

INTERNATIONAL A-LEVEL MATHEMATICS

MA05

(9660/MA05) Unit M2 Mechanics

Mark scheme

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Key to mark scheme abbreviations

M	Mark is for method
m	Mark is dependent on one or more M marks and is for method
A	Mark is dependent on M or m marks and is for accuracy
B	Mark is independent of M or m marks and is for method and accuracy
E	Mark is for explanation
✓ or ft	Follow through from previous incorrect result
CAO	Correct answer only
CSO	Correct solution only
AWFW	Anything which falls within
AWRT	Anything which rounds to
ACF	Any correct form
AG	Answer given
SC	Special case
oe	Or equivalent
A2, 1	2 or 1 (or 0) accuracy marks
–x EE	Deduct x marks for each error
NMS	No method shown
PI	Possibly implied
SCA	Substantially correct approach
sf	Significant figure(s)
dp	Decimal place(s)
ISW	Ignore subsequent working

Q	Answer	Marks	Comments
1(a)	Frictionless	B1	oe
		1	

Q	Answer	Marks	Comments
1(b)(i)	<p>[Tension = Weight of P]</p> $T = [mg =] 3 \times 9.8$ $= 29.4 \text{ [N]}$	B1	
		1	

Q	Answer	Marks	Comments
1(b)(ii)	<p>Reaction force R acting on B due to contact with slope</p> $R = [mg \cos 6^\circ =] 4 \times 9.8 \times \cos 6^\circ$ $R = 38.985... \text{ [N]}$ <p>Forces on B acting down the slope</p> $= 3 \times 9.8 + 4 \times 9.8 \times \sin 6^\circ$ $= 33.497... \text{ [N]}$ <p>Forces in equilibrium on B, parallel to the slope</p> $\mu \times 38.985... = 33.497...$ $\mu = 0.86$	<p>B1</p> <p>B1</p> <p>M1</p> <p>A1</p>	<p>AWRT 39</p> <p>ft their 38.985... [N] and 33.497... [N] provided their 33.497... [N] comes from considering two forces AWRT 0.86 Note: Unrounded answer is 0.859235...</p>
		4	

Q	Answer	Marks	Comments
1(c)(i)	9.8 [m s ⁻²] Vertically downwards	B1	Must have both magnitude and direction
		1	

Q	Answer	Marks	Comments
1(c)(ii)	Forces in equilibrium on <i>B</i> , parallel to the slope Friction = $4 \times 9.8 \times \sin 6^\circ$ Friction = 4.1 [N]	M1 A1	PI by correct final answer AWRT 4.1 Note: unrounded answer is 4.0975... [N]
		2	

	Question 1 total	9	
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Q	Answer	Marks	Comments
2(a)	$v = u + at \Rightarrow a = \frac{v - u}{t}$ $a = \frac{5.2 - 0}{0.55}$ $a = 9.45 \text{ [m s}^{-2}\text{]}$	B1	
		1	

Q	Answer	Marks	Comments
2(b)	Newton's 2nd Law $mg - R = ma$ $R = 25 \times 10^{-3} \times 9.8 - 25 \times 10^{-3} \times 9.45$ $R = 8.8 \times 10^{-3}$	M1 A1	Forms the correct equation of motion PI by correct value of R $R = 0.245 - 0.23625$ oe, AWRT 8.8×10^{-3} Note: If $a = 9.45$ used, unrounded answer is 8.75×10^{-3} If $a = 9.4545\dots$ used, unrounded answer is $8.636\dots \times 10^{-3}$
		2	

Q	Answer	Marks	Comments
2(c)(i)	$E = \frac{1}{2}mv^2$ $E = \frac{1}{2} \times 25 \times 10^{-3} \times 5.2^2$ $E = 0.338 \text{ [J]}$	B1	AG Must be convincingly shown with the correct calculation seen
		1	

Q	Answer	Marks	Comments
2(c)(ii)	<p>Conservation of Energy: Loss in GPE = Gain in KE + Work Done against R</p> $mgh = 0.338 + Rh$ $h = \frac{0.338}{mg - R} = \frac{0.338}{25 \times 10^{-3} \times 9.8 - 8.75 \times 10^{-3}}$ $h = 1.43 \text{ [m]}$	<p>M1</p> <p>A1ft</p>	<p>Equation of the form: Loss in GPE = Gain in KE + Work Done against R</p> <p>AWRT 1.43 ft their value for R but must use 25×10^{-3} kg for mass</p>
		2	

