do not ISW
A1	110 or better (112.166.....) or accept $247.8....^\circ$



Question	Scheme	Marks	AOs
4	Use of Impulse = change in momentum	M1	3.1a
	$0.5(\mathbf{v} - 8\mathbf{i}) = \lambda(-\mathbf{i} + \mathbf{j})$ $(\mathbf{v} = (-2\lambda + 8)\mathbf{i} + 2\lambda\mathbf{j})$	A1	1.1b
	Use of Pythagoras:	M1	3.1a
	e.g. $160 = (-2\lambda + 8)^2 + (2\lambda)^2$ $(160 = 4\lambda^2 - 32\lambda + 64 + 4\lambda^2)$	A1	1.1b
	Form and solve quadratic in λ : $8\lambda^2 - 32\lambda - 96 = 0$ $(\lambda^2 - 4\lambda - 12 = (\lambda - 6)(\lambda + 2) = 0)$	M1	2.1
	$\Rightarrow \lambda = 6$	A1	1.1b
	Find the required angle: $180^\circ - \tan^{-1} 3$	M1	1.1b
	$\theta = 108$	A1	2.2a
		(8)	
(8 marks)			
Notes:			
M1	Must be subtracting two values for momentum, but condone subtraction in the wrong order		
A1	Correct unsimplified equation		
M1	Correct use of final speed with their $\mathbf{v}$		
A1	Correct unsimplified equation in one unknown or pair of simultaneous equations		
M1	Simplify and solve for λ from correct working		
A1	Correct positive solution only		
M1	Complete method to solve for θ		
A1	108 or better (108.4349....)		

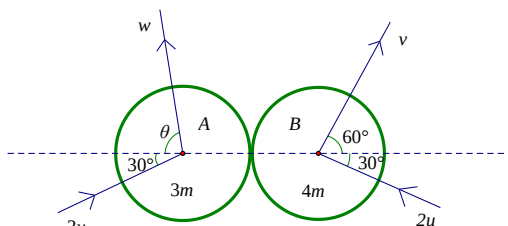
Question	Scheme	Marks	AOs	Notes
3				
	Momentum of P after impulse = ai (or aj)	B1	2.2a	Correct interpretation of angle of deflection (velocity or momentum a multiple of i or j)
Either	Use of $\mathbf{I} = m(\mathbf{v} - \mathbf{u})$: $(\mathbf{I}) = 0.5(2a\mathbf{i} - (4\mathbf{i} + 4\mathbf{j})) = (a - 2)\mathbf{i} - 2\mathbf{j}$	M1	3.3	Form vector triangle or equation for $\mathbf{v}$ or their ai
	Use of Pythagoras to form equation in a	M1	3.4	Use trigonometry or Pythagoras' theorem to form equation in a
	$6.25 = 0.25((2a - 4)^2 + 16)$ $(4a^2 - 16a + 7 = 0)$	A1ft A1	1.1b 1.1b	Unsimplified equation with at most one error. Follow their ai Correct unsimplified equation
Or	$\lambda^2 + \mu^2 = \frac{25}{4}$	M1		
	$\mathbf{I} = \lambda\mathbf{i} + \mu\mathbf{j} = \frac{1}{2}((x - 4)\mathbf{i} - 4\mathbf{j})$	M1		
	$\mu = -2$	A1		Dependent on 2 nd M (for impulse)
	$\lambda^2 = \frac{9}{4}$	A1		

