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Pearson Edexcel

Mark Scheme (Final)

January 2020

Pearson Edexcel International Advanced Level in Mechanics M2 (WME02/01)

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General Marking Guidance

- All candidates must receive the same treatment. Examiners must mark the first candidate in exactly the same way as they mark the last.
- Mark schemes should be applied positively. Candidates must be rewarded for what they have shown they can do rather than penalised for omissions.
- Examiners should mark according to the mark scheme not according to their perception of where the grade boundaries may lie.
- There is no ceiling on achievement. All marks on the mark scheme should be used appropriately.
- All the marks on the mark scheme are designed to be awarded. Examiners should always award full marks if deserved, i.e. if the answer matches the mark scheme. Examiners should also be prepared to award zero marks if the candidate's response is not worthy of credit according to the mark scheme.
- Where some judgement is required, mark schemes will provide the principles by which marks will be awarded and exemplification may be limited.
- When examiners are in doubt regarding the application of the mark scheme to a candidate's response, the team leader must be consulted.
- Crossed out work should be marked UNLESS the candidate has replaced it with an alternative response.

PEARSON EDEXCEL IAL MATHEMATICS

General Instructions for Marking

1. The total number of marks for the paper is 75.

2. The Edexcel Mathematics mark schemes use the following types of marks:

'M' marks
These are marks given for a correct method or an attempt at a correct method. In Mechanics they are usually awarded for the application of some mechanical principle to produce an equation.
e.g. resolving in a particular direction, taking moments about a point, applying a suvat equation, applying the conservation of momentum principle etc.
The following criteria are usually applied to the equation.

To earn the M mark, the equation
(i) should have the correct number of terms
(ii) be dimensionally correct i.e. all the terms need to be dimensionally correct
e.g. in a moments equation, every term must be a 'force x distance' term or 'mass x distance', if we allow them to cancel 'g' s.
For a resolution, all terms that need to be resolved (multiplied by sin or cos) must be resolved to earn the M mark.

M marks are sometimes dependent (DM) on previous M marks having been earned.
e.g. when two simultaneous equations have been set up by, for example, resolving in two directions and there is then an M mark for solving the equations to find a particular quantity – this M mark is often dependent on the two previous M marks having been earned.

'A' marks
These are dependent accuracy (or sometimes answer) marks and can only be awarded if the previous M mark has been earned. E.g. M0 A1 is impossible.

'B' marks
These are independent accuracy marks where there is no method (e.g. often given for a comment or for a graph)

A few of the A and B marks may be f.t. – follow through – marks.

3. General Abbreviations

These are some of the traditional marking abbreviations that will appear in the mark schemes.

- bod – benefit of doubt
- ft – follow through
- the symbol $\surd$ will be used for correct ft
- cao – correct answer only
- cso - correct solution only. There must be no errors in this part of the question to obtain this mark
- isw – ignore subsequent working
- awrt – answers which round to
- SC: special case
- oe – or equivalent (and appropriate)
- dep – dependent
- indep – independent
- dp decimal places
- sf significant figures
- $*$ The answer is printed on the paper
- ⌐ The second mark is dependent on gaining the first mark

4. All A marks are 'correct answer only' (cao.), unless shown, for example, as A1 ft to indicate that previous wrong working is to be followed through. After a misread however, the subsequent A marks affected are treated as A ft, but manifestly absurd answers should never be awarded A marks.

5. For misreading which does not alter the character of a question or materially simplify it, deduct two from any A or B marks gained, in that part of the question affected.

6. If a candidate makes more than one attempt at any question:
    - If all but one attempt is crossed out, mark the attempt which is NOT crossed out.
    - If either all attempts are crossed out or none are crossed out, mark all the attempts and score the highest single attempt.

7. Ignore wrong working or incorrect statements following a correct answer.

General Principles for Mechanics Marking

(But note that specific mark schemes may sometimes override these general principles)

- Rules for M marks: correct no. of terms; dimensionally correct; all terms that need resolving (i.e. multiplied by cos or sin) are resolved.
- Omission or extra g in a resolution is an accuracy error not method error.
- Omission of mass from a resolution is a method error.
- Omission of a length from a moments equation is a method error.
- Omission of units or incorrect units is not (usually) counted as an accuracy error.
- DM indicates a dependent method mark i.e. one that can only be awarded if a previous specified method mark has been awarded.
- Any numerical answer which comes from use of g = 9.8 should be given to 2 or 3 SF.
- Use of g = 9.81 should be penalised once per (complete) question.

