GCE

Further Mathematics B MEI

Y421/01: Mechanics major

A Level

Mark Scheme for June 2025

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This mark scheme is published as an aid to teachers and students, to indicate the requirements of the examination. It shows the basis on which marks were awarded by examiners. It does not indicate the details of the discussions which took place at an examiners' meeting before marking commenced.

All examiners are instructed that alternative correct answers and unexpected approaches in candidates' scripts must be given marks that fairly reflect the relevant knowledge and skills demonstrated.

Mark schemes should be read in conjunction with the published question papers and the report on the examination.

MARKING INSTRUCTIONS

PREPARATION FOR MARKING
RM ASSESSOR

1. Make sure that you have accessed and completed the relevant training packages for on-screen marking: *RM Assessor Online Training: OCR Essential Guide to Marking*.

2. Make sure that you have read and understood the mark scheme and the question paper for this unit. These are available in RM Assessor

3. Log-in to RM Assessor and mark the **required number** of practice responses ("scripts") and the **required number** of standardisation responses.

MARKING

1. Mark strictly to the mark scheme.

2. Marks awarded must relate directly to the marking criteria.

3. The schedule of dates is very important. It is essential that you meet the RM Assessor 50% and 100% (traditional 40% Batch 1 and 100% Batch 2) deadlines. If you experience problems, you must contact your Team Leader (Supervisor) without delay.

4. If you are in any doubt about applying the mark scheme, consult your Team Leader by telephone, email or via the RM Assessor messaging system.

5. **Crossed-Out Responses**
   Where a candidate has crossed out a response and provided a clear alternative then the crossed-out response is not marked. Where no alternative response has been provided, examiners may give candidates the benefit of the doubt and mark the crossed-out response where legible.

Rubric Error Responses – Optional Questions
Where candidates have a choice of question across a whole paper or a whole section and have provided more answers than required, then all responses are marked and the highest mark allowable within the rubric is given. Enter a mark for each question answered into RM Assessor, which will select the highest mark from those awarded. *(The underlying assumption is that the candidate has penalised themselves by attempting more questions than necessary in the time allowed.)*

Multiple-Choice Question Responses
When a multiple-choice question has only a single, correct response and a candidate provides two responses (even if one of these responses is correct), then no mark should be awarded (as it is not possible to determine which was the first response selected by the candidate).
When a question requires candidates to select more than one option/multiple options, then local marking arrangements need to ensure consistency of approach.

Contradictory Responses
When a candidate provides contradictory responses, then no mark should be awarded, even if one of the answers is correct.

Short Answer Questions (requiring only a list by way of a response, usually worth only one mark per response)
Where candidates are required to provide a set number of short answer responses then only the set number of responses should be marked. The response space should be marked from left to right on each line and then line by line until the required number of responses have been considered. The remaining responses should not then be marked. Examiners will have to apply judgement as to whether a 'second response' on a line is a development of the 'first response', rather than a separate, discrete response. *(The underlying assumption is that the candidate is attempting to hedge their bets and therefore getting undue benefit rather than engaging with the question and giving the most relevant/correct responses.)*

Short Answer Questions (requiring a more developed response, worth two or more marks)
If the candidates are required to provide a description of, say, three items or factors and four items or factors are provided, then mark on a similar basis – that is downwards (as it is unlikely in this situation that a candidate will provide more than one response in each section of the response space).

Longer Answer Questions (requiring a developed response)
Where candidates have provided two (or more) responses to a medium or high tariff question which only required a single (developed) response and not crossed out the first response, then only the first response should be marked. Examiners will need to apply professional judgement as to whether the second (or a subsequent) response is a 'new start' or simply a poorly expressed continuation of the first response.

6. Always check the pages (and additional objects if present) at the end of the response in case any answers have been continued there. If the candidate has continued an answer there, then add the annotation 'SEEN' to confirm that the work has been seen and mark any responses using the annotations in section 11.

7. There is a NR (**No Response**) option. Award NR (No Response):

   - if there is nothing written at all in the answer space
   - OR if there is a comment which does not in any way relate to the question (e.g., 'can't do', 'don't know')
   - OR if there is a mark (e.g., a dash, a question mark) which is not an attempt at the question.

   Note: Award 0 marks – for an attempt that earns no credit (including copying out the question).

8. The RM Assessor **comments box** is used by your Team Leader to explain the marking of the practice responses. Please refer to these comments when checking your practice responses. **Do not use the comments box for any other reason.**

9. Assistant Examiners will send a brief report on the performance of candidates to their Team Leader (Supervisor) via email by the end of the marking period. The report should contain notes on particular strengths displayed as well as common errors or weaknesses. Constructive criticism of the question paper/mark scheme is also appreciated.

10. For answers marked by levels of response: Not applicable in F501
    To determine the level – start at the highest level and work down until you reach the level that matches the answer
    To determine the mark within the level, consider the following

Descriptor	Award mark
On the borderline of this level and the one below	At bottom of level
Just enough achievement on balance for this level	Above bottom and either below middle or at middle of level (depending on number of marks available)
Meets the criteria but with some slight inconsistency	Above middle and either below top of level or at middle of level (depending on number of marks available)
Consistently meets the criteria for this level	At top of level

11. **Annotations**

Annotation	Meaning
✓and ✗	
BOD	Benefit of doubt
FT	Follow through
ISW	Ignore subsequent working
M0, M1	Method mark awarded 0, 1
A0, A1	Accuracy mark awarded 0, 1
B0, B1	Independent mark awarded 0, 1
SC	Special case
^	Omission sign
MR	Misread
BP	Blank Page
Seen	
Highlighting	

Other abbreviations in mark scheme	Meaning
dep*	Mark dependent on a previous mark, indicated by *. The * may be omitted if only one previous M mark
cao	Correct answer only
oe	Or equivalent
rot	Rounded or truncated
soi	Seen or implied
www	Without wrong working
AG	Answer given
awrt	Anything which rounds to
BC	By Calculator
DR	This question included the instruction: In this question you must show detailed reasoning.

Subject Specific Marking Instructions

a. Annotations must be used during your marking. For a response awarded zero (or full) marks a single appropriate annotation (cross, tick, M0 or ^) is sufficient, but not required.

