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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)	(6, 5) The centre of mass of the uniform rectangular lamina is at its geometric centre	B1 E1	 Allow any mention of symmetry of the rectangle
		2	

Q	Answer	Marks	Comments
1(b)	$(3+4+7+9+11)\overline{X}$ $=3\times2+4\times2+7\times10+9\times10+11\times6$ $\overline{X}=\frac{240}{34}$ $(3+4+7+9+11)\overline{Y}$ $=3\times2+4\times8+7\times8+9\times2+11\times5$ $\overline{Y}=\frac{167}{34}$ $\left(\frac{240}{34},\frac{167}{34}\right)$	M1 A1 M1 A1 	Forms equation for x-coordinate of the centre of mass. Condone one error **oe** Forms equation for y-coordinate of the centre of mass. Condone one error **oe** If **M1 A0 M1 A0**, then allow **SC1** for both x and y-coordinates given as decimals **AWRT** 7.1 and **AWRT** 4.9
		4	

Q	Answer	Marks	Comments
1(c)	$\tan\theta = \dfrac{10-\dfrac{167}{34}}{\dfrac{240}{34}}$ $\left[=\dfrac{\dfrac{173}{34}}{\dfrac{240}{34}}=\dfrac{173}{240}\right]$ $\theta = \tan^{-1}\left(\dfrac{173}{240}\right)$ $\theta = 36°$	M1 A1ft A1	**M1**: At least numerator or denominator correct, **ft** their coordinates for COM **A1**: Both numerator and denominator correct, **ft** their coordinates for COM **PI** by **AWRT** 36° or **AWRT** 54° **AWRT** 36° Unrounded answer is 35.785…°
		3	

	Question 1 Total	**9**	

Q	Answer	Marks	Comments
2(a)	$\frac{1}{2}\times 4\times 3.2^2 - \frac{1}{2}\times 4\times 1.2^2$ $= 17.6\ [\text{J}]$	 B1	 **AG** Must be convincingly shown with a correct numerical expression for the loss in kinetic energy seen Accept -17.6 [J] following from correct working
		1	

Q	Answer	Marks	Comments
2(b)(i)	Forces in equilibrium in the direction perpendicular to the plane $25 = 4\times 9.8\cos\theta$ $\cos\theta = \dfrac{25}{4\times 9.8}$ $\theta = 50°$	 M1 A1	 **AWRT** 50
		2	

Q	Answer	Marks	Comments
2(b)(ii)	Loss in KE = Gain in GPE		
	$17.6 = 4 \times 9.8 \times h$	**M1**	**oe**, such as calculates force down the slope, $4 \times 9.8 \times \sin(50°) = 30.0289...$
	$h \left[= \frac{17.6}{4 \times 9.8} \right] = 0.4489...$	**A1**	**oe**, such as $\frac{22}{49}$ or forms an equation for the work done against the force down the slope $30.0289...d = 17.6$
	$d = \frac{h}{\sin\theta} = \frac{0.4489...}{\sin(50°)}$		
	$d = 0.58$	**A1**	**AWFW** [0.58, 0.59]
		3	

Q	Answer	Marks	Comments
2(c)	$t \left[= \frac{2s}{u+v} \right] = \frac{2 \times 0.58}{3.2 + 1.2}$ or $t \left[= \frac{v-u}{a} \right] = \frac{1.2 - 3.2}{-9.8 \times \sin(50°)}$		
	$t = 0.2649...$	**B1**	**AWFW** [0.26, 0.27]
	$T = 2 \times 0.2649...$		
	$T = 0.53$	**B1**	**AWFW** [0.53, 0.54]
		2	

	Question 2 Total	**8**	

Q	Answer	Marks	Comments
3(a)	$\frac{P}{v} + 2900g\sin(3°) - 3000 = 0$	M1 A1	**M1**: Three-term force equation for the van's motion **A1**: Correct equation **PI** by **AWFW** [1512, 1513] [newtons]
	$P = 15\times(3000 - 2900\times 9.8\sin(3°))$	m1	
	$P = 23000$	A1	**AWRT** 23 000 Unrounded answer is 22 689. … W
		4	