Or	Use of $\mathbf{I} = m(\mathbf{v} - \mathbf{u})$ to form vector triangle	M1	3.3	
	Form equation in their a	M1	3.4	
	$6.25 = a^2 + 8 - 2a\sqrt{8} \times \frac{1}{\sqrt{2}}$ $\left(4 \times 6.25 = b^2 + 32 - 2b\sqrt{32} \times \frac{1}{\sqrt{2}} \text{ for velocity } b\mathbf{i} \right)$ $(4a^2 - 16a + 7 = 0)$	A1ft A1	1.1b 1.1b	
	$a = \frac{7}{2}, \frac{1}{2} \Rightarrow \mathbf{I} = \frac{3}{2}\mathbf{i} - 2\mathbf{j} \text{ (Ns)}$	M1	1.1b	Complete correct method to solve to find a pair of values for λ and μ
	or $\mathbf{I} = -\frac{3}{2}\mathbf{i} - 2\mathbf{j} \text{ (Ns)}$	A1	1.1b	Two correct pairs of values for λ and μ
	or $\mathbf{I} = -2\mathbf{i} - \frac{3}{2}\mathbf{j} \text{ (Ns)}$	M1	2.2a	Use symmetry in complete correct method to find one of the other pairs of values for λ and μ
	or $\mathbf{I} = -2\mathbf{i} + \frac{3}{2}\mathbf{j} \text{ (Ns)}$	A1	1.1b	All four correct pairs (They do not need to write out the impulse in full)
		(9)		
(9 marks)				



Question	Scheme	Marks	AOs
3	Use of change in momentum	M1	3.1a
	$(\mathbf{I}) = 0.4\lambda(2\mathbf{i} + \mathbf{j}) - 0.4 \times 7\mathbf{i}$	A1	1.1b
	Use of Pythagoras to form an equation for magnitude of impulse	M1	1.1b
	E.g. $1.6 = (0.8\lambda - 2.8)^2 + (0.4\lambda)^2$ $1.6 = 0.4^2((2\lambda - 7)^2 + \lambda^2)$	A1	1.1b
	$5\lambda^2 - 28\lambda + 39 = 0 \Rightarrow \lambda = \dots$	dM1	2.1
	$\lambda = 2.6, \lambda = 3$	A1	2.2a
		(6)	
(6 marks)			
Notes: Accept column vectors throughout			
M1	Form an expression for change in momentum in λ , correct number of terms and dimensionally correct. Must use velocities and both components. Subtraction may be either way round. If present, ignore LHS. For the M mark, condone poor expanding of the velocity i.e. $(0.8\lambda\mathbf{i} + 0.4\mathbf{j})$ or $(0.8\mathbf{i} + 0.4\lambda\mathbf{j})$ M0 if speed is used		
A1	Correct unsimplified expression for change in momentum, accept terms either way round. Must use conventional vector notation ie column vector form or $\mathbf{i}$ - $\mathbf{j}$ form. If present, ignore LHS. A0 for unconventional vector notation, unless recovered.		
M1	Correct use of Pythagoras (squaring and adding) to form an equation for magnitude of impulse. Must use the given magnitude, $\sqrt{1.6}$, and the change in momentum components, to form an equation in λ only. Other unknowns may be introduced to represent the impulse components. E.g. $\begin{pmatrix} a \\ b \end{pmatrix} = 0.4 \begin{pmatrix} 2\lambda \\ \lambda \end{pmatrix} - 0.4 \begin{pmatrix} 7 \\ 0 \end{pmatrix}$ However, the M mark is only awarded when Pythagoras is used correctly to form an equation in λ only. E.g. $(\sqrt{1.6})^2 = a^2 + b^2 \Rightarrow 1.6 = (0.8\lambda - 2.8)^2 + (0.4\lambda)^2$		
A1	Correct unsimplified equation in λ only.		
dM1	Dependent on previous two M's. Complete method using the change in momentum and magnitude of impulse to form a 3TQ in λ only and solve to find two λ values. No need to see the method for solving 3TQ. Must reach $\lambda = \dots$		
A1	Both correct values o.e. eg $\lambda = \frac{13}{5}, \lambda = 3$		