For responses that are not awarded either 0 or full marks, you must make it clear how you have arrived at the mark you have awarded and all responses must have enough annotation for a reviewer to decide if the mark awarded is correct without having to mark it independently.

It is vital that you annotate standardisation scripts fully to show how the marks have been awarded.

Award NR (No Response)
- if there is nothing written at all in the answer space and no attempt elsewhere in the script
- OR if there is a comment which does not in any way relate to the question (e.g. 'can't do', 'don't know')
- OR if there is a mark (e.g. a dash, a question mark, a picture) which isn't an attempt at the question.

Note: Award 0 marks only for an attempt that earns no credit (including copying out the question).

If a candidate uses the answer space for one question to answer another, for example using the space for 8(b) to answer 8(a), then give benefit of doubt unless it is ambiguous for which part it is intended.

b. An element of professional judgement is required in the marking of any written paper. Remember that the mark scheme is designed to assist in marking incorrect solutions. Correct solutions leading to correct answers are awarded full marks but work must not always be judged on the answer alone, and answers that are given in the question, especially, must be validly obtained; key steps in the working must always be looked at and anything unfamiliar must be investigated thoroughly. Correct but unfamiliar or unexpected methods are often signalled by a correct result following an apparently incorrect method. Such work must be carefully assessed. When a candidate adopts a method which does not correspond to the mark scheme, escalate the question to your Team Leader who will decide on a course of action with the Principal Examiner.

If you are in any doubt whatsoever you should contact your Team Leader.

c. The following types of marks are available.

M

A suitable method has been selected and applied in a manner which shows that the method is essentially understood. Method marks are not usually lost for numerical errors, algebraic slips or errors in units. However, it is not usually sufficient for a candidate just to indicate an intention of using

some method or just to quote a formula; the formula or idea must be applied to the specific problem in hand, e.g. by substituting the relevant quantities into the formula. In some cases the nature of the errors allowed for the award of an M mark may be specified.
A method mark may usually be implied by a correct answer unless the question includes the DR statement, the command words “Determine” or “Show that”, or some other indication that the method must be given explicitly.

A
Accuracy mark, awarded for a correct answer or intermediate step correctly obtained. Accuracy marks cannot be given unless the associated Method mark is earned (or implied). Therefore M0 A1 cannot ever be awarded.

B
Mark for a correct result or statement independent of Method marks.

Unless otherwise indicated, marks once gained cannot subsequently be lost, e.g. wrong working following a correct form of answer is ignored. Sometimes this is reinforced in the mark scheme by the abbreviation isw. However, this would not apply to a case where a candidate passes through the correct answer as part of a wrong argument.

d. When a part of a question has two or more ‘method’ steps, the M marks are in principle independent unless the scheme specifically says otherwise; and similarly where there are several B marks allocated. (The notation ‘dep*’ is used to indicate that a particular mark is dependent on an earlier, asterisked, mark in the scheme.) Of course, in practice it may happen that when a candidate has once gone wrong in a part of a question, the work from there on is worthless so that no more marks can sensibly be given. On the other hand, when two or more steps are successfully run together by the candidate, the earlier marks are implied and full credit must be given.

e. The abbreviation FT implies that the A or B mark indicated is allowed for work correctly following on from previously incorrect results. Otherwise, A and B marks are given for correct work only – differences in notation are of course permitted. A (accuracy) marks are not given for answers obtained from incorrect working. When A or B marks are awarded for work at an intermediate stage of a solution, there may be various alternatives that are equally acceptable. In such cases, what is acceptable will be detailed in the mark scheme. If this is not the case please, escalate the question to your Team Leader who will decide on a course of action with the Principal Examiner.

Sometimes the answer to one part of a question is used in a later part of the same question. In this case, A marks will often be ‘follow through’. In such cases you must ensure that you refer back to the answer of the previous part question even if this is not shown within the image zone. You may find it easier to mark follow through questions candidate-by-candidate rather than question-by-question.

f. Unless units are specifically requested, there is no penalty for wrong or missing units as long as the answer is numerically correct and expressed either in SI or in the units of the question. (e.g. lengths will be assumed to be in metres unless in a particular question all the lengths are in km, when this would be assumed to be the unspecified unit.)
We are usually quite flexible about the accuracy to which the final answer is expressed; over-specification is usually only penalised where the scheme explicitly says so.
- When a value is given in the paper only accept an answer correct to at least as many significant figures as the given value.
- When a value is not given in the paper accept any answer that agrees with the correct value to 2 s.f. unless a different level of accuracy has been asked for in the question, or the mark scheme specifies an acceptable range.
  NB for Specification A the rubric specifies 3 s.f. as standard, so this statement reads “3 s.f”.

Follow through should be used so that only one mark in any question is lost for each distinct accuracy error.
Candidates using a value of 9.80, 9.81 or 10 for g should usually be penalised for any final accuracy marks which do not agree to the value found with 9.8 which is given in the rubric.

g. Rules for replaced work and multiple attempts:
- If one attempt is clearly indicated as the one to mark, or only one is left uncrossed out, then mark that attempt and ignore the others.
- If more than one attempt is left not crossed out, then mark the last attempt unless it only repeats part of the first attempt or is substantially less complete.
- if a candidate crosses out all of their attempts, the assessor should attempt to mark the crossed out answer(s) as above and award marks appropriately.

h. For a genuine misreading (of numbers or symbols) which is such that the object and the difficulty of the question remain unaltered, mark according to the scheme but following through from the candidate’s data. A penalty is then applied; 1 mark is generally appropriate, though this may differ for some units. This is achieved by withholding one A or B mark in the question. Marks designated as cao may be awarded as long as there are no other errors.
If a candidate corrects the misread in a later part, do not continue to follow through. E marks are lost unless, by chance, the given results are established by equivalent working. Note that a miscopy of the candidate’s own working is not a misread but an accuracy error.