  N.B. Over-accuracy or under-accuracy of correct answers should only be penalised *once* per complete question. However, premature approximation should be penalised every time it occurs.

  Marks must be entered in the same order as they appear on the mark scheme.
- In all cases, if the candidate clearly labels their working under a particular part of a question i.e. (a) or (b) or (c),……then that working can only score marks for that part of the question.
- Accept column vectors in all cases.
- Misreads – if a misread does not alter the character of a question or materially simplify it, deduct two from any A or B marks gained, bearing in mind that after a misread, the subsequent A marks affected are treated as A ft
- Mechanics Abbreviations

  M(A) Taking moments about A.

  N2L Newton's Second Law (Equation of Motion)

  NEL Newton's Experimental Law (Newton's Law of Impact)

  HL Hooke's Law

  SHM Simple harmonic motion

  PCLM Principle of conservation of linear momentum

  RHS, LHS Right hand side, left hand side.

Question Number	Scheme	Marks
1.	Use of $56 = FV$	B1
	Equation of motion	M1
	$F + 75g\sin\alpha - 40 = 75\times\frac{1}{3}$	A1
	$\left(\frac{56}{V} = 65 - 49 = 16\right)$	A1
	$V = \frac{56}{16} = 3.5$	A1
		[5]

Notes

B1	
M1	Require all terms. Dimensionally correct.(Omission of g is an accuracy error.) Condone sine / cosine confusion and sign errors
A1	Unsimplified equation with at most one error. In F or in V. Two signs inconsistent is 2 errors.
A1	Correct unsimplified equation. In F or in V.
A1	Max 3 s.f.. Not $\frac{7}{2}$ Not $3\frac{1}{2}$

Question Number	Scheme	Marks
2	Work energy equation KE lost = WD + PE gain	M1
	$\frac{1}{2}\times 2\times 16 = \text{WD} + 2g\times 2.5\sin\theta$	A1
	$(\text{WD} = 9)$	A1
	Use of $F = \mu\times 2g\cos\theta$	B1
	Use of Work done $= 2.5F$	B1
	$9 = 2.5\times\mu\times 2g\cos\theta \Rightarrow \mu = 0.19$	A1 (6) **[6]**

M1	Must be using work-energy. Require all terms. Dimensionally correct. Allow their WD, but must be WD, not F Condone sine/cosine confusion and sign errors
A1	Unsimplified equation with at most one error
A1	Correct unsimplified equation NB: $16 = WD + 7$ **seen** scores 3 marks
B1	$(F = \mu\times 19.398...)$ Allow $\pm$ This mark is available if they use a *suvat* approach
B1	Allow $\pm$
A1	Or 0.186. Max 3 sf. Not $\frac{3\sqrt{3}}{28}$

Question Number	Scheme	Marks
3	Use of $m\mathbf{v} = \mathbf{I} + m\mathbf{u}$	M1
	Component of momentum parallel to original direction $= 6\times 0.75 + \sqrt{24}\cos 60 \ \left(= 4.5 + \sqrt{6}\right)$	A1 A1
	Use of Pythagoras: $\left(\frac{3}{4}v =\right)\sqrt{\left(4.5+\sqrt{6}\right)^2 + 18}$	M1
	$v = 10.9 \ \left(\text{m s}^{-1}\right), 11\left(\text{m s}^{-1}\right)$	A1
	Alternative for the 1st 5 marks:	
	Vector triangle for impulses or velocities	M1
	Use of cosine rule	M1
	$\left(\frac{3}{4}v\right)^2 = 4.5^2 + 24 - 2\times 4.5\times\sqrt{24}\times\cos 120°$	A1 A1
	$v = 10.9 \ \left(\text{m s}^{-1}\right), 11\left(\text{m s}^{-1}\right)$	A1
	Change in direction $= \tan^{-1}\dfrac{3\sqrt{2}}{4.5+\sqrt{6}}$	M1
	$= 31.4° \ (31°)$	A1 (7)
	Notes	**[7]**
M1	Need to consider both components.	
A1	Or equivalent	
M1	Or equivalent.	
A1	Correct LHS	
A1	Or better	
M1	Must be using correct triangle - need $120°$ seen or implied	
A1	Correct unsimplified	
A1	Or better	
M1	Or equivalent use of trig. With their components to find **the required angle** Eg angle $= \cos^{-1}\left(\dfrac{4.5^2 + (mv)^2 - 24}{2\times 4.5\times(mv)}\right)$ Or from scalar product, $\cos^{-1}\left(\dfrac{6\times 9.27...}{6\times 10.9...}\right)$	
A1	0.548 radians (0.55 radians) or better. Do not ISW	

