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A Level Further Mathematics B (MEI)

Y431 Mechanics Minor

Sample Question Paper Version 2

Date – Morning/Afternoon

Time allowed: 1 hour 15 minutes

You must have:
- Printed Answer Booklet
- Formulae Further Mathematics B (MEI)

You may use:
- a scientific or graphical calculator

INSTRUCTIONS
- Use black ink. HB pencil may be used for graphs and diagrams only.
- Complete the boxes provided on the Printed Answer Booklet with your name, centre number and candidate number.
- Answer **all** the questions.
- **Write your answer to each question in the space provided in the Printed Answer Booklet.** Additional paper may be used if necessary but you must clearly show your candidate number, centre number and question number(s).
- Do **not** write in the bar codes.
- You are permitted to use a scientific or graphical calculator in this paper.
- Final answers should be given to a degree of accuracy appropriate to the context.
- The acceleration due to gravity is denoted by g m s^{-2}. Unless otherwise instructed, when a numerical value is needed, use $g = 9.8$.

INFORMATION
- The total number of marks for this paper is **60**.
- The marks for each question are shown in brackets **[ ]**.
- You are advised that an answer may receive **no marks** unless you show sufficient detail of the working to indicate that a correct method is used. You should communicate your method with correct reasoning.
- The Printed Answer Booklet consists of **12** pages. The Question Paper consists of **8** pages.

Answer **all** the questions.

1 In this question, **i** and **j** are perpendicular unit vectors in a horizontal plane.

A particle P has mass 10 kg and a speed of 20 m s^{-1} in the direction of $4\mathbf{i} + 3\mathbf{j}$. A force of $(-4\mathbf{i} + 15\mathbf{j})$ N acts on P for 8 seconds.

(i) Calculate the impulse of the force over the 8 seconds. **[1]**

(ii) Hence find the speed of P at the end of the 8 seconds. **[3]**

2 A car of mass 1200 kg is travelling in a straight line along a horizontal road. At a time when the power of the driving force is 25 kW, the car has a speed of 12.5 m s^{-1} and is accelerating at 1.5 m s^{-2}.

Calculate the magnitude of the resistance to the motion of the car. **[5]**

3 **(i)** Find the dimensions of

- density and
- pressure (force per unit area). **[2]**

The frequency, f, of the note emitted by an air horn is modelled as $f = ks^{\alpha} p^{\beta} d^{\gamma}$, where

- s is the length of the horn,
- p is the air pressure,
- d is the air density,
- k is a dimensionless constant.

(ii) Determine the values of α, β and γ. **[4]**

A particular air horn emits a note at a frequency of 512 Hz and the air pressure and air density are recorded. At another time it is found that the air pressure has fallen by 2% and the air density has risen by 1%. The length of the horn is unchanged.

(iii) Calculate the new frequency predicted by the model. **[2]**

4 Fig. 4 shows a non-uniform rigid plank AB of weight 900 N and length 2.5 m. The centre of mass of the plank is at G which is 2 m from A. The end A rests on rough horizontal ground and does not slip. The plank is held in equilibrium at 20° above the horizontal by a force of T N applied at B at an angle of 55° above the horizontal as shown in Fig. 4.

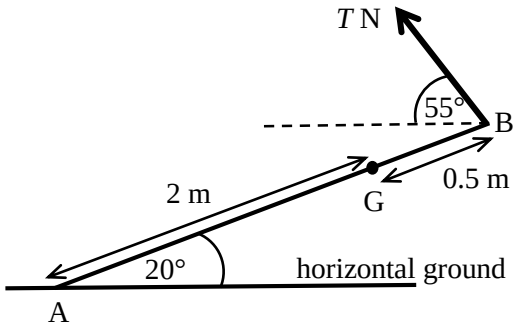

Fig. 4

(i) Show that $T = 700$ (correct to 3 significant figures). **[4]**

(ii) Determine the possible values of the coefficient of friction between the plank and the ground. **[5]**

5 A young man of mass 60 kg swings on a trapeze. A simple model of this situation is as follows.

The trapeze is a light seat suspended from a fixed point by a light inextensible rope. The man's centre of mass, G, moves on an arc of a circle of radius 9 m with centre O, as shown in Fig. 5. The point C is 9 m vertically below O. B is a point on the arc where angle COB is 45°.