Q	Answer	Marks	Comments
2(d)	<p>Conservation of Energy:</p> <p>Gain in GPE + Work Done against R</p> <p>= Loss in KE</p> $mg\Delta y + R\Delta y = \frac{1}{2}mv^2$ $25 \times 10^{-3} \times 9.8 \times 0.65 + 8.8 \times 10^{-3} \times 0.65$ $= \frac{1}{2}mv^2$ $v = 3.63... \left[\text{m s}^{-1} \right]$ <p>Magnitude of impulse exerted on the pebble</p> $= 25 \times 10^{-3} \times 3.63... - 25 \times 10^{-3} \times (-5.2)$ $= 0.22 \left[\text{kg m s}^{-1} \right]$	<p>M1</p> <p>A1ft</p> <p>M1</p> <p>A1</p>	<p>$\Delta y = 0.65$</p> <p>Equation of the form: Gain in GPE + Work Done against R = Loss in KE PI by AWRT 0.23 or AWRT 3.6 ft their value for R but must use 25×10^{-3} kg for mass</p> <p>Calculation for the impulse using their v Condone one sign error</p> <p>CAO</p>
		4	

	Question 2 total	10	
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Q	Answer	Marks	Comments
4(a)(i)	<p>Clockwise moments about A</p> $= d \times 219 \times 9.8$ <p>Anticlockwise moments about A</p> $= 6.5 \times 1645 \sin(19^\circ) [= 3481.137...]$ <p>Equilibrium</p> $2146.2d = 3481.137...$ $d = \frac{3481.137...}{2146.2}$ <p>or $d = 1.6220...$</p> $d = 1.622 \text{ [to 4 sf]}$	<p>M1</p> <p>M1</p> <p>A1</p>	<p>Finds the correct clockwise or anticlockwise moment about A</p> <p>Finds the correct clockwise and anticlockwise moment about A</p> $d = \frac{6.5 \times 1645 \sin(19^\circ)}{219 \times 9.8}$ <p>AG Must be convincingly shown Must see clear correct working leading to final value, or 1.6220...</p>
		3	

Q	Answer	Marks	Comments
4(a)(ii)	<p>Forces horizontally on rod</p> $T_A \cos(46^\circ) = T_B \cos(19^\circ)$ $T_A = \frac{1645 \cos(19^\circ)}{\cos(46^\circ)}$ $T_A = 2239$	<p>M1</p> <p>A1</p>	<p>oe such as considering forces vertically on the rod or considering moments about B PI by 1610.64... [N] or 10469.16... [N m]</p> $T_A = \frac{1610.64...}{\sin(46^\circ)}$ <p>or $T_A = \frac{219 \times 9.8 \times (6.5 - 1.622)}{6.5 \times \sin(46^\circ)}$</p> <p>AWRT 2239 Note: unrounded answer is 2239.05...</p>
		2	

Q	Answer	Marks	Comments
4(b)	<p>String A will break (before string B)</p> <p>Equilibrium of forces in the horizontal direction when $T_A = 3000$</p> $3000\cos(46^\circ) = T_B \cos(19^\circ)$ $T_B = 2204.055\dots$ <p>Equilibrium of forces in the vertical direction</p> $3000 \times \sin(46^\circ) + 2204.055\dots \times \sin(19^\circ) = 2146.2 + mg$ $m = \frac{2158.019\dots + 717.57\dots - 2146.2}{9.8}$ $m = 74.427\dots$ <p>Hence, $0 \leq m < 74$</p>	<p>M1</p> <p>A1</p> <p>M1</p> <p>A1</p>	<p>Identifies that string A will reach a tension of 3000 N before string B, or uses 3000 N as the tension in string A only PI by AWRT 2204 seen or used</p> <p>AWRT 2204</p> <p>M1: Four terms with at least three correct. May be in terms of T_A and T_B</p> <p>AWRT 74 Condone $m < 74$ and $m \leq 74$</p>
		4	

Q	Answer	Marks	Comments
4(b) ALT	String A will break (before string B)	M1	Identifies that string A will reach a tension of 3000 N before string B , or uses 3000 N as the tension in string A
	Clockwise moments about B $= 6.5 \times 3000 \sin(46^\circ) \quad [= 14027.12611]$	M1	Finds the correct clockwise or anticlockwise moment about B
	Anticlockwise moments about B $= (6.5 - 1.622) \times m \times 9.8$ $+ (6.5 - 1.622) \times 219 \times 9.8$ $\quad [= 47.8044m + 10469.1636]$		
	Principle of Moments $14027.12611 = 47.8044m + 10469.1636$ $m = 74.427...$	A1	Forms correct equation based upon equilibrium
	Hence, $0 \leq m < 74$	A1	AWRT 74 Condone $m < 74$ and $m \leq 74$
		4	