1

Question Number	Scheme	Marks
4(a)	Moments about AC	M1
	$18\times\frac{3a}{2}-2\pi\times\frac{8a}{3\pi}+2\pi\left(3a+\frac{8a}{3\pi}\right)=18\overline{y}$	A1
	NB: valid to use $18\times\frac{3a}{2}-2\pi\times d+2\pi\left(3a+d\right)=18\overline{y}$ for $d\neq 0$ without stating value for d Use of $d=0\Rightarrow$ M0	
	$\left(27a+6\pi a=18\overline{y}\right)$	A1
	The same incorrect distance used twice in place of $\frac{8a}{3\pi}$ is one error The same incorrect area for the semicircle used twice is one error.	A1 (4)
	$27a+6\pi a=18\overline{y}\ \Rightarrow\overline{y}=\frac{9+2\pi}{6}a$ *	
4b	$M\overline{x}+kM\times 6a=\left(1+k\right)M\overline{x}_T$	M1
	$3a+6ak=\left(1+k\right)\overline{x}_T$ o.e.	A1
	$M\overline{y}=\left(1+k\right)M\overline{y}_T$	M1
	$\left(1+k\right)\overline{y}_T=\frac{9+2\pi}{6}a$	A1
NB	For their second equation they could use $\tan\phi$ and their $\overline{x}_T$ or $\overline{y}_T$ to form an expression for $\overline{y}_T$ or $\overline{x}_T$	
	$\tan\phi=\frac{3}{2}=\frac{\overline{x}_T}{\overline{y}_T}\ \Rightarrow\ \frac{3}{2}=\frac{6\left(3a+6ak\right)}{\left(9+2\pi\right)a}$	DM1
	$\Rightarrow k=\frac{\pi}{12}-\frac{1}{8}$ or equivalent	A1 (6)
	Notes	
M1	All terms. Dimensionally correct. Condone sign errors	
A1	Unsimplified equation with at most one error.	
A1	Correct unsimplified equation	
A1	Obtain **given answer** from sufficient correct exact working. Must see a separate conclusion for $\overline{y}$.	
NB	e.g. $\overline{y}_T=\frac{2\left(3+6k\right)a}{3\left(1+k\right)}$	
DM1	Form equation in k and solve for k.Dependent on the previous 2 M marks.	
A1	$k=0.137\ \ \left(0.14\right)$ or better See over for alternative solution to 4(b)	

Question Number	Scheme	Marks
4(b) alt	Distance of original c of m from vertical through A	M1
	$\left(\frac{9+2\pi}{6}a-2a\right)\times\sin\phi\left(=\frac{\sqrt{13}(2\pi-3)a}{26}\right)$	A1
	Distance of additional particle from vertical through A	M1
	$6a\times\cos\phi\left(=\frac{12a}{\sqrt{13}}\right)$	A1
	$mg\times\frac{\sqrt{13}(2\pi-3)a}{26}=kmg\times\frac{12a}{\sqrt{13}}$	DM1
	$k=0.137\quad(0.14)$	A1 **(6)**
	Notes	**[10]**
M1		
A1	Or equivalent	
M1	Distance of additional particle from vertical through A	
M1		
A1	Or equivalent	
DM1	Moments about A Dependent on the 2 previous M marks	
A1	(0.14 or better)	

Question Number	Scheme	Marks
5a	Use of $\mathbf{a}=\dfrac{\mathrm{d}\mathbf{v}}{\mathrm{d}t}$: $\mathbf{a}=6t\mathbf{i}+2\mathbf{j}$	M1
	$t=0 \Rightarrow \mathbf{a}=2\mathbf{j}\ \left(\mathrm{m\,s^{-2}}\right)$	A1 (2)
5b	$11(2t-4)=\left(3t^2-4\right)$	M1
	$3t^2-22t+40=0 \Rightarrow \left(t=\dfrac{10}{3}\right)\ t=4$	M1
	$\mathbf{v}=44\mathbf{i}+4\mathbf{j}$, speed $=\sqrt{44^2+4^2}$	DM1
	$=4\sqrt{122}\ \left(\mathrm{m\ s^{-1}}\right)$	A1 (4)
5c	Use of $\mathbf{r}=\int \mathbf{v}\mathrm{d}t$	M1
	$\mathbf{r}=\left(t^3-4t\right)\mathbf{i}+\left(t^2-4t\right)\mathbf{j}$	A1
	Set $\mathbf{r}=0$ and solve for t	M1
	$t^3-4t=0 \Rightarrow t=0,2,(-2)$	
	$t^2-4t=0 \Rightarrow t=0,4$	
	the only common value is $t=0$, so does not return to O.*	A1* (4)
	Notes	**[10]**

5a M1 Powers going down

A1 Must see vector answer but ISW if go on to state the magnitude.