Question	Scheme	Marks	AOs
4			
	Parallel to line of centres:	M1	3.1b
	$9mu \cos 30^\circ - 8mu \cos 30^\circ = 4mv \cos 60^\circ - 3mw \cos \theta$ $(u \cos 30^\circ = 2v - 3w \cos \theta) \quad (u \cos 30^\circ = 2v - 3w_x)$	A1	1.1b
	$\uparrow A : (w_y =) w \sin \theta = 3u \sin 30^\circ \left(= \frac{3u}{2} \right)$ $\uparrow B : v \sin 60^\circ = 2u \sin 30^\circ (=u) \quad \left(v = \frac{2u}{\sqrt{3}} \right)$	B1 B1	3.4 3.4
	$(w_x =) w \cos \theta = \frac{1}{3}(2v - u \cos 30^\circ) = \frac{5u\sqrt{3}}{18}$ $(w_y =) w \sin \theta = \frac{3u}{2}$ $\left(\Rightarrow \tan \theta = \frac{9\sqrt{3}}{5}, \theta = 72.2^\circ \right)$	M1	1.1b
	Direction deflected by 77.8° (78° or better)	A1	2.2a
	Magnitude of impulse	M1	3.1b
	$= 4m(v \cos 60^\circ - (-2u \cos 30^\circ))$	A1	1.1b
	$= 4m \left(\frac{1}{2} \times \frac{u}{\sin 60^\circ} - \left(-2u \frac{\sqrt{3}}{2} \right) \right) = \frac{16\sqrt{3}}{3} mu$	A1	2.2a
	OR: magnitude $= 3m(3u \cos 30^\circ + w \cos \theta)$ $= 3m \left(+\frac{5u\sqrt{3}}{18} - \left(-\frac{3u\sqrt{3}}{2} \right) \right) = \frac{16\sqrt{3}}{3} mu$		
		(9)	
(Total 9 Marks)			
M1	Use of CLM parallel to the line of centres. Need all 4 terms. Dimensionally correct. Condone sign errors and sin/cos confusion.		

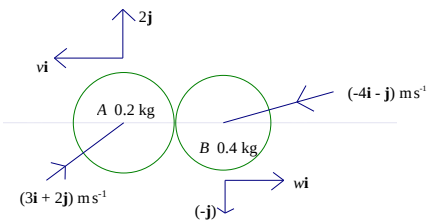
A1	Correct unsimplified equation. Allow e.g. w_x in place of $w\cos\theta$ and v_x in place of $v\cos 60^\circ$. Allow if they have divided through by a common factor e.g. m
	NB there is no mark for the correct use of the impact law because the candidates are not required to find the coefficient of restitution. They might however find it as part of an alternative method. In this case, the M marks below are for a complete correct method to achieve the required result. Ignore work to find e if it is not used.
B1 B1	No change perpendicular to line of centres for one sphere. Allow e.g. w_y in place of $w\sin\theta$. Check the diagrams – the vertical components are often shown there. No change perpendicular to line of centres for both spheres
M1	Use scalar product or solve simultaneous equations to find θ for a relevant angle using their w_x They need to get as far as $\theta =$ a numerical value for a relevant angle
A1	78° or better
M1	Use of $I = mv - mu$ in direction of line of centres. Condone subtraction in either order Allow M1 if they think that they have subtracted but they have not actually taken account of the change of direction. Allow M1 if they go direct to the correct expression with a + without telling you that they have taken account of the change in direction Allow M1 if they go straight to an unsimplified expression in surds using values already found earlier.
A1	Correct unsimplified expression. Allow the negative of this
A1	Any equivalent simplified form. Must be positive. Condone if they change sign at the very end without explaining why. Accept $9.2(376\dots)mu$ (2 sf or better)
	NB You might see candidates using the right angle and matrix multiplication to rotate the initial velocity of B to find the correct components of the velocity of B after impact.



