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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)	[Tension = Weight of *P*] $T = [mg =]\ 3 \times 9.8$ $= 29.4\ [\text{N}]$	B1	
		1	

Q	Answer	Marks	Comments
1(b)(ii)	Reaction force R acting on *B* due to contact with slope $R = [mg\cos 6^\circ =]\ 4 \times 9.8 \times \cos 6^\circ$ $R = 38.985...\ [\text{N}]$	B1	**AWRT** 39
	Forces on *B* acting down the slope $= 3 \times 9.8 + 4 \times 9.8 \times \sin 6^\circ$ $= 33.497...\ [\text{N}]$	B1	
	Forces in equilibrium on *B*, parallel to the slope $\mu \times 38.985... = 33.497...$	M1	**ft** their $38.985...\ [\text{N}]$ and $33.497...\ [\text{N}]$ provided their $33.497...\ [\text{N}]$ comes from considering two forces
	$\mu = 0.86$	A1	**AWRT** 0.86 Note: Unrounded answer is 0.859235…
		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 *B*, parallel to the slope		
	Friction $= 4 \times 9.8 \times \sin 6^\circ$	**M1**	**PI** by correct final answer
	Friction $= 4.1\ [\text{N}]$	**A1**	**AWRT** 4.1 Note: unrounded answer is 4.0975… [N]
		2	

	Question 1 total	**9**	

Q	Answer	Marks	Comments
2(a)	$v = u + at \Rightarrow a = \dfrac{v-u}{t}$ $a = \dfrac{5.2 - 0}{0.55}$ $a = 9.45$ $\left[\mathrm{m\,s^{-2}}\right]$	**B1**	
		1	

Q	Answer	Marks	Comments
2(b)	Newton's 2nd Law $mg - R = ma$ $R = 25\times10^{-3}\times9.8 - 25\times10^{-3}\times9.45$ $R = 8.8\times10^{-3}$	**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 $a = 9.4545...$ used, unrounded answer is $8.636...\times10^{-3}$
		2	

Q	Answer	Marks	Comments
2(c)(i)	$E = \dfrac{1}{2}mv^2$ $E = \dfrac{1}{2}\times25\times10^{-3}\times5.2^2$ $E = 0.338$ $[\mathrm{J}]$	**B1**	**AG** Must be convincingly shown with the correct calculation seen
		1	

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

Q	Answer	Marks	Comments
2(d)	Conservation of Energy: Gain in GPE + Work Done against R = Loss in KE $mg\Delta y + R\Delta y = \dfrac{1}{2}mv^2$ $25 \times 10^{-3} \times 9.8 \times 0.65 + 8.8 \times 10^{-3} \times 0.65$ $= \dfrac{1}{2}mv^2$ $v = 3.63...\ [\text{m s}^{-1}]$ Magnitude of impulse exerted on the pebble $= 25 \times 10^{-3} \times 3.63... - 25 \times 10^{-3} \times (-5.2)$ $= 0.22\ [\text{kg m s}^{-1}]$	 **M1** **A1ft** **M1** **A1**	 $\Delta y = 0.65$ 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 Calculation for the impulse using their v Condone one sign error **CAO**
		4	

	Question 2 total	**10**	

Q	Answer	Marks	Comments
3(a)	$\frac{P}{v} - 3v^k = ma$	M1 A1	**M1**: Forms a three-term equation of motion, **oe** **A1**: Fully correct equation of motion
	$4^k = \frac{\frac{250}{4} - 42}{3} = \frac{41}{6}$	m1	Isolating the term in k
	$k = \frac{\ln\left(\frac{41}{6}\right)}{\ln(4)}$ or $k = \log_4\left(\frac{41}{6}\right)$ or $k = 1.3862...$		
	$k = 1.386$ [to 4 sf]	A1	**AG** Must be convincingly shown by either the exact value of k in terms of logarithms seen or by sight of 1.3862…
		4	

Q	Answer	Marks	Comments
3(b)	$\frac{250}{v} - 3v^{1.386} = 0$	M1	Forms a correct equation
	$v^{2.386} = \frac{250}{3}$	m1	Isolating the term in v
	$v = \left(\frac{250}{3}\right)^{\frac{1}{2.386}}$		
	$v = 6.38$ [m s^{-1}]	A1	**AWRT** 6.38
		3	