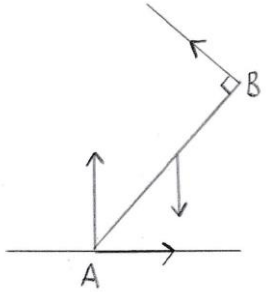
i. If a calculator is used, some answers may be obtained with little or no working visible. Allow full marks for correct answers, provided that there is nothing in the wording of the question specifying that analytical methods are required such as the bold “In this question you must show detailed reasoning”, or the command words “Show” or “Determine”. Where an answer is wrong but there is some evidence of method, allow appropriate method marks. Wrong answers with no supporting method score zero. If in doubt, consult your Team Leader.

j. If in any case the scheme operates with considerable unfairness consult your Team Leader.

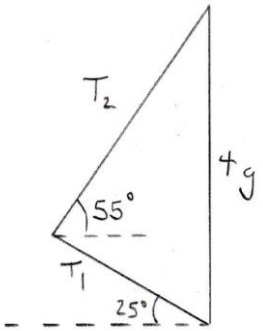
Question	Answer	Marks	AO	Guidance
1	Work done by 35 N force $= 35\cos\theta \times 4$	B1	1.1	Correct expression for the work done by the 35 N force
	$\frac{1}{2} \times 3 \times 1.5^2 = 35\cos\theta \times 4 - 25 \times 4$	M1	3.3	Use of Work-Energy principle – equation with the correct number of dimensionally correct relevant terms. Allow sign errors and sin/cos mix on 'work done by 35 N force' term
	$\theta = 42.4^\circ$	A1	1.1	awrt 42 www (42.4053…) or 0.74 (0.74011…) radians **SC B1** for correct answer with no working **or** from using N2L and suvat
		[3]		

Question	Answer	Marks	AO	Guidance
2(a)	$km\times1+2m\times4-7m\times2=0$	**M1**	**3.1a**	Taking moments about the y-axis (oe) to form an equation in k (and possibly m) = 0 – allow sign errors only – correct answer implies this mark. Condone lack of m
	$k=6$	**A1** **[2]**	**1.1**	Cao
2(b)	$(7m+2m+km)\times d=7m\times3+2m\times2-km\times2$	**M1**	**3.1a**	Taking moments about the x-axis (oe) – allow sign errors only. Allow their value of k from part **(a)** or k – a correct answer implies this mark. Condone lack of m
	$d=\frac{13}{15}$	**A1** **[2]**	**1.1**	awrt 0.87 www

Question	Answer	Marks	AO	Guidance
3(a)	$\mathbf{a} = \begin{pmatrix} 8\cos 2t \\ -2\sin t \\ 0 \end{pmatrix}$ ms^{-2}	B1 [1]	1.1	oe – condone $\left(8\cos 2t\mathbf{i} - 2\sin t\mathbf{j}\right)$
3(b)	$\mathbf{v} = \begin{pmatrix} 4\sin 2t \\ 2\cos t \\ 0 \end{pmatrix} (+\mathbf{c})$	M1*	1.1	Attempt to integrate – answer either of the form $\mathbf{v} = \alpha \sin 2t\mathbf{i} + \beta \cos t\mathbf{j}$ **or** correct **i** and **j** components +**c** not required – allow use of **i**,**j**,**k** throughout
	$t = 0, \mathbf{v} = \begin{pmatrix} 0 \\ 5 \\ 6 \end{pmatrix} \Rightarrow \mathbf{v} = \begin{pmatrix} 4\sin 2t \\ 2\cos t + 3 \\ 6 \end{pmatrix}$	A1	1.1	or for $\mathbf{v} = \begin{pmatrix} 4\sin 2t \\ 2\cos t \\ 0 \end{pmatrix} + \mathbf{c}$ where $\mathbf{c} = \begin{pmatrix} 0 \\ 3 \\ 6 \end{pmatrix}$
	$t = \frac{1}{3}\pi \Rightarrow \mathbf{v} = \begin{pmatrix} 2\sqrt{3} \\ 4 \\ 6 \end{pmatrix}$	M1dep*	3.4	Substitute $t = \frac{1}{3}\pi$ into their integrated expression for **v** (allow this mark even if no + **c**)
	$\Rightarrow \lvert\mathbf{v}\rvert = \sqrt{\left(2\sqrt{3}\right)^2 + 4^2 + 6^2}$	M1	1.1	Correct method for finding the required speed (allow this mark even if no + **c**) – dependent on both **M** marks
	$\lvert\mathbf{v}\rvert = 8$ ms^{-1}	A1 [5]	1.1	cao of 8 www

Question	Answer	Marks	AO	Guidance
4(a)		B1 [1]	1.1	Correct force diagram with all four forces shown: weight of the rod (vertically downwards), normal contact (vertically upwards), frictional contact at A (to the right), and tension in the string with appropriate arrows on all four forces
4(b)	$2\times 3g\cos 50 = 4T$	M1	1.1	Moments about A – correct number of terms, allow sin/cos mix but must be a component of the weight, allow g missing
	$T = 9.45\text{ N}$	A1 [2]	1.1	9.44897… allow awrt 9.4 www
4(c)	$R(\uparrow): R_A + T\cos 50 = 3g$	M1*	3.3	Resolving vertically for the rod – correct number of dimensionally correct terms, allow sign errors, allow sin/cos mix. Allow with their value of T or T – if correct then $R_A = 23.32631...$
	$R(\rightarrow): F_A = T\sin 50$	M1*	3.3	Resolving horizontally for the rod – correct number of dimensionally correct terms, allow sin/cos mix. Allow with their value of T or T – if correct then $F_A = 7.23833...$
	$\left(\sqrt{R_A{}^2 + F_A{}^2} =\right)\sqrt{(3g - 9.45\cos 50)^2 + (9.45\sin 50)^2}$	M1dep*	3.4	Correct method for the total contact force
	Total contact force = 24.4 N	A1 [4]	1.1	24.423… allow awrt 24 www