5b M1 Use of velocity parallel to $11\mathbf{i}+\mathbf{j}$ 11 must be on the correct side.

DM1 Select the larger root (dependent on the previous 2 M1 marks and on 2 positive roots) and use Pythagoras. Condone if they find both speeds

A1 Any equivalent simplified surd form $\left(\sqrt{1952}\right)$ ISW

44.18... implies M1 if correct surd form not seen.
Both values for speed given is A0

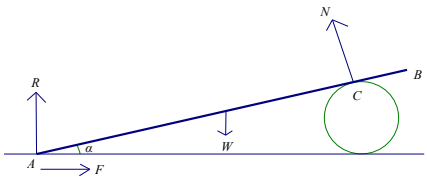
M1 Powers going up

A1 If a constant of integration is introduced, they must conclude it is equal to the zero vector

M1 Consider both components

Or equivalent clear explanation of **given result**.

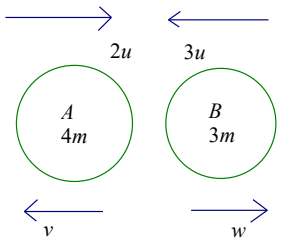
A1* Condone if they ignore $t=0$. Do not need to see the roots. But do need to see the factorised form for each component if using this method.

Question Number	Scheme	Marks
6a	 Resolve vertically $\updownarrow R + N\cos\alpha = W$ Take moments about A $7aN = 4a\cos\alpha \times W$ Obtain equation in R, W and α $N = W \times \frac{4}{7}\cos\alpha \Rightarrow$ $R = W - \frac{4}{7}W\cos^2\alpha$ $= W\left(1 - \frac{4}{7}\cos^2\alpha\right)$ * Alternative equations $R\sin\alpha + F\cos\alpha = W\sin\alpha$ $N + R\cos\alpha = W\cos\alpha + F\sin\alpha$ $W.3a\cos\alpha + F.7a\sin\alpha = R.7a\cos\alpha$ First 4 marks for alternative methods	M1 A1 M1 A1 DM1 A1* (6) M1 A1 M1 A1 DM1 A1* (6)
6a M1		
A1	Correct unsimplified equation	
M1		
A1	Correct unsimplified equation	
DM1	Solve for R in terms of W. Dependent on the 2 preceding M marks	
A1*	Obtain **given answer** from correct working	
Alt:	Parallel to the rod Perpendicular to the rod Moments about C	
M1	Equation in R. All terms needed. Condone sin/cos confusion and sign errors	
A1	Correct unsimplified equation	
M1	Sufficient additional equations to solve for R in terms of W. Dimensionally correct. All terms needed. Condone sin/cos confusion and sign errors	
A1	Correct unsimplified equation	

Question Number	Scheme	Marks
6b	$R = W\left(1 - \frac{4}{7} \times \frac{9}{10}\right) = \frac{17W}{35}$	B1
	Resolve horizontally	M1
	$F = N\sin\alpha = \frac{4}{7} \times \frac{3}{\sqrt{10}} \times \frac{1}{\sqrt{10}} W$	A1
	$\left(= \frac{6}{35} W\right)$	
	Use of $F \leq \mu R$	M1
	$\Rightarrow \mu \geq \frac{6}{17}$	A1 (5)
	Notes	**[11]**
6b B1	Seen or implied	
M1	Obtain equation in	
A1	Correct unsimplified equation in F and W (trig. substituted) $(0.171W)$	
M1	Correct method to find the critical value. Condone with any symbol.	
A1	0.35 or better (0.3529.....) from correct working Final answer. Do not ISW	