	Question 3 total	**7**	

Q	Answer	Marks	Comments
4(a)(i)	Clockwise moments about A		
	$= d \times 219 \times 9.8$	**M1**	Finds the correct clockwise or anticlockwise moment about A
	Anticlockwise moments about A		
	$= 6.5 \times 1645\sin(19°)$ $[= 3481.137...]$	**M1**	Finds the correct clockwise and anticlockwise moment about A
	Equilibrium		
	$2146.2d = 3481.137...$		
	$d = \dfrac{3481.137...}{2146.2}$ or $d = 1.6220...$		$d = \dfrac{6.5 \times 1645\sin(19°)}{219 \times 9.8}$
	$d = 1.622$ [to 4 sf]	**A1**	**AG** Must be convincingly shown Must see clear correct working leading to final value, or 1.6220…
		3	

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

Q	Answer	Marks	Comments
4(b)	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* only **PI** by **AWRT** 2204 seen or used
	Equilibrium of forces in the horizontal direction when $T_A = 3000$ $3000\cos(46°) = T_B \cos(19°)$		
	$T_B = 2204.055...$	A1	**AWRT** 2204
	Equilibrium of forces in the vertical direction $3000 \times \sin(46°) + 2204.055... \times \sin(19°) = 2146.2 + mg$	M1	**M1**: Four terms with at least three correct. May be in terms of T_A and T_B
	$m = \dfrac{2158.019... + 717.57... - 2146.2}{9.8}$ $m = 74.427...$		
	Hence, $0 \le m < 74$	A1	**AWRT** 74 Condone $m < 74$ and $m \le 74$
		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*		
	$= 6.5 \times 3000 \sin(46^\circ)$ $[= 14027.12611]$	**M1**	Finds the correct clockwise or anticlockwise moment about *B*
	Anticlockwise moments about *B*		
	$= (6.5 - 1.622) \times m \times 9.8$ $+ (6.5 - 1.622) \times 219 \times 9.8$ $[= 47.8044m + 10469.1636]$		
	Principle of Moments		
	$14027.12611 = 47.8044m + 10469.1636$	**A1**	Forms correct equation based upon equilibrium
	$m = 74.427...$		
	Hence, $0 \le m < 74$	**A1**	**AWRT** 74 Condone $m < 74$ and $m \le 74$
		4	

	Question 4 total	**9**	

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

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

Q	Answer	Marks	Comments
5(b)(ii)	$T = \dfrac{7.0}{20\cos(25°)}$	**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**	

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

Q	Answer	Marks	Comments
6(b)	$\mathbf{a} = \begin{bmatrix} -96\cos 4t \\ -96\sin 4t \end{bmatrix}$	B1ft	Correct acceleration vector **PI**
	$\lvert\mathbf{a}\rvert = 96\ \left[\text{m s}^{-1}\right]$ or $\mathbf{F} = \begin{bmatrix} -336\cos 4t \\ -336\sin 4t \end{bmatrix}$	B1ft	Correct magnitude of acceleration or correct force vector
	$\lvert\mathbf{F}\rvert = 336 \Rightarrow k = 336$	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 $\sin(OPC)=\frac{4d}{5d}=\frac{4}{5}$ **PI** by use of $\left[T\sin(OPC)=\right]\frac{8mg}{9}$
	$R=mg-\frac{4m}{9d}\times\left(\sqrt{2gd}\right)^2$	**M1**	Eliminates v **PI** by use of $T=\frac{10mg}{9}$ or correct final answer
	$R=mg-\frac{8mg}{9}$		
	$R=\frac{mg}{9}$	**A1**	**CAO**
		4	

	Question 7 total	**7**	

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

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

	Question 8 total	**9**	

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		
	$\omega \left[= 2\pi \times \dfrac{8}{25}\right] = \dfrac{16\pi}{25}$ $\left[\text{rad s}^{-1}\right]$	A1	Ignore incorrect units or missing units
		2	

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

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

	Question 9 total	**7**	