Question	Answer	Marks	AO	Guidance
5(a)	$[P] = \mathrm{ML^2T^{-3}}$	B1 [1]	2.5	Condone $[\mathrm{ML^2T^{-3}}]$ only but not ml^2t^{-3}, not W for weight, not $\frac{\mathrm{ML^2}}{\mathrm{T^3}}$, etc.
5(b)	For the equation to be dimensionally consistent $[1] = \frac{[v]^\delta}{[U]^3}$ and so $[v]^\delta = [U]^3$ and as v and U are both speeds therefore $\delta = 3$	B1 [1]	2.4	Correct reasoning (why $\delta = 3$) e.g. dimensions of v^δ and U^3 must be the same, condone 'v and U must be equal'
5(c)	$\left[\frac{\mathrm{d}v}{\mathrm{d}x}\right] = \frac{\mathrm{LT^{-1}}}{\mathrm{L}} = \mathrm{T^{-1}}$	B1 [1]	2.2a	**AG** oe e.g. $\left[\frac{\mathrm{d}v}{\mathrm{d}x}\right] = \left[\frac{\mathrm{d}v}{\mathrm{d}t}\right] \times \left[\frac{\mathrm{d}t}{\mathrm{d}x}\right] = \frac{\mathrm{LT^{-2}}}{\mathrm{LT^{-1}}} = \mathrm{T^{-1}}$ **must** be at least one step before given answer - **must** be using correct dimensional analysis notation
5(d)	$\mathrm{M}^\alpha \left(\mathrm{LT^{-1}}\right)^\beta \mathrm{T^{-1}} = \left(\mathrm{ML^2T^{-3}}\right)^\gamma$ M: $\alpha = \gamma$ L: $\beta = 2\gamma$ T: $-\beta - 1 = -3\gamma$ $\alpha = 1, \beta = 2, \gamma = 1$	M1* M1dep* A1 [3]	2.1 1.1 1.1	Setting up an equation in M, L and T using their $[P]$ from part **(a)** together with correct $[v]$ and $\left[\frac{\mathrm{d}v}{\mathrm{d}x}\right]$ - can be implied by 3 correct equations Forming all three equations in α, β, γ All three values correct
5(e)	$\left[\frac{2mU^2}{P}\right] = \frac{\mathrm{M} \times \left(\mathrm{LT^{-1}}\right)^2}{\mathrm{ML^2T^{-3}}}$ $= \frac{\mathrm{ML^2T^{-2}}}{\mathrm{ML^2T^{-3}}} = \mathrm{T}$ so yes, expression for T is dimensionally consistent.	M1 A1 [2]	2.1 2.2a	Obtaining $\frac{\mathrm{M} \times \left(\mathrm{LT^{-1}}\right)^2}{[P]}$ with their $[P]$ from part **(a)** - **must** be using correct dim. analysis notation www – obtaining T and 'yes'

Question	Answer	Marks	AO	Guidance
6(a)		B1 [1]	1.1	Correct closed figure – all three sides labelled correctly together with angles 25 and 55 labelled oe (e.g. 80 degree angle opposite 4g). Must be forces. Allow T_1 for m_1g and T_2 for m_2g (but not T and T) – condone lack of arrows
6(b)	$\frac{4g}{\sin 80} = \frac{m_1 g}{\sin 35}$ or $\frac{4g}{\sin 80} = \frac{m_2 g}{\sin 65}$ $m_1 = 2.33$ $m_2 = 3.68$	M1 A1 A1 A1 [4]	3.4 1.1 2.2b 1.1	Attempt at sine rule at least once with at least one correct angle used (35, 65 or 80) to form an equation in either m_1 or m_2 (and possibly g) One correct equation for either m_1 or m_2 - allow with g consistently missing 2.3296… awrt 2.3 www 3.68115… awrt 3.7 www
	Alternative for first two marks in 6(b) Resolving either vertically **or** horizontally at B to form an equation in m_1, m_2 (and possibly g) $\rightarrow: m_1 g\cos 25 = m_2 g\cos 55$ $\uparrow: m_1 g\sin 25 + m_2 g\sin 55 = 4g$	M1 A1		Correct number of dimensionally correct terms but allow consistent omission of g. Allow sign errors and sin/cos mix but must be an equation in the two masses (and not tensions) For both correct

Question	Answer	Marks	AO	Guidance
7(a)	$4\times6+6\times3=4\times u_A+6\times5$	M1	3.3	Attempt at CLM, correct number of terms but allow sign errors only (if correct then $u_A=3$)
	$'3'-5=-e(6-3)$	M1	3.3	Attempt at NEL with their u_A, correct number of terms, allow sign errors only
	$e=\frac{2}{3}$	A1	1.1	Must be exact
		[3]		
7(b)	$6\times5=6\times v_B+2\times v_C$	M1	3.3	Attempt at CLM between B and C, correct number of terms, but allow sign errors only
	$v_B-v_C=-\frac{3}{5}(5-0)$	M1	3.3	Attempt at NEL between B and C, correct number of terms, but allow sign errors only
	$v_B=3$ (and $v_C=6$)	A1	1.1	
	$v_B=u_A$ (and $v_C>v_B$) so therefore no further collisions	A1	2.4	Must refer to the speeds in their explanation of why there are no further collisions – dependent on correct value for v_B
		[4]		
7(c)	Impulse of A on B: $6(5-3)$ or $-4(3-6)$ (=12) or Impulse of B on C: $2(6)$ or $-6(3-5)$ (=12)	M1	1.1	Use of Impulse = Change of momentum at least once with full working shown
	The magnitude of the impulse of A on B (in the first collision) is 12 Ns and is equal in magnitude to the impulse of B on C (in the second collision).	A1	1.1	Full working for both collisions together with ±12 must be seen (but no further explanation that they are equal is required). If different signs, then allow for example $\lvert-12\rvert=\lvert12\rvert$ oe (e.g. 'same magnitude') If 12 stated either once or twice with no working, then **SC B1**
		[2]		
7(d)	KE before first collision: $\frac{1}{2}\times4\times6^2+\frac{1}{2}\times6\times3^2\ (=99)$	B1	1.1	or $\frac{1}{2}\times4\times6^2+\frac{1}{2}\times6\times3^2-\frac{1}{2}\times4\times3^2+\frac{1}{2}\times6\times5^2(=6)$
	KE after second collision: $\frac{1}{2}\times4\times3^2+\frac{1}{2}\times6\times3^2+\frac{1}{2}\times2\times6^2\ (=81)$	B1	1.1	or $\frac{1}{2}\times6\times5^2-\frac{1}{2}\times6\times3^2-\frac{1}{2}\times2\times6^2(=12)$
	Total loss is 18 J	B1	1.1	