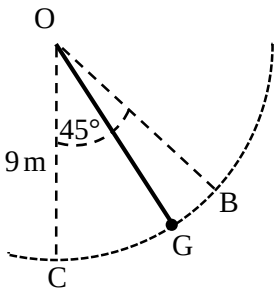

Fig. 5

(i) Calculate the gravitational potential energy lost by the man if he swings from B to C. **[3]**

In this model it is also assumed that there is no resistance to the man's motion and he starts at rest from B.

(ii) Using an energy method, find the man's speed at C. **[2]**

A new model is proposed which also takes into account resistance to the man's motion.

(iii) State whether you would expect any such model to give a larger, smaller or the same value for the man's speed at C. Give a reason for your answer. **[1]**

A particular model takes account of the resistance by assuming that there is a force of constant magnitude 15 N always acting in the direction opposing the man's motion. This new model also takes account of the man 'pushing off' along the arc from B to C with a speed of $1.5\,\text{m}\,\text{s}^{-1}$.

(iv) Using an energy method, find the man's speed at C. **[5]**

6 My cat Jeoffry has a mass of 4 kg and is sitting on rough ground near a sledge of mass 8 kg. The sledge is on a large area of smooth horizontal ice.

Initially, the sledge is at rest and Jeoffry jumps and lands on it with a horizontal velocity of $2.25\,\text{m}\,\text{s}^{-1}$ parallel to the runners of the sledge. On landing, Jeoffry grips the sledge with his claws so that he does not move relative to the sledge in the subsequent motion.

(i) Show that the sledge with Jeoffry on it moves off with a speed of $0.75\,\text{m}\,\text{s}^{-1}$. **[2]**

With the sledge and Jeoffry moving at $0.75\,\text{m}\,\text{s}^{-1}$, the sledge collides *directly* with a stationary stone of mass 3 kg. The stone may move freely over the ice. The coefficient of restitution in the collision is $\frac{4}{15}$.

(ii) Calculate the velocity of the sledge and Jeoffry immediately after the collision. **[6]**

In a new situation, Jeoffry is initially sitting at rest on the sledge when it is stationary on the ice. He then walks from the back to the front of the sledge.

(iii) Giving a brief reason for your answer, describe what happens to the sledge during his walk. **[2]**

Jeoffry is again sitting on the sledge when it is stationary on the ice. He jumps off and, after he has lost contact with the sledge, has a horizontal speed relative to the sledge of $3\,\text{m}\,\text{s}^{-1}$.

(iv) Determine the speed of the sledge after Jeoffry loses contact with it. **[4]**

7 Fig. 7 shows a container for flowers which is a vertical cylindrical shell with a closed horizontal base. Its radius and its height are both $\frac{1}{2}$ m. Both the curved surface and the base are made of the same thin uniform material. The mass of the container is M kg.

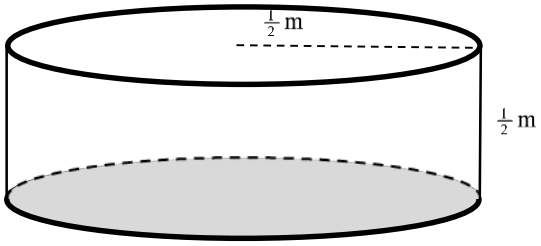

Fig. 7

(i) Find, as a fraction, the height above the base of the centre of mass of the container. **[3]**

The container would hold $\frac{3}{2}M$ kg of soil when full to the top.

Some soil is put into the empty container and levelled with its top surface y m above the base. The centre of mass of the container with this much soil is z m above the base.

(ii) Show that $z = \dfrac{1+9y^2}{6(1+3y)}$. **[4]**

(iii) It is given that $\dfrac{\mathrm{d}z}{\mathrm{d}y} = 0$ when $y = 0.14$ (to 2 significant figures) and that $\dfrac{\mathrm{d}^2z}{\mathrm{d}y^2} > 0$ at this value of y.

When putting in the soil, how might you use this information if the container is to be placed on slopes without it tipping over? **[2]**

END OF QUESTION PAPER

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…day June 20XX – Morning/Afternoon

A Level Further Mathematics B (MEI)

Y431 Mechanics Minor

SAMPLE MARK SCHEME

Duration: 1 hour 15 minutes

MAXIMUM MARK 60

This document consists of 12 pages

Text Instructions

1. Annotations and abbreviations

Annotation in scoris	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
Highlighting	
Other abbreviations in mark scheme	**Meaning**
E1	Mark for explaining a result or establishing a given result
dep*	Mark dependent on a previous mark, indicated by *
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 indicates that the instruction **In this question you must show detailed reasoning** appears in the question.