Question	Scheme	Marks	AOs
7(a)	Component parallel to the wall: $\left[\frac{1}{\sqrt{2}}(\mathbf{i} + \mathbf{j}) \cdot (8\mathbf{i} + 2\mathbf{j}) \right]$	M1	2.1
	$= 5\sqrt{2}$	A1	1.1b
	Use of impact law perpendicular to wall:	M1	3.4
	Component perpendicular to wall after impact $\frac{1}{3} \left[\frac{1}{\sqrt{2}}(-\mathbf{i} + \mathbf{j}) \cdot (8\mathbf{i} + 2\mathbf{j}) \right] = -\sqrt{2}$	A1	1.1b
	For a complete method to find $\mathbf{v}$	M1	1.1b
	$\Rightarrow \mathbf{v} = (5\mathbf{i} + 5\mathbf{j}) + (-\mathbf{i} + \mathbf{j}) = (4\mathbf{i} + 6\mathbf{j})$ *	A1*	2.2a
	(6)		
(a) alt	If $\mathbf{v} = a\mathbf{i} + b\mathbf{j}$ component parallel to the wall:	M1	2.1
	$(8\mathbf{i} + 2\mathbf{j}) \cdot (\mathbf{i} + \mathbf{j}) = (a\mathbf{i} + b\mathbf{j}) \cdot (\mathbf{i} + \mathbf{j}) \quad (a + b = 10)$	A1	1.1b
	Use of impact law:	M1	3.4
	$-\frac{1}{3}(8\mathbf{i} + 2\mathbf{j}) \cdot (-\mathbf{i} + \mathbf{j}) = (a\mathbf{i} + b\mathbf{j}) \cdot (-\mathbf{i} + \mathbf{j}) \quad (2 = -a + b)$	A1	1.1b
	For a complete method to find $\mathbf{v}$	M1	1.1b
	$\Rightarrow \mathbf{v} = (4\mathbf{i} + 6\mathbf{j})$ *	A1*	2.2a
	(6)		
(a) alt 2	Angle to wall $= 31^\circ$, component parallel to the wall:	M1	2.1
	$= \sqrt{68} \cos 31^\circ = 7.07$	A1	1.1b
	Component perpendicular to the wall	M1	3.4
	$= \frac{1}{3} \sqrt{68} \sin 31^\circ = 1.42$	A1	1.1b
	For a complete method to find $\mathbf{v}$	M1	1.1b
	$\Rightarrow \mathbf{v} = (\sqrt{52} \cos 56.3^\circ \mathbf{i} + \sqrt{52} \sin 56.3^\circ \mathbf{j}) = (4\mathbf{i} + 6\mathbf{j})$	A1*	2.2a
	(6)		
(b)	$\mathbf{I} = 0.25(4\mathbf{i} + 6\mathbf{j}) - 0.25(8\mathbf{i} + 2\mathbf{j})$ $(\mathbf{I} = 0.25(-\mathbf{i} + \mathbf{j}) - 0.25(3\mathbf{i} - 3\mathbf{j})) \quad (\mathbf{I} = (-\mathbf{i} + \mathbf{j}))$	M1	3.1b

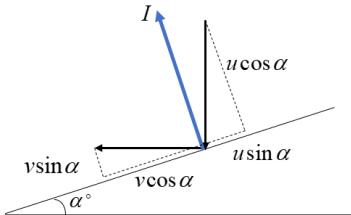
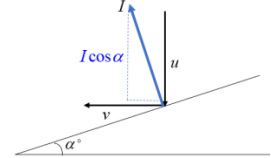
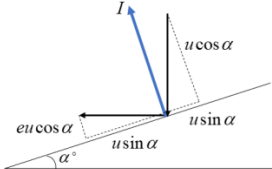
	Use of Pythagoras	M1	1.1b
	$ \mathbf{I} = \sqrt{2} \text{ (Ns)}$	A1	1.1b
		(3)	
(9 marks)			
Notes:			
(a)M1	Use of scalar product or equivalent. Allow M1 if not using unit vector		
A1	Correct unsimplified expression for component parallel to wall		
M1	Correct use of impact law perpendicular to the wall. Condone sign error		
A1	Correct unsimplified expression for component perpendicular to wall		
M1	Complete method to solve for $\mathbf{v}$		
A1*	Obtain given result from correct working		
(b) M1	Use of $\mathbf{I} = m\mathbf{v} - m\mathbf{u}$ with velocities or perpendicular components of velocities. Must be subtracting but allow subtraction in either order.		
M1	Correct use of Pythagoras to find modulus		
A1	Accept 1.4 Ns or better		