		[3]		
Question	**Answer**	**Marks**	**AO**	**Guidance**
8(a)	Either $\ddot{x}+\omega^2 x=0$ or $T=\dfrac{2\pi}{\omega}$	**M1**	**1.2**	Either correct expression for $\ddot{x}$ in terms of x and ω, or correct relationship for T in terms of ω and π - can be implied by correct differential equation
	$\ddot{x}=-\dfrac{4\pi^2}{T^2}x$ or $\ddot{x}=-\left(\dfrac{2\pi}{T}\right)^2 x$	**A1** **[2]**	**2.1**	Must be in this form
8(b)	$R-mg=m\ddot{x}$	**M1**	**3.3**	Use of N2L with correct number of dimensionally correct terms but allow sign errors – allow with either $\ddot{x}$ or their expression for $\ddot{x}$ from part **(a)**
	$R=mg-\dfrac{4\pi^2 mx}{T^2}$	**A1**	**1.1**	soi e.g. stating that this expression is the normal contact force (between the box and the platform)
	$mg-\dfrac{4\pi^2 ma}{T^2}>0$	**M1**	**3.4**	Setting their expression for $R > 0$ (or = 0 or with any inequality) and setting $x=\pm a$ **or** for $(m)\ddot{x}=\pm(m)g$ (or with an inequality) with $x=\pm a$
	$\left(gT^2-4\pi^2 a>0\Rightarrow\right)\ T^2>\dfrac{4\pi^2 a}{g}\Rightarrow T>2\pi\sqrt{\dfrac{a}{g}}$	**A1** **[4]**	**2.2a**	**AG** – dependent on seeing $m\left(\dfrac{4\pi^2 a}{T^2}\right)<mg$. Allow those who correctly derive $T>2\pi\sqrt{\dfrac{x}{g}}$ and then set $x = a$ without reasoning
8(c)	$R_{\min}=mg-m\times 4\pi^2\times\dfrac{g}{16\pi^2 a}\times a\quad\left(=\dfrac{3}{4}mg\right)$ or $R_{\max}=mg-m\times 4\pi^2\times\dfrac{g}{16\pi^2 a}\times -a\quad\left(=\dfrac{5}{4}mg\right)$	**M1**	**3.1b**	Use of their two term expression for R (possibly seen in part **(b)**) with correct given T to calculate either $R_{\min}$ **or** $R_{\max}$ (so must be substituting $x=\pm a$) or for considering either $\pm mg\pm\dfrac{4\pi^2 mx}{T^2}$ with correct given T and $x = a$ (condone without m's)
	$5:3$	**A1**	**1.1**	Allow $10:6$ (oe) but not $3:5$

		[2]		
Question	**Answer**	**Marks**	**AO**	**Guidance**
9(a)	$V = \pi\int_0^{\frac{1}{2}\pi} \cos x \,\mathrm{d}x$	**M1***	**1.2**	Correct integral expression for V – limits not required for this mark
	$V = \pi$	**A1**	**1.1**	cao – may be implied by a value of 1 if seen as part of $\bar{x} = \dfrac{V\bar{x}}{V}$ calculation
	$V\bar{x} = \pi\int_0^{\frac{1}{2}\pi} x\cos x \,\mathrm{d}x$	**M1***	**1.1**	Correct integral for $V\bar{x}$ – limits not required
	$V\bar{x} = \pi\left[x\sin x + \cos x\right]_0^{\frac{1}{2}\pi}$ $\left(= \pi\left(\frac{1}{2}\pi - 1\right)\right)$	**A1**	**1.1**	Correct integrated expression for $V\bar{x}$ – limits not required for this mark – may be implied by $x\sin x + \cos x$ if seen as part of $\bar{x} = \dfrac{V\bar{x}}{V}$ calculation
	$\bar{x} = \dfrac{V\bar{x}}{V} = \dfrac{\pi\left(\frac{1}{2}\pi - 1\right)}{\pi}$	**M1dep***	**3.4**	Correct use of $\bar{x} = \dfrac{V\bar{x}}{V}$ with their expressions for $V\bar{x}$ and V
	$\bar{x} = \frac{1}{2}\pi - 1$	**A1**	**1.1**	cao – must be exact – allow for full marks those who consider $\bar{x} = \dfrac{\int_0^{\frac{1}{2}\pi} x\cos x \,\mathrm{d}x}{\int_0^{\frac{1}{2}\pi} \cos x \,\mathrm{d}x}$ (so no π present)
		[6]		
9(b)	$\tan\alpha = \dfrac{1}{\frac{1}{2}\pi - 1}$	**M1**	**3.1b**	Use of $\tan\alpha = \dfrac{1}{\bar{x}}$ (allow reciprocal) with their $\bar{x}$ or equivalent single equation soi
	$\alpha = 60.3$	**A1**	**1.1**	60.282… so allow awrt 60 www in part **(a)** or 1.052… in rad so allow awrt 1.1 – allow if θ used
		[2]		
9(c)	$\tan\beta = 0.4$	**M1**	**1.2**	Use of condition for sliding that $\tan\theta = \mu$ soi