2. Subject-specific Marking Instructions for A Level Further Mathematics B (MEI)

a Annotations should be used whenever appropriate during your marking. The A, M and B annotations must be used on your standardisation scripts for responses that are not awarded either 0 or full marks. It is vital that you annotate standardisation scripts fully to show how the marks have been awarded. For subsequent marking you must make it clear how you have arrived at the mark you have awarded.

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 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
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.

E
A given result is to be established or a result has to be explained. This usually requires more working or explanation than the establishment of an unknown result.

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. This rule should be applied to each case. When a value is not given in the paper accept any answer that agrees with the correct value to 2 s.f. Follow through should be used so that only one mark is lost for each distinct accuracy error, except for errors due to premature approximation which should be penalised only once in the examination. There is no penalty for using a wrong value for *g*. E marks will be lost except when results agree to the accuracy required in the question.

g Rules for replaced work: if a candidate attempts a question more than once, and indicates which attempt he/she wishes to be marked, then examiners should do as the candidate requests; if there are two or more attempts at a question which have not been crossed out, examiners should mark what appears to be the last (complete) attempt and ignore the others. NB Follow these maths-specific instructions rather than those in the assessor handbook.

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 papers. This is achieved by withholding one A mark in the question. Marks designated as cao may be awarded as long as there are no other errors. E marks are lost unless, by chance, the given results are established by equivalent working. 'Fresh starts' will not affect an earlier decision about a misread. Note that a miscopy of the candidate's own working is not a misread but an accuracy error.

i If a graphical calculator is used, some answers may be obtained with little or no working visible. Allow full marks for correct answers (provided, of course, that there is nothing in the wording of the question specifying that analytical methods are required). 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.

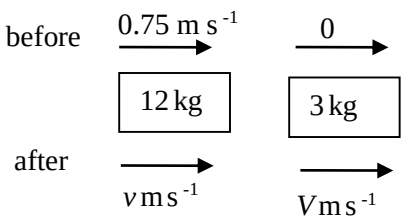
k Anything in the mark scheme which is in square brackets […] is not required for the mark to be earned on this occasion, but shows what a complete solution might look like.

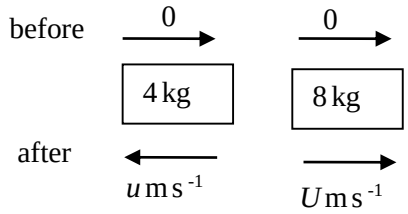
Question			Answer	Marks	AOs	Guidance	
1	(i)		Impulse is $8(-4\mathbf{i}+15\mathbf{j})=(-32\mathbf{i}+120\mathbf{j})$ N s	B1 [1]	1.2		
1	(ii)		Initial momentum is $\frac{20}{5}(4\mathbf{i}+3\mathbf{j})\times 10=(160\mathbf{i}+120\mathbf{j})$ N s $10\mathbf{v}=(160\mathbf{i}+120\mathbf{j})+(-32\mathbf{i}+120\mathbf{j})=(128\mathbf{i}+240\mathbf{j})$ so $\lvert\mathbf{v}\rvert=27.2$ and speed is 27.2 m s^{-1}	B1 M1 A1 [3]	1.1 3.4 1.1	Any form. May be implied Use of $\mathbf{I}=m\mathbf{v}-m\mathbf{u}$	
2			Let driving force be D N and resistance R N. N2L in the direction of motion: $D-R=1200\times 1.5$ $25\,000=D\times 12.5$ This gives $R=\frac{25000}{12.5}-1200\times 1.5=200$ [5]	 M1 A1 M1 A1 A1	 3.3 1.1 3.4 1.1 1.1	 Use of N2L. Allow F in place of $D-R$. Any form Use of $P=Dv$ Any form	N2L is Newton's 2nd law