Q	Answer	Marks	Comments
3(b)	$\frac{95\,000}{15} + 2900g\sin(3°) - 3000 = 2900a$	M1	Forms a three-term expression for the resultant force set equal to $2900a$ **PI** by $4820.72\ldots = 2900a$
	$a = \frac{6333.33... + 1487.38... - 3000}{2900}$		
	$a = 1.7\ \left[\text{m s}^{-2}\right]$	A1	**AWRT** 1.7 Unrounded answer is 1.66… m s^{-2}
		2	

	Question 3 Total	**6**	

Q	Answer	Marks	Comments
4(a)(i)	0.24 rad s^{-1}	**B1** **B1**	Correct value Correct units
		2	

Q	Answer	Marks	Comments
4(a)(ii)	$v = r\omega$ $v = 50 \times 0.24$ $v = 12$	 **M1** **A1ft**	 **ft** their angular speed
		2	

Q	Answer	Marks	Comments
4(a)(iii)	$\frac{mv^2}{r} = \mu mg \Rightarrow \mu = \frac{v^2}{gr}$ $\mu = \frac{12^2}{9.8 \times 50} \left[= \frac{72}{245} = 0.2938... \right]$ $\mu \geq 0.29$	 **M1** **A1**	or $m\omega^2 r = \mu mg \Rightarrow \mu = \frac{\omega^2 r}{g}$ or $\mu = \frac{0.24^2 \times 50}{9.8} \left[= \frac{72}{245} = 0.2938... \right]$ **ACF**, eg $\mu \geq \frac{72}{245}$
		2	

Q	Answer	Marks	Comments
4(b)	As 0.18 < 0.29 [there is not enough friction to provide the resultant force to move around a circle of radius 50 metres at 12 m s^{-1}] [so the] car cannot still move around the roundabout [in a circle of radius 50 metres at 12 m s^{-1}]	**E1ft** **E1ft**	Correct reasoning for their $\frac{72}{245} = 0.29 \left[2\text{sf}\right]$ from **part (a)(iii)** **oe** such as 2116.8 [N] < 3456 [N] Correct statement for their $\frac{72}{245} = 0.29 \left[2\text{sf}\right]$ from **part (a)(iii)** **E0 E1** is not possible
		2	

	Question 4 Total	**8**	

Q	Answer	Marks	Comments
5(a)	$\mathbf{a} = \begin{bmatrix} 2e^{2t} \\ 8\cos 4t \\ -6\sin 3t \end{bmatrix}$	**B1**	**PI**
	$\mathbf{v} = \begin{bmatrix} e^{2t} \\ 2\sin 4t \\ 2\cos 3t \end{bmatrix} + \mathbf{c}$	**M1 A1**	**M1**: At least two components correct **A1**: All three components correct Condone omission of constant(s) of integration for **M1 A1**
	When $t = 0$		
	$\begin{bmatrix} 1 \\ 0 \\ 2 \end{bmatrix} + \mathbf{c} = \begin{bmatrix} 2 \\ -5 \\ 3 \end{bmatrix}$	**M1**	**PI**
	$\mathbf{c} = \begin{bmatrix} 1 \\ -5 \\ 1 \end{bmatrix}$	**A1**	
	$\mathbf{v} = \begin{bmatrix} e^{2t} + 1 \\ 2\sin 4t - 5 \\ 2\cos 3t + 1 \end{bmatrix}$	**A1**	**ACF**
		6	

Q	Answer	Marks	Comments
5(b)	When $t = \frac{\pi}{12}$ $\mathbf{v} = \begin{bmatrix} e^{\frac{\pi}{6}} + 1 \\ -5 + \sqrt{3} \\ 1 + \sqrt{2} \end{bmatrix}$ $\lvert\mathbf{v}\rvert = \sqrt{\left(e^{\frac{\pi}{6}} + 1\right)^2 + \left(-5 + \sqrt{3}\right)^2 + \left(1 + \sqrt{2}\right)^2}$ $\lvert\mathbf{v}\rvert = 4.9 \left[\text{m s}^{-1}\right]$	**M1** **A1**	Substitutes $t = \frac{\pi}{12}$ into their velocity vector, simplified or unsimplified **PI** **AWRT** 4.9
		2	