	$\beta = 21.8$	**A1** **[2]**	**1.1**	21.80140… so allow awrt 22 www or 0.380506… so allow awrt 0.38 www – allow if θ used
Question	**Answer**	**Marks**	**AO**	**Guidance**
10(a)	$T\cos\theta = 2g$	**M1***	**3.3**	Resolving vertically – correct number of terms – allow sin/cos mix, but must be using 2 for the mass
	$T\sin\theta + T = 2r\omega^2$	**M1***	**3.3**	Applying N2L horizontally – correct number of dimensionally correct terms – allow sin/cos mix and sign errors, allow r or their (possibly incorrect) r – if using two different tensions e.g. T_1 and T_2 then do not award this mark until $T_1 = T_2$ soi but must be using 2 for the mass
	$T\sin\theta + T = 2(1.5\tan\theta)\omega^2$ **and** $T\cos\theta = 2g$	**A1**	**1.1**	
	$\left(\frac{2g}{\cos\theta}\right)\sin\theta + \frac{2g}{\cos\theta} = (3\tan\theta)\omega^2$	**M1dep***	**3.4**	Eliminate T to obtain an equation in θ, g and ω
	$\omega^2 = \frac{2g}{3}\left(\frac{1+\sin\theta}{\sin\theta}\right)$ or $\frac{2g}{3}\left(1+\frac{1}{\sin\theta}\right)$	**A1**	**1.1**	Correct expression for ω^2 in terms of g and $\sin\theta$
	$\omega^2 = \frac{2g}{3}\left(1+\frac{1}{\sin\theta}\right)$ (but $0 < \sin\theta < 1$ therefore) $1+\frac{1}{\sin\theta} > 2$			
	so $\omega^2 > \frac{4}{3}g \Rightarrow \omega > 2\sqrt{\frac{g}{3}}$	**A1**	**2.2a**	**AG –** as answer given sufficient working must be shown e.g. $\omega^2 = \frac{2}{3}\left(\frac{g}{\sin\theta} + g\right) \Rightarrow \omega^2 > \frac{2}{3}(g+g)$ etc. Allow from a correct expression for $\sin\theta$ e.g. $\frac{2g}{3\omega^2 - 2g}$ and setting this < 1 (so not dependent on previous **A1** mark but must be from a correct equation involving ω, g and $\sin\theta$). Note that setting $\sin\theta = 1$ in an equation for ω^2 e.g. $\omega^2 = \frac{2g}{3}(1+1)$ followed by $\omega^2 > \frac{4}{3}g$ is **A0**

		[6]		

Question	Answer	Marks	AO	Guidance
10(b)	$\frac{2g}{3}\left(\frac{1+\sin\theta}{\sin\theta}\right)=2g$	**M1***	**1.1**	Set their expression for ω^2 of the form $ag\left(\frac{b+c\sin\theta}{d\sin\theta}\right)$ with non-zero a, b, c and d equal to $2g$ (oe) to obtain an equation in θ (and possibly g) only e.g. if correct then $\frac{2g}{\cos\theta}+2g\tan\theta=6g\tan\theta$
	$\theta=\frac{1}{6}\pi\Rightarrow T=\frac{2g}{\cos\frac{1}{6}\pi}$ **or** $T=\frac{2(1.5\tan\frac{1}{6}\pi)\times 2g}{1+\sin\frac{1}{6}\pi}$	**M1dep***	**3.4**	Substitute their value of θ into (one of) their equations for T to obtain an expression/equation in T (and g) only. Note that some may not find θ and instead use exact values of $\sin\theta$ and $\tan\theta$ in terms of T e.g. $T\left(1+\frac{\sqrt{T^2-4g^2}}{T}\right)=6g\left(\frac{\sqrt{T^2-4g^2}}{2g}\right)$
	$T=\frac{4g}{\sqrt{3}}$	**A1**	**1.1**	Or any **exact** equivalent
		[3]		

Question	Answer	Marks	AO	Guidance
11(a)	(The spheres are smooth and as) B is at rest before the collision the line of centres must be parallel to the direction of motion of B after collision. If B travels directly towards R, then the line of centres must therefore be parallel to **j**	**B1** **[1]**	**2.4**	**Must** mention **impulse** or **direction of motion** of B is in the **j**-direction (oe for **j**-direction)
11(b)		**M1***	**3.3**	Attempt at either CLM or NEL (parallel to the loc) – correct number of terms, allow sign errors, condone *m* absent from CLM
	$w+b=8$	**A1**	**1.1**	Correct application of CLM e.g. $-w+b=8$
	$w-b=-0.6(8-0)$ or $b-w=0.6\times 8$	**A1**	**1.1**	Correct consistent application of NEL e.g. $w+b=8\times 0.6$
	$w=1.6$ $(b=6.4)$	**A1**	**1.1**	Correct velocity component of W parallel to **j** after collision e.g. $w=-1.6$
	$\tan\alpha=\frac{8}{6}(\Rightarrow \alpha=53.1301...)$	**B1**	**3.4**	Where α is the angle to the horizontal of the direction of motion of W before collision **or** for complementary angle $\tan\delta=\frac{6}{8}(\Rightarrow \delta=36.86989...)$
	$\tan\beta=\frac{1.6}{6}(\Rightarrow \beta=14.9314...)$	**M1dep***	**3.4**	Where β is the angle to the horizontal of the direction of motion of W after collision – for $\tan\beta=\frac{w}{6}$ with their w **or** for complementary angle $\tan\phi=\frac{6}{w}(\Rightarrow \phi=75.06858...$ if correct$)$
	Deflected angle is $\alpha-\beta=38^\circ$	**A1** **[7]**	**2.2a**	Must be in degrees to the nearest integer **or** better (38.1986…)

Question	Answer	Marks	AO	Guidance
12(a)	Change in GPE is $\pm mgh$ and KE is $\pm\left(\frac{1}{2}mv^2 - \frac{1}{2}m\left(\sqrt{4ga}\right)^2\right)$	B1	2.1	For both change in GPE **and** KE – could appear in a conservation of energy equation
	EPE is $\dfrac{4mg(h-a)^2}{2a}$	B1	1.1	Correct EPE at depth h
	$\frac{1}{2}m\left(\sqrt{4ga}\right)^2 = -mgh + \frac{1}{2}mv^2 + \dfrac{4mg(h-a)^2}{2a}$	M1	3.3	Conservation of energy – correct number of dimensionally correct relevant terms, allow sign errors
	$v = \sqrt{10gh - \dfrac{4gh^2}{a}}$	A1 [4]	2.1	**AG** – www so any errors seen in derivation of given answer is **A0**
12(b)	$v = 0 \Rightarrow 10gh - \dfrac{4gh^2}{a} = 0$	M1	3.1b	Setting the given expression for v from part **(a)** equal to zero
	$h = \frac{5}{2}a$	A1 [2]	1.1	
12(c)	Max speed $\Rightarrow mg - \dfrac{4mg}{a}(h-a) = 0$	M1*	3.1b	Use of N2L with correct number of terms with acceleration = 0 **or** $\dfrac{4mge}{a} = mg\left(\Rightarrow e = 0.25a\right)$ or differentiate their v^2 (oe) to obtain $2v\dfrac{\mathrm{d}v}{\mathrm{d}h} = 10g - \dfrac{8gh}{a}$ and set $v\dfrac{\mathrm{d}v}{\mathrm{d}h} = 0$
	$h = \frac{5}{4}a$	A1	1.1	Possibly implied in a conservation of energy equation
	$v = \sqrt{10g\left(\frac{5}{4}a\right) - \dfrac{4g}{a} \times \dfrac{25a^2}{16}}$	M1dep*	3.4	Substitute expression for h in terms of a (with $h > a$) into their v or v^2
	$v = \dfrac{5}{2}\sqrt{ag}$	A1 [4]	1.1	oe