Question			Answer	Marks	AOs	Guidance	
3	(i)		[density] = M L $^{-3}$ [pressure] = M L T $^{-2}$ / L^{-2} = M L $^{-1}$ T $^{-2}$	**B1** **B1** **[2]**	**1.2** **1.1**		
3	(ii)		$T^{-1} = L^{\alpha}\ (M\ L^{-1}\ T^{-2})^{\beta}\ (M\ L^{-3})^{\gamma}$ $\alpha = -1$ $\beta = \frac{1}{2}$ $\gamma = -\frac{1}{2}$	**M1** **M1** **A1** **A1** **[4]**	**3.3** **1.1** **1.1** **2.2a**	Set up compare coefficients of M, L and T One correct All correct	
3	(iii)		Suppose the values for $f = 512$ are s_0 , p_0 and d_0				
			either $\frac{f'}{512} = \frac{ks_0\sqrt{\frac{0.98p_0}{1.01d_0}}}{ks_0\sqrt{\frac{p_0}{d_0}}} = \sqrt{\frac{0.98}{1.01}}$ **or**	**M1**	**3.1b**	Any complete method	
			Find k using $512 = ks_0\sqrt{\frac{p_0}{d_0}}$ so substituting for k, $f' = \frac{512}{s_0}\sqrt{\frac{d_0}{p_0}} \times s_0\sqrt{\frac{0.98p_0}{1.01d_0}}$	**M1**		oe Method must have k eliminated	
			so f' = 504.33… so 504 Hz (3 s.f.)	**A1** **[2]**	**1.1**		

Question			Answer	Marks	AOs	Guidance	
4	(i)		a.c moments about A	**M1**	**3.1b**	All required forces present and resolved	
			either				
			$T \times 2.5\sin(55+20) - 900 \times 2\cos 20 = 0$	**A1** **A1**	**1.1** **2.1**	55 + 20 All correct	
			or				
			$T\cos 55 \times 2.5\sin 20 + T\sin 55 \times 2.5\cos 20 ...$ $-900 \times 2\cos 20 = 0$	**A1** **A1**		Horizontal and vertical components of T both correct All correct	
			so T = 700.4457… so 700 N (3 s. f.) AG	**A1** **[4]**	**1.1**		
4	(ii)		At A, take friction $F \rightarrow$ and normal reaction $R \uparrow$				
			Resolving → and ↑	**M1**	**3.1b**		
			$F - T\cos 55 = 0$	**A1**	**1.1**		
			$R + T\sin 55 - 900 = 0$	**A1**	**1.1**		
			$F \leq \mu R$	**M1**	**3.4**	Use of Coulomb's law. Allow use of =	
			so $\mu \geq$ 1.2315… so $\mu \geq$ 1.23 (3 s. f.)	**A1** **[5]**	**3.2a**	Must have ≥	

Question			Answer	Marks	AOs	Guidance	
5	(i)		$60\times 9.8\times 9(1-\cos 45)$ J	M1	1.1a	GPE change is *mgh*	GPE is gravitational potential energy
				A1	1.1	Finding *h*	
			$= 5292\times\left(1-\frac{\sqrt{2}}{2}\right) = 1549.99\ldots$	A1	1.1		
			so change in GPE is 1550 J (3 s.f.)	[3]			
5	(ii)		$\frac{1}{2}\times 60\times v^2 = 5292\times\left(1-\frac{\sqrt{2}}{2}\right)$	M1	3.3	Conservation of energy	
			so $v = 7.1879\ldots$ so speed is $7.19\,\text{m s}^{-1}$ (3 s.f.)	A1	1.1		
				[2]			
5	(iii)		Smaller, because work is done against the resistance, so the final kinetic energy is lower.	E1	3.5b		
				[1]			
5	(iv)		$\frac{1}{2}\times 60\times v^2 - \frac{1}{2}\times 60\times 1.5^2$	M1	3.3	W-E equation with KE, GPE and WD	W-E is work-energy KE is Kinetic Energy WD is work done
				A1	1.1	KE terms correct	
			$= 5292\times\left(1-\frac{\sqrt{2}}{2}\right) - 15\times\frac{1}{8}\times 2\times\pi\times 9$	B1	3.4	WD against resistance	
				A1	1.1	Correct, accept only sign errors	
			$v = 7.0980\ldots$ so speed is $7.10\,\text{m s}^{-1}$ (3 s.f.)	A1	1.1		
				[5]			