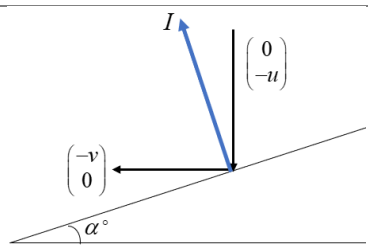


Question	Scheme	Marks	AOs	Notes
6(a)				
	Perpendicular to line of centres: $2\mathbf{j}$	B1	3.4	Use the model to find the component perpendicular to the line of centres. Correct value seen or implied
	CLM parallel to the line of centres	M1	3.1b	Use of CLM parallel to line of centres. Need all terms and dimensionally correct. Condone sign errors
	$0.2 \times 3 - 0.4 \times 4 = 0.4w - 0.2v \quad (-5 = 2w - v)$	A1	1.1b	Correct unsimplified equation.
	Impact law parallel to the line of centres	M1	3.4	Correct use of impact law parallel to the line of centres. Condone sign errors
	$7e = v + w \Rightarrow 3 = v + w$	A1	1.1b	Correct equation with $\frac{3}{7}$ used.
	Complete strategy to find $\mathbf{v}_A$	M1	3.1b	Complete strategy to find components parallel and perpendicular to line of centres, eg by using CLM and impact law
	$\mathbf{v}_A = -\frac{11}{3}\mathbf{i} + 2\mathbf{j} \text{ (ms}^{-1}\text{) follow their } 2\mathbf{j}$	A1ft	1.1b	$\mathbf{v}_A$ correct, follow their $a\mathbf{j}$ for $2\mathbf{j} (a \neq 0)$
	(7)			
6(b)	Magnitude of impulse on A: $0.2 \left(\frac{11}{3} - (-3) \right)$	M1	3.1b	Evidence of use of $m(v-u)$ parallel to the line of centres
	$= 0.2 \left(\frac{11}{3} + 3 \right) = \frac{4}{3} \text{ (Ns)}$	A1	1.1b	1.3 (Ns) or better
	(2)			

Question	Scheme	Marks	AOs	Notes
6(c)	Use of scalar product to find the angle	M1	3.1a	Complete method for finding the required angle. Allow for $\tan^{-1} \frac{3}{2}$ or $\tan^{-1} \frac{2}{3}$ and $\tan^{-1} \frac{6}{11}$ or $\tan^{-1} \frac{11}{6}$
	$\cos \theta = \frac{(3\mathbf{i} + 2\mathbf{j}) \cdot \left(-\frac{11}{3}\mathbf{i} + 2\mathbf{j}\right)}{\sqrt{13} \times \sqrt{\frac{157}{9}}}$	A1ft	1.1b	A correct unsimplified expression Follow their $\mathbf{V}_A$. Do not ISW
	$\theta = 118^\circ$	A1	1.1b	Correct answer only. (Q asks for the nearest degree) Do not ISW
	Alternative method: $180^\circ - \tan^{-1} \frac{2}{3} - \tan^{-1} \frac{6}{11}$ Or $\tan^{-1} \frac{3}{2} + \tan^{-1} \frac{11}{6}$			62° probably scores M1A0A0
		(3)		
(Total 12 marks)				



Question	Scheme	Marks	AOs
6(a)			
	CLM along the plane:	M1	3.1a
	$(m)u \sin \alpha = (m)v \cos \alpha$	A1	1.1b
	Impulse-momentum perp to the plane:	M1	3.1a
	$I = m(v \sin \alpha - (-u \cos \alpha))$	A1	1.1b
	$I = m\left(\frac{u \sin^2 \alpha}{\cos \alpha} + u \cos \alpha\right) = \frac{mu}{\cos \alpha}(\sin^2 \alpha + \cos^2 \alpha) = mu \sec \alpha^*$	A1*	2.2a
	(5)		
6(a) alt1		M1	3.1a
	Impulse-momentum vertically.	M1	3.1a
	$I \cos \alpha = m(0 - -u)$	A1	1.1b
		A1	1.1b
	$I = mu \sec \alpha^*$	A1*	2.2a
	(5)		
6(a) alt 2	Introduce and use an expression for e 		
	CLM along the plane:	M1	3.1a
	$u \sin \alpha$ unchanged	A1	1.1b
	Finds an expression for e together with Impulse-momentum perpendicular to the plane $\tan \alpha = \frac{eu \cos \alpha}{u \sin \alpha} \Rightarrow e = \tan^2 \alpha$ and	M1	3.1a
	$I = m(eu \cos \alpha - (-u \cos \alpha))$		
	$I = m(u \cos \alpha \tan^2 \alpha - (-u \cos \alpha))$	A1	1.1b
	$I = m\left(\frac{u \sin^2 \alpha}{\cos \alpha} + u \cos \alpha\right) = \frac{mu}{\cos \alpha}(\sin^2 \alpha + \cos^2 \alpha) = mu \sec \alpha^*$	A1*	2.2a
	(5)		