Question	Answer	Marks	AO	Guidance
12(d)	$\frac{1}{2}m\left(\sqrt{4ag}\right)^2 = mgX + \frac{4mg\left(X-a\right)^2}{2a}$ $X = \frac{3}{2}a$	M1 A1 [2]	3.4 1.1	Conservation of energy – correct number of dimensionally correct terms, allow sign errors
12(e)	The model assumes that Hooke's law is applicable throughout the entire motion which may not be the case if the relationship between the extension and tension of the string is not linear (which may be the case in situations when the magnitude of the tension is large).	B1 [1]	3.5b	Understanding of the elastic limit of Hooke's law and that Hooke's law may not apply throughout the entire motion of P. Other acceptable answers include: mention of energy lost to other sources e.g. heat/sound mention of resistive forces, etc.

Question	Answer	Marks	AO	Guidance
13(a)	$x = 30\cos\theta \times t$ **or** $X = 30\cos\theta \times t$	**B1**	**1.1**	Condone $s = \ldots$
	$y = 30\sin\theta \times t - \frac{1}{2} \times 10 \times t^2$ **or** $-h = 30\sin\theta \times t - \frac{1}{2} \times 10 \times t^2$	**B1**	**1.1**	Allow 9.8 or g for the acceleration due to gravity – condone $s = \ldots$
	$y = 30\sin\theta\left(\frac{x}{30\cos\theta}\right) - 5\left(\frac{x}{30\cos\theta}\right)^2$	**M1***	**3.4**	Eliminate t from their x and y expressions with the correct number of relevant terms (so their expressions for x and y can only contain sign errors and sin/cos mix) – if cartesian equation stated (then must be correct for **M1**) or if $s = ut + \frac{1}{2}at^2$ used directly (so no expressions for x/y stated/seen) then max 3 marks (**B0 B0 M1 M1 A1**)
	$-h = X\tan\theta - \frac{5X^2}{900}\left(1 + \tan^2\theta\right)$	**M1dep***	**3.1b**	Replace y with $-h$, x with X, and use of $1 + \tan^2\theta = \sec^2\theta$ to obtain a quadratic in $\tan\theta$
	$\left(-180h = 180X\tan\theta - X^2(1 + \tan^2\theta)\right)$ $\Rightarrow X^2\tan^2\theta - 180X\tan\theta + X^2 - 180h = 0$	**A1**	**2.1**	**AG www** but condone x for X. Condone substitution of $y = -h$ and $x = X$ into a correct quadratic equation in $\tan\theta$ followed by the correct answer with no intermediate work. Any errors seen in derivation of given answer then **A0**
		[5]		
13(b)	$(-180X)^2 - 4(X^2)(X^2 - 180h)$ **or** $X^2(2\tan\theta) - 180X = 0$	**M1***	**3.1b**	Correct use of discriminant oe (e.g. differentiating with respect to $\tan\theta$ or θ and setting equal to zero) on given result from part **(a)** to obtain an (un-simplified) quadratic in X^2
	$32400X^2 - 4X^4 + 720X^2h = 0$	**M1dep***	**3.4**	Sets discriminant equal to zero and expands to obtain two terms in X^2 and one term in X^4 oe e.g. substituting their $\tan\theta = \frac{90}{X}$ into given equation
	$8100 - X^2 + 180h = 0 \Rightarrow X^2 = 8100 + 180h$	**A1**	**1.1**	
		[3]		

Question	Answer	Marks	AO	Guidance
13(c)	$x^2 = 8100 + 180(-y)$	M1	3.1a	Set $h = -y$ and $X = x$ in their expression of the form $X^2 = p + qh$ from part **(b)** where p, q are constants
	$y = -\frac{1}{180}x^2 + 45$	A1	2.1	If **M0** then **SC B1** for either $y = -\frac{1}{180}x^2(+c)$ or $y = ... + 45$
		[2]		

Question	Answer	Marks	AO	Guidance
14(a)	Change in GPE = $\pm mgr(1-\cos\theta)$	B1	1.1	Either correct change in KE or GPE energy
	or change in KE = $\pm\left(\frac{1}{2}mv^2-\frac{1}{2}m\left(\sqrt{2gr}\right)^2\right)$			
	$mgr(1-\cos\theta)=\frac{1}{2}m\left(v^2-2gr\right)$ $\left(v^2=4gr-2gr\cos\theta\right)$	M1	3.3	Use of conservation of energy – correct number of dimensionally correct terms, allow sign errors and sin/cos mix on change in GPE term
	Downward acceleration component: $\frac{v^2}{r}\cos\theta+\sin\theta\frac{\mathrm{d}v}{\mathrm{d}t}$	M1	3.1b	Allow sin/cos mix only
	$\frac{\mathrm{d}v}{\mathrm{d}t}=g\sin\theta$	B1	1.2	soi – condone $a=g\sin\theta$
	$a_v=\left(4g-2g\cos\theta\right)\times\cos\theta+g\sin^2\theta$			
	$\Rightarrow a_v=\left(4\cos\theta-2\cos^2\theta+1-\cos^2\theta\right)g=\left(1+4\cos\theta-3\cos^2\theta\right)g$	A1 [5]	2.1	**AG www– sufficient working must be shown**
	Alternative for final 3 marks of part (a)			
	N2L$\downarrow$: $mg+R\cos\theta=ma$ [1] or $\downarrow$: $mg-R\cos\theta=ma$ [2]	M1		Allow sin/cos mix only
	$R+mg\cos\theta=\frac{m}{r}\left(4gr-2gr\cos\theta\right)\left(\Rightarrow R=mg\left(4-3\cos\theta\right)\right)$ [1]	A1		Correct (un-simplified) consistent expression/equation for R in terms of m, g and θ (so **must** have both correct equation [1]s **or** both correct equation [2]s)
	or $mg\cos\theta-R=\frac{m}{r}\left(4gr-2gr\cos\theta\right)\left(\Rightarrow R=mg\left(3\cos\theta-4\right)\right)$ [2]			
	$ma=mg+mg\cos\theta\left(4-3\cos\theta\right)\Rightarrow a=\left(1+4\cos\theta-3\cos^2\theta\right)g$	A1		**AG www – sufficient working must be shown**