	Question 5 Total	**8**	

Q	Answer	Marks	Comments
6(a)	$x = (u\cos\theta)t$	B1	oe
	$y = (u\sin\theta)t - \frac{1}{2}gt^2$	B1	
	$t = \frac{x}{u\cos\theta}$		
	$y = (u\sin\theta)\times\frac{x}{u\cos\theta} - \frac{1}{2}g\times\left(\frac{x}{u\cos\theta}\right)^2$	M1 A1	**M1**: Eliminates t in both terms with at least one term correct **A1**: All correct with correct substitutions shown
	$(u\sin\theta)\times\frac{x}{u\cos\theta} = x\tan\theta$		
	$-\frac{1}{2}g\times\left(\frac{x}{u\cos\theta}\right)^2 = -\frac{gx^2}{2u^2}\times\frac{1}{\cos^2\theta}$		
	$-\frac{gx^2}{2u^2}\times\frac{1}{\cos^2\theta} = -\frac{gx^2}{2u^2}\sec^2\theta$		
	$y = x\tan\theta - \frac{gx^2}{2u^2}\sec^2\theta$	A1	
	$y = x\tan\theta - \frac{gx^2}{2u^2}(1+\tan^2\theta)$		
	$y = x\tan\theta - \frac{gx^2}{2u^2} - \frac{gx^2}{2u^2}\tan^2\theta$		
	$\frac{gx^2}{2u^2}\tan^2\theta - x\tan\theta + y + \frac{gx^2}{2u^2} = 0$	A1	**AG** Must be convincingly shown
		6	

Q	Answer	Marks	Comments
6(b)	$\frac{9.8\times5^2}{2\times8^2}\tan^2\theta - 5\tan\theta + 1.5 + \frac{9.8\times5^2}{2\times8^2} = 0$	**M1**	Substitutes $u = 8$, $x = 5$ and $y = 1.5$ into the result from **part (a)**
	$\frac{245}{128}\tan^2\theta - 5\tan\theta + \frac{437}{128} = 0$	**A1**	Correct three-term quadratic equation or expression in $\tan\theta$, **ACF** **PI** by correct discriminant, simplified or unsimplified
	[Discriminant =] $\left(-5\right)^2 - 4\times\left(\frac{245}{128}\right)\times\left(\frac{437}{128}\right)$ $\left[= -\frac{4665}{4096} = -1.1...\right]$	**B1ft**	Attempts to find the discriminant of their quadratic equation by substituting in the values of a, b and c or $\tan\theta = \frac{5 \pm \sqrt{\left(-5\right)^2 - 4\times\left(\frac{245}{128}\right)\times\left(\frac{437}{128}\right)}}{2\times\frac{245}{128}}$
	$-\frac{4665}{4096} < 0$ Hence, no real solutions, so no possible angle for the ball to pass over the wall	**E1**	Shows that the simplified discriminant is less than zero **oe** and gives a correct conclusion
		4	

	Question 6 Total	**10**	

Q	Answer	Marks	Comments
7(a)(i)	$s = ut + \frac{1}{2}at^2$ $u = 0 \Rightarrow a = \frac{2s}{t^2}$ $a = \frac{2 \times 3}{4^2}$ $a = \frac{3}{8} = 0.375 \left[\text{m s}^{-2}\right]$	**B1**	**CAO, AWRT** 0.38
		1	

Q	Answer	Marks	Comments
7(a)(ii)	$a = \frac{3}{8} = 0.375 \left[\text{m s}^{-2}\right]$	**B1ft**	**AWRT** 0.38
	String connecting particles is inextensible	**E1**	A valid explanation
		2	

Q	Answer	Marks	Comments
7(b)	Equation of motion for A		
	$T-5\mu g\cos(25°)-5g\sin(25°)=5a$	**B1**	**oe** $T-44.409...\mu=22.583...$
	Equation of motion for B		
	$11g\sin(25°)-11\mu g\cos(25°)-T=11a$	**B1**	**oe** $T+97.699...\mu=41.433...$
	$6g\sin(25°)-16\mu g\cos(25°)=16a$	**M1**	Eliminates T using both of their equations of motion **PI** by **AWRT** 28.5
	$\mu=\dfrac{6g\sin(25°)-16a}{16g\cos(25°)}$	**m1**	Attempts to rearrange for μ
	$\mu=\dfrac{6\times9.8\sin(25°)-16\times0.375}{16\times9.8\cos(25°)}$		
	$\mu=0.133$	**A1**	**AG** Must be convincingly shown with a correct exact form for μ or $\mu=0.1326...$ seen before final answer
		5	