6(a) alt 3	Use a vector approach and magnitude of impulse		
	CLM along the plane:	M1	3.1a
	$(m)u \sin \alpha = (m)v \cos \alpha$ (this leads to $v = u \tan \alpha$)	A1	1.1b
	Impulse-momentum as a vector equation followed by Pythagoras to find the magnitude. $I = m \begin{pmatrix} -v \\ u \end{pmatrix}$ and $ I = m\sqrt{v^2 + u^2}$	M1	3.1a
	$ I = m\sqrt{u^2 \tan^2 \alpha + u^2}$	A1	1.1b
	$I = m\sqrt{u^2(1 + \tan^2 \alpha)} = m\sqrt{u^2 \sec^2 \alpha} = mu \sec \alpha^*$	A1*	2.2a
		(5)	
6(b)	NEL: $eu \cos \alpha = v \sin \alpha$	M1	3.4
	Squaring and adding their expressions for $v \sin \alpha$ and $v \cos \alpha$.	M1	1.1b
	$v^2 = u^2(\sin^2 \alpha + e^2 \cos^2 \alpha)^*$	A1*	1.1b
		(3)	
6(c)	KE loss = $\frac{1}{2}mu^2 - \frac{1}{2}mu^2(\sin^2 \alpha + e^2 \cos^2 \alpha)$.	M1	2.1
	Use $\sin^2 \alpha + \cos^2 \alpha = 1$ to give KE loss = $\frac{1}{2}mu^2(1 - e^2) \cos^2 \alpha^*$	A1*	1.1b
		(2)	
6(d)	Use $\tan^2 \alpha = e$ to eliminate α in given expression from (c)	M1	3.1a
	KE Loss = $\frac{1}{2}mu^2(1 - e)$ or $\frac{1}{2}mu^2 \frac{1}{1 + e}(1 - e^2)$	A1	1.1b
		(2)	
(12 marks)			
Notes:			
(a)			
M1	Correct no. of terms, dimensionally correct, mass $\times$ velocity, condone sin/cos confusion.		
A1	Correct equation		
M1	Dimensionally correct. Must be subtracting, but condone subtracting in the wrong order and sin/cos confusion		

A1	Correct unsimplified equation
A1*	Given answer correctly obtained. Must be EXACT factorisation.
(b)	
M1	Attempt at NEL
M1	Squaring and adding their expressions for $v \sin \alpha$ and $v \cos \alpha$ to obtain v^2 .
A1*	Given answer correctly obtained. Must be EXACT.
(c)	
M1	Expression for difference of KE in terms of m , u , α and e
A1*	Given answer correctly obtained. Factorisation must be EXACT.
(d)	
M1	Complete method to eliminate α e.g. using $\tan^2 \alpha = e$ to eliminate α Any trig identity used must be correct eg $\sec^2 \alpha = 1 + e$ or $\cos^2 \alpha = \frac{1}{1+e}$
A1	Correct answer.

Question	Scheme	Marks	AOs
	Note: The diagram below is an aide for marking. In reality, the velocity components cannot be represented by the side lengths of the snooker table. The magnitude of PC is not the magnitude of $U \cos \alpha$		