Question	Answer	Marks	AO	Guidance
14(b)	$\frac{\mathrm{d}a_v}{\mathrm{d}\theta} = g\left(-4\sin\theta + 6\cos\theta\sin\theta\right)$	M1*	3.1a	Attempt to differentiate – allow sign errors only and condone g missing throughout
		A1	1.1	Correct derivative of given result
	$g\left(-4\sin\theta + 6\cos\theta\sin\theta\right) = 0$	M1dep*	1.1	Set derivative equal to zero
	Alternative for first 3 marks of part (b)			
	$-3\left[\cos^2\theta - \frac{4}{3}\cos\theta\right] + 1 = -3\left[\left(\cos\theta - \frac{2}{3}\right)^2 - \frac{4}{9}\right] + 1$	M1*		Attempt to complete the square (take out a factor of ± 3 and half coefficient)
	$= -3\left(\cos\theta - \frac{2}{3}\right)^2 + \frac{7}{3}$	A1		At least correct up to $-3\left(\cos\theta - \frac{2}{3}\right)^2 + \ldots$
	Set their $\left(\cos\theta - \frac{2}{3}\right)$ equal to zero	M1dep*		
	$\left(\sin\theta = 0 \text{ or}\right)\ \cos\theta = \frac{2}{3}$	A1	1.1	Obtain at least $\cos\theta = \frac{2}{3}$
	$mg\cos\theta - R = \frac{m}{r}\left(4gr - 2gr \times \frac{2}{3}\right)$ **or** $mg\cos\theta + R = \frac{m}{r}\left(4gr - 2gr \times \frac{2}{3}\right)$	M1	3.3	Attempt N2L radially – correct number of terms but allow sign errors and sin/cos mix. Must substitute their expression for v^2 and using their value of $\cos\theta$ where $\lvert\cos\theta\rvert < 1$ and $\neq 0$ **dependent on both previous M marks**
	$R = 4mg - 3mg \times \frac{2}{3} \Rightarrow R = 2mg$	A1	1.1	Correct magnitude of the force of the bead (so must be positive) – must be in terms of m and g
	or $R = 3mg \times \frac{2}{3} - 4mg \Rightarrow R = -2mg$ so magnitude is $2mg$	[6]		

Question	Answer	Marks	AO	Guidance
15	$AB^2 = l^2 - (b-a)^2$	B1	3.3	
	Attempt to resolve either parallel or perpendicular to AB	M1*	3.1b	Allow sign errors and sin/cos mix – where θ is the angle between the horizontal and the rod, and m is the mass of the rod. Allow W for mg throughout. **This mark can also be awarded for resolving vertically** $R_A\cos\theta + R_B\cos\theta + F_A\sin\theta + F_B\sin\theta = mg$
	$F_A + F_B = mg\sin\theta$ **and** $R_A + R_B = mg\cos\theta$	A1	1.1	$F_A + F_B = W\sin\theta$ **and** $R_A + R_B = W\cos\theta$
	$\mu R_A + \mu R_B = mg\sin\theta$	M1dep*	3.1b	Use of $F = \mu R$ twice (at both A and B) – note that $\mu R_A + \mu R_B = W\sin\theta$ (oe) implies both **M** marks
	$\mu(mg\cos\theta) = mg\sin\theta \Rightarrow \mu = \tan\theta$	A1	1.1	
	$\mu = \dfrac{b-a}{\sqrt{l^2-(b-a)^2}}$	A1	2.2a	
		[6]		
	Alternative solution 1 $AB^2 = l^2 - (b-a)^2$	B1		
	Attempt to resolve horizontally	M1*		Correct number of terms, allow sign errors and sin/cos mix only
	$R_A\sin\theta + R_B\sin\theta = F_A\cos\theta + F_B\sin\theta$	A1		
	$R_A\sin\theta + R_B\sin\theta = \mu R_A\cos\theta + \mu R_B\sin\theta$	M1dep*		Use of $F = \mu R$ twice
	$(R_A + R_B)\sin\theta = \mu(R_A + R_B)\cos\theta \Rightarrow \mu = \tan\theta$	A1		Obtains $\mu = \tan\theta$
	$\mu = \dfrac{b-a}{\sqrt{l^2-(b-a)^2}}$	A1		
		[6]		

Question	Answer	Marks	AO	Guidance
	Alternative solution 2			
	$AB^2 = l^2 - (b-a)^2$	**B1**		
	Attempt to resolve either parallel or perpendicular to AB	**M1***		Attempt to resolve either parallel or perpendicular to AB – allow sign errors and sin/cos mix – where θ is the angle between the horizontal and the rod, and m is the mass of the rod.
	$F_A + F_B = mg\sin\theta$ **and** $R_A + R_B = mg\cos\theta$	**A1**		
	$F_A + F_B = mg\left(\frac{b-a}{l}\right)$ **or** $R_A + R_B = mg \times \frac{AB}{l}$	**A1**		Allow AB or their expression for AB (even if incorrect)
	$\mu R_A + \mu R_B = mg\left(\frac{b-a}{l}\right) \Rightarrow \mu\left(mg \times \frac{AB}{l}\right) = mg\left(\frac{b-a}{l}\right)$	**M1dep***		Use of $F = \mu R$ twice (at both A and B) to obtain a correct equation containing μ, follow through their expression for AB^2 only
	$\mu = \frac{b-a}{\sqrt{l^2-(b-a)^2}}$	**A1**		
		[6]		

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