Question			Answer	Marks	AOs	Guidance	
6	(i)		PCLM in direction of motion: $4 \times 2.25 + 0 = 12v$ so $v = 0.75$ so $0.75\,\text{m s}^{-1}$.	**M1** **E1** **[2]**	**3.3** **1.1**	Use of PCLM	PCLM is Principle of conservation of linear momentum
6	(ii)		 PCLM in initial direction of the sledge $12\times0.75 = 12v + 3V$ so $4v + V = 3$ NEL $\frac{V-v}{0-0.75} = -\frac{4}{15}$ so $V - v = 0.2$ Solving, $v = 0.56$	**B1** **M1** **A1** **M1** **A1** **A1** **[6]**	**3.3** **3.4** **1.1** **3.4** **2.1** **1.1**	oe Award also if final answer correct PCLM Any form NEL Must be the right way up. Any form	
6	(iii)		The sledge moves (in the opposite direction to Jeoffry) No horizontal external force acts on the cat + sledge system, so linear momentum is conserved.	**E1** **E1** **[2]**	**2.2a** **2.4**		

Question			Answer	Marks	AOs	Guidance	
6	(iv)		Let the absolute speeds of J and sledge be u and U respectively  				
			PCLM	**M1**	**3.3**	Correct analysis	
			$4u = 8U$	**B1**	**1.1**	PCLM	
			relative motion				
			$u + U = 3$	**B1**	**3.1b**	relative motion. May use, say, v and $v + 3$	
			so $U = 1$ so 1 m s^{-1}	**A1** **[4]**	**1.1**		

Question			Answer	Marks	AOs	Guidance	
7	(i)		Let M be the mass of the container. Mass of base is $\frac{\pi(0.5)^2}{2\pi\times0.5\times0.5+\pi(0.5)^2}M = \frac{1}{3}M$ Height of CoM of container above the base is $\bar{y}_C$ where $M\bar{y}_C = \frac{1}{3}M\times0+\frac{2}{3}M\times\frac{1}{4}$ so $\bar{y}_C = \frac{1}{6}$	**B1** **M1** **A1** **[3]**	**3.1b** **1.1** **1.1**	Accept surface density = 1 without comment. Or find mass of sides or… Correct method	CoM means centre of mass
7	(ii)		Height of CoM of container + content at height y above the base is z where $\left(M+\frac{y}{0.5}\times1.5M\right)z = M\times\frac{1}{6}+\frac{y}{0.5}\times1.5M\times\frac{y}{2}$ so $(1+3y)z = \frac{1}{6}+\frac{3}{2}y^2$ so $z = \frac{\frac{1}{6}(1+9y^2)}{(1+3y)} = \frac{1+9y^2}{6(1+3y)}$ AG	**M1** **A1** **A1** **A1** **[4]**	**3.4** **1.1** **2.1** **1.1**	Dealing with composite parts Masses and coms OK	
7	(iii)		This establishes a minimum for z at $y \approx 0.14$ so it is the height of filling that gives the lowest combined CoM. and … This would give the steepest angle at which the container could be inclined to the horizontal before tipping over.	**E1** **E1** **[2]**	**2.2a** **2.2b**	Or anything sensible, relevant and true, such as Given it does not slide, this is the steepest slope on which it could be placed without it tipping.	

Question	AO1	AO2	AO3(PS)	AO3(M)	Totals
1i	1	0	0	0	1
1ii	2	0	0	1	3
2	3	0	0	2	5
3i	2	0	0	0	2
3ii	2	1	0	1	4
3iii	1	0	1	0	2
4i	2	1	1	0	4
4ii	2	0	2	1	5
5i	3	0	0	0	3
5ii	1	0	0	1	2
5iii	0	0	0	1	1
5iv	3	0	0	2	5
6i	1	0	0	1	2
6ii	2	1	0	3	6
6iii	0	2	0	0	2
6iv	2	0	1	1	4
7i	2	0	1	0	3
7ii	2	1	0	1	4
7iii	0	2	0	0	2
Totals	31	8	6	15	60

Summary of Updates

Date	Version	Change
October 2019	2	Amendments to the front cover rubric instructions to candidates

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A Level Further Mathematics B (MEI)

Y431 Mechanics Minor

Printed Answer Booklet Version 2

Date – Morning/Afternoon

Time allowed: 1 hour 15 minutes

You must have:
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- Formulae Further Mathematics B (MEI)

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Last name									
Centre number						**Candidate number**				

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1 (i)	
1 (ii)	
2	
	(answer space continued on next page)

2	**(continued)**
3 (i)	
3 (ii)	

3 (iii)

4 (i)

4(ii)

5 (i)

5 (ii)

5 (iii)

5 (iv)

6 (i)

6 (ii)

(answer space continued on next page)

6 (ii)	**(continued)**
6 (iii)	
6 (iv)	

7 (i)	

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7 (ii)	
7 (iii)	

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