	Question 4 total	9	
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Q	Answer	Marks	Comments
5(a)	$x = (u \cos \theta)t$ $y = -(u \sin \theta)t - \frac{1}{2}gt^2 + h$ $t = \frac{x}{u \cos \theta}$ $y = h - (u \sin \theta) \times \frac{x}{u \cos \theta} - \frac{1}{2}g \times \left(\frac{x}{u \cos \theta} \right)^2$ $(u \sin \theta) \times \frac{x}{u \cos \theta} = x \tan \theta$ $-\frac{1}{2}g \times \left(\frac{x}{u \cos \theta} \right)^2 = -\frac{gx^2}{2u^2} \times \frac{1}{\cos^2 \theta}$ $-\frac{gx^2}{2u^2} \times \frac{1}{\cos^2 \theta} = -\frac{gx^2}{2u^2} \sec^2 \theta$ $y = h - x \tan \theta - \frac{gx^2}{2u^2} \sec^2 \theta$	<p>B1</p> <p>M1 A1</p> <p>M1 A1</p> <p>A1</p>	<p>oe</p> <p>M1: Three terms with at least two terms correct oe A1: All correct oe</p> <p>M1: Eliminates t in both terms with at least one term correct A1: All correct</p> <p>AG Must be convincingly shown</p>
		6	

Q	Answer	Marks	Comments
5(b)(i)	$0 = 4 - x \tan(25^\circ)$	M1	Forms quadratic equation in x
	$-x^2 \times \frac{9.8}{2 \times 20^2} \sec^2(25^\circ)$		
	$x = 7.0075\dots, \quad x = -38.274\dots$	A1	Solves quadratic equation in x and obtains at least one correct solution
	7.0 [m], reject -38 [m]	A1	Clear rejection of negative value leading to AWRT 7.0 [m]
		3	

Q	Answer	Marks	Comments
5(b)(ii)	$T = \frac{7.0}{20 \cos(25^\circ)}$	M1	Forms a correct equation for T
	$T = 0.39 \text{ [s]}$	A1	AWRT 0.39 [s] Note: unrounded answer is 0.386... [s]
		2	

	Question 5 total	11	
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Q	Answer	Marks	Comments
6(a)(i)	$\mathbf{v} = \begin{bmatrix} -24 \sin 4t \\ 24 \cos 4t \end{bmatrix}$	M1 A1	M1: At least one component correct A1: Both components correct
		2	

Q	Answer	Marks	Comments
6(a)(ii)	<p>When $t = \frac{\pi}{3}$, $\mathbf{v} = \begin{bmatrix} 12\sqrt{3} \\ -12 \end{bmatrix}$</p> <p>When $t = \frac{\pi}{3}$, $\mathbf{r} = \begin{bmatrix} -3 \\ 2 - 3\sqrt{3} \end{bmatrix}$</p> <p>$\mathbf{v} \cdot \mathbf{r} = (12\sqrt{3}) \times (-3) + (-12) \times (2 - 3\sqrt{3})$</p> <p>$\mathbf{v} \cdot \mathbf{r} = -24$</p> <p>$\cos \theta$</p> <p>$= \frac{-24}{\sqrt{(12\sqrt{3})^2 + (-12)^2} \times \sqrt{(-3)^2 + (2 - 3\sqrt{3})^2}}$</p> <p>$\cos \theta = \frac{-1}{\sqrt{40 - 12\sqrt{3}}}$</p> <p>$\theta = 103^\circ$</p>	<p>B1</p> <p>B1</p> <p>M1</p> <p>A1</p> <p>m1</p> <p>A1</p>	<p>Correct velocity vector at $t = \frac{\pi}{3}$ PI by later working</p> <p>Correct position vector at $t = \frac{\pi}{3}$ PI by later working</p> <p>Attempt to calculate scalar product</p> <p>Correct evaluated value for scalar product PI by correct angle</p> <p>Relates angle to their values for the scalar product and the modulus of their velocity and position PI by correct angle</p> <p>$\cos \theta = -0.2281\dots$</p> <p>CAO</p>
		6	

Q	Answer	Marks	Comments
6(b)	$\mathbf{a} = \begin{bmatrix} -96 \cos 4t \\ -96 \sin 4t \end{bmatrix}$	B1ft	Correct acceleration vector PI
	$ \mathbf{a} = 96 \text{ [m s}^{-1}\text{]} \text{ or } \mathbf{F} = \begin{bmatrix} -336 \cos 4t \\ -336 \sin 4t \end{bmatrix}$	B1ft	Correct magnitude of acceleration or correct force vector
	$ \mathbf{F} = 336 \Rightarrow k = 336$	B1	Allow 340 (2 sf) from correct working
		3	
	Question 6 total	11	