Question Number	Scheme	Marks
7a	NB: sine/cosine confusion is not condoned in projectile questions Use of conservation of energy $\frac{1}{2}m\times 25^2=\frac{1}{2}m\times 15^2+mgh$ $\Rightarrow h=20$ or 20.4 (m)	M1 A1 A1 (3)
7b	Vertical distance $20.4=25\sin\alpha\times 3-4.5\times 9.8$ $\alpha=59°$ or $59.3°$	M1 A1ft A1 (3)
7c	Horizontal component of speed is constant $\Rightarrow 25\cos\alpha=15\cos\beta$ $\beta=32°$ or $31.8°$	M1 A1ft A1 (3)
7c alt	Vertical distance $20.4=-15\sin\beta\times 3+4.5\times 9.8$ $\beta=32°$ or $31.8°$	M1 A1ft A1 (3)
	Notes	
7a M1	Need energy equation with all 3 terms. Must be dimensionally correct. Condone sign errors.	
A1	Correct unsimplified equation	
A1	Max 3 sf Not $\frac{1000}{49}$ nor $\frac{200}{g}$	
7b M1	Use of *suvat* to find α	
A1ft	Correct unsimplified equation in their h	
A1	0.554 rads. Max 3 sf From CWO	
7c M1	Or horizontal distance travelled	
A1ft	Correct unsimplified in α or their α	
A1	0.554 rads. Max 3 sf From CWO	
7c alt		
M1	Use of *suvat* to find β	
A1ft	e.g. using $s=vt-\frac{1}{2}gt^2$. Correct unsimplified equation in their h	
A1	0.554 rads. Max 3 sf From CWO	

Question Number	Scheme	Marks
7d	Min speed = horizontal component $= 25\cos\alpha \left(= 15\cos\beta\right)$ $= 13$ or 12.8 (m s^{-1})	M1 A1 (2)
7e	By considering vertical component of speed at B: $15\sin 31.8° - gT = -15\sin 31.8°$ $T = 1.6$ or 1.61 (s)	M1 A1ft A1 (3)
	Notes	**[14]**
7d M1 **A1**	Follow their angle. Must show working if using incorrect angle. Max 3 sf From CWO	
7e M1 **A1ft** **A1**	Complete method using *suvat* to find T Correct unsimplified equation in T - follow their angles. Max 3 sf From CWO	

Question Number	Scheme	Marks
8		
	Change in KE $\frac{4m}{2}\left(4u^2-v^2\right)+\frac{3m}{2}\left(9u^2-w^2\right)=\frac{473}{24}mu^2$ $\left(48v^2+36w^2=43u^2\right)$	M1 A1
	Equation for CLM Need all terms. Dimensionally correct. Condone sign errors. $8mu-9mu=-4mv+3mw$ $\left(u=4v-3w\right)$	M1 A1
	Impact law $w+v=5eu$	M1 A1
	$48v^2+36\left(\frac{4v-u}{3}\right)^2=43u^2$ Or $48\left(\frac{u+3w}{4}\right)^2+36w^2=43u^2$ Or $\frac{48}{49}(1+15e)^2+\frac{36}{49}(20e-1)^2=43$	DM1
	$112v^2-32uv-39u^2=0$ $=(4v-3u)(28v+13u)$ Or $63w^2+18uw-40u^2=0$ $=(21w+20u)(3w-2u)$ Or $25200e^2=2023$	DM1

Notes

	The first 8 marks are available if they have ignored the information about the final directions Work with their directions. Ignore the diagram if that is to the candidate's advantage.
M1	Need all terms. Dimensionally correct. Accept ±
A1	Correct unsimplified equation in *v*, *w* or their *v*, *w*
M1	Need all terms. Dimensionally correct. Condone sign errors.
A1	Correct unsimplified equation with their correct signs
M1	Must be used the right way round
A1	Or equivalent in their *w*, *v*. Signs for *v*, *w* consistent with CLM eqn
DM1	Form equation for *v* or *w* or *e* Dependent on M marks scored for the equations used.
DM1	Solve for *v* or *w* or *e* . Dependent on the preceding M

Question Number	Scheme	Marks
8	$v = \frac{3u}{4}$ $w = \frac{2u}{3}$ $\frac{3u}{4} + \frac{2u}{3} = 5eu$, $e = \frac{17}{60}$ Use of $I = m(v-u)$ $4m\left(2u + \frac{3u}{4}\right) = 11mu$	A1 A1 DM1 A1 (12)
	Notes	**[12]**
A1	v or w correct	
A1	$\frac{3u}{4} + \frac{2u}{3} = 5eu$	
DM1	Must be attempting to subtract corresponding values for u and v Dependent on the first 4 M marks	
A1	Or $3m\left(3u + \frac{2u}{3}\right)$ from correct solution only	

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