Q	Answer	Marks	Comments
7(c)	Speed of A at 4 seconds		
	$u\left[=\frac{2\times3}{4}\right]=1.5\left[\text{m s}^{-1}\right]$	**B1**	
	Acceleration of A after 4 seconds		
	$a=-\mu g\cos(25°)-g\sin(25°)$	**M1**	Uses friction and weight to find acceleration or forms a 3-term energy equation
	$a=-5.32\left[\text{m s}^{-2}\right]$	**A1**	**PI** or forms a fully correct 3-term energy equation, such as $\frac{1}{2}\times5\times1.5^2$ $=5\times9.8\times s\sin\left(25^\circ\right)$ $+0.133\times5\times9.8\cos\left(25^\circ\right)\times s$
	$v^2=u^2+2as\ \Rightarrow\ s=\frac{v^2-u^2}{2a}$		$5.625=49s\sin\left(25^\circ\right)$ $+6.517\cos\left(25^\circ\right)s$
	$s=\frac{0^2-1.5^2}{2\times-5.32...}$	**m1**	$s=\frac{5.625}{49\sin\left(25^\circ\right)+6.517\cos\left(25^\circ\right)}$
	$s=0.211...\left[\text{m}\right]$	**A1**	
	Will collide with peg after travelling $3+0.211\ldots$ metres		
	Therefore, minimum value of x is 3.22 to 3 sf	**A1ft**	**AWFW** [3.21, 3.22] $3+$ their $0.211...$
		6	

	Question 7 Total	**14**	

Q	Answer	Marks	Comments
8	$\frac{mv^2}{r} = \frac{k}{r^n}$	**M1**	Forms equation of motion
	$k = 6\times 0.5^2 \times 2^{n-1}$	**A1**	**oe** $k = 1.5\times 2^{n-1} = 0.75\times 2^n$
	$k = 6\times 0.02^2 \times 10^{n-1}$	**A1**	**oe** $k = 0.0024\times 10^{n-1} = 0.00024\times 10^n$
	$6\times 0.5^2 \times 2^{n-1} = 6\times 0.02^2 \times 10^{n-1}$	**M1**	Eliminates k **PI**
	$\frac{3}{2} = \frac{3}{1250}\times 5^{n-1}$		
	$5^{n-1} = 625$	**m1**	**oe** **PI**
	$n = 5$	**A1**	**CAO**
	$k = 6\times 0.5^2 \times 2^{5-1}$		
	$k = 24$	**A1**	**CAO**

	Question 8 Total	**7**	

Q	Answer	Marks	Comments
9(a)	Forces in equilibrium in the vertical direction $R\cos(15°) = 20 \times 9.8$ $R = \dfrac{20 \times 9.8}{\cos(15°)}$ $R = 202.9...$ $R = 203$	**M1** **A1**	Forms equation for vertical equilibrium with at least one side correct **AG** Must be convincingly shown with a correct exact form for R or $R = 202.9...$ seen before final answer
		2	

Q	Answer	Marks	Comments
9(b)(i)	Forces in equilibrium in the horizontal direction $[\text{Reaction force from wall} =] 203 \times \sin(15°)$ $[\text{Reaction force from wall} =] 52.5\ [\text{N}]$	**M1** **A1**	 **AWRT** 52.5
		2	

Q	Answer	Marks	Comments
9(b)(ii)	$52.5\ [\text{N}]$ Newton's third law	**B1ft** **E1**	**ft** their reaction force from **(b)(i)** A correct explanation
		2	

Q	Answer	Marks	Comments
9(c)	Clockwise moments about A $2.5\times 20\times 9.8\times \sin\theta \ [=490\sin\theta]$	**B1**	
	Anticlockwise moments about A $5\times 52.5\times \cos\theta \ [=262.5\cos\theta]$	**B1ft**	**ft** their reaction force from **(b)(i)**
	Principle of Moments $490\sin\theta = 262.5\cos\theta$	**M1**	Sets their clockwise moments equal to their anticlockwise moments
	$\tan\theta = 0.5357... \ \left[=\frac{15}{28}\right]$ $\theta = 28°$	**A1**	**AWRT** 28°
		4	

	Question 9 Total	**10**	