Q	Answer	Marks	Comments
7(a)	$\cos(OPC) \left[= \frac{3d}{5d} \right] = \frac{3}{5}$	B1	Clearly justifies use of $\frac{3}{5}$
	Resultant force towards C		
	$T \cos(OPC) = \frac{mv^2}{r}$	M1	oe $T \cos(OPC) = \frac{mv^2}{3d}$
	$T \times \frac{3}{5} = \frac{mv^2}{3d}$		
	$T = \frac{5mv^2}{9d}$	A1	AG Must be convincingly shown
		3	

Q	Answer	Marks	Comments
7(b)	Equilibrium in the vertical direction		
	$R + T \sin(OPC) = mg$	M1	Forms equation for the equilibrium of forces in vertical direction PI
	$R = mg - \frac{5mv^2}{9d} \times \frac{4d}{5d}$	M1	Use of $T = \frac{5mv^2}{9d}$ and $\sin(OPC) = \frac{4d}{5d} = \frac{4}{5}$
	$R = mg - \frac{4m}{9d} \times (\sqrt{2gd})^2$	M1	PI by use of $[T \sin(OPC) =] \frac{8mg}{9}$ Eliminates v
	$R = mg - \frac{8mg}{9}$		PI by use of $T = \frac{10mg}{9}$ or correct final answer
	$R = \frac{mg}{9}$	A1	CAO
		4	

	Question 7 total	7	
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Q	Answer	Marks	Comments
8(a)	The lamina is symmetric about the line OX	E1	Allow any mention of symmetry
		1	

Q	Answer	Marks	Comments
8(b)(i)	$\rho \times \frac{\pi r^2}{2} \times \frac{4r}{3\pi} = \rho \times \frac{\pi k^2 r^2}{2} \times \frac{4kr}{3\pi}$ $+ \rho \times \left(\frac{\pi r^2}{2} - \frac{\pi k^2 r^2}{2} \right) \bar{X}$ $\bar{X} = \frac{\frac{2r^3}{3} - \frac{2k^3 r^3}{3}}{\frac{\pi r^2}{2} - \frac{\pi k^2 r^2}{2}}$ $[\bar{X} =] \frac{4r(1-k^3)}{3\pi(1-k^2)}$	<p>M1 m1 A1</p> <p>M1</p> <p>A1</p>	<p>M1: At least one of the three terms correct PI m1: At least two of the three terms correct PI A1: Fully correct equation</p> <p>Condone lack of ρ</p> <p>Attempt to solve for $\bar{X}$</p> <p>CAO</p>
		5	

Q	Answer	Marks	Comments
8(b)(ii)	$\tan \theta = \frac{4r(1-k^3)}{3\pi(1-k^2)r}$ <p>When $k = 0.5$</p> $\tan \theta = \frac{14}{9\pi}$ $\theta = 26^\circ$	<p>M1</p> <p>m1</p> <p>A1</p>	<p>Forms equation for the angle using their answer to part (b)(i) provided it is in the correct form</p> <p>PI $\tan \theta = 0.495\dots$</p> <p>AWRT 26</p>
		3	

	Question 8 total	9	
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Q	Answer	Marks	Comments
9(a)	$\omega = 2\pi f$	M1	A correct formula for angular speed seen or used
	8 complete revolutions in 25 second $\omega \left[= 2\pi \times \frac{8}{25} \right] = \frac{16\pi}{25} \text{ [rad s}^{-1}\text{]}$	A1	Ignore incorrect units or missing units
		2	

Q	Answer	Marks	Comments
9(b)	$\frac{5\pi^2}{r^3} = m\omega^2 r$	M1	Forms equation of motion PI
	$r^4 = \frac{5\pi^2}{m\omega^2}$	m1	Rearranges for r^4 or r PI by $r^4 = \frac{625}{256} = 2.441\dots$
	When $\omega = \frac{16\pi}{25}$ $r = \sqrt[4]{\frac{5\pi^2}{5 \times \left(\frac{16\pi}{25}\right)^2}} = \frac{5}{4} \text{ [m]}$	A1	ISW
		3	

Q	Answer	Marks	Comments
9(c)	When $\omega = \frac{16\pi}{25}$ and $r = \frac{5}{4}$ $KE = \frac{1}{2}mv^2 = \frac{1}{2} \times 5 \times \left(\frac{16\pi}{25} \times \frac{5}{4}\right)^2$	M1	ft their ω and r
	$KE = 16 \text{ [J]}$	A1	AWRT 16 Note: unrounded answer is 15.791... [J] Allow $\frac{8\pi^2}{5} \text{ [J]}$ or $1.6\pi^2 \text{ [J]}$
		2	

	Question 9 total	7	
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