

Markscheme

May 2024

**Mathematics:
Applications and interpretation**

Higher level

Paper 3

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Instructions to Examiners

Abbreviations

- M** Marks awarded for attempting to use a correct **Method**.
- A** Marks awarded for an **Answer** or for **Accuracy**; often dependent on preceding **M** marks.
- R** Marks awarded for clear **Reasoning**.
- AG** Answer given in the question and so no marks are awarded.
- FT** Follow through. The practice of awarding marks, despite candidate errors in previous parts, for their correct methods/answers using incorrect results.

Using the markscheme

1 General

Award marks using the annotations as noted in the markscheme *eg M1, A2*.

2 Method and Answer/Accuracy marks

- Do **not** automatically award full marks for a correct answer; all working **must** be checked, and marks awarded according to the markscheme.
- It is generally not possible to award **M0** followed by **A1**, as **A** mark(s) depend on the preceding **M** mark(s), if any.
- Where **M** and **A** marks are noted on the same line, *e.g. M1A1*, this usually means **M1** for an **attempt** to use an appropriate method (*e.g.* substitution into a formula) and **A1** for using the **correct** values.
- Where there are two or more **A** marks on the same line, they may be awarded independently; so if the first value is incorrect, but the next two are correct, award **A0A1A1**.
- Where the markscheme specifies **A3**, **M2** *etc.*, do **not** split the marks, unless there is a note.
- The response to a “show that” question does not need to restate the **AG** line, unless a **Note** makes this explicit in the markscheme.
- Once a correct answer to a question or part question is seen, ignore further working even if this working is incorrect and/or suggests a misunderstanding of the question. This will encourage a uniform approach to marking, with less examiner discretion. Although some candidates may be advantaged for that specific question item, it is likely that these candidates will lose marks elsewhere too.
- An exception to the previous rule is when an incorrect answer from further working is used **in a subsequent part**. For example, when a correct exact value is followed by an incorrect decimal approximation in the first part and this approximation is then used in the second part. In this situation, award **FT** marks as appropriate but do not award the final **A1** in the first part.

Examples:

	Correct answer seen	Further working seen	Any FT issues?	Action
1.	$8\sqrt{2}$	5.65685... (incorrect decimal value)	No. Last part in question.	Award A1 for the final mark (condone the incorrect further working)
2.	$\frac{35}{72}$	0.468111... (incorrect decimal value)	Yes. Value is used in subsequent parts.	Award A0 for the final mark (and full FT is available in subsequent parts)

3 Implied marks

Implied marks appear in **brackets e.g. (M1)**, and can only be awarded if **correct** work is seen or implied by subsequent working/answer.

4 Follow through marks (only applied after an error is made)

Follow through (**FT**) marks are awarded where an incorrect answer from one **part** of a question is used correctly in **subsequent** part(s) (e.g. incorrect value from part (a) used in part (d) or incorrect value from part (c)(i) used in part (c)(ii)). Usually, to award **FT** marks, **there must be working present** and not just a final answer based on an incorrect answer to a previous part. However, if all the marks awarded in a subsequent part are for the answer or are implied, then **FT** marks should be awarded for *their* correct answer, even when working is not present.

For example: following an incorrect answer to part (a) that is used in subsequent parts, where the markscheme for the subsequent part is **(M1)A1**, it is possible to award full marks for *their* correct answer, **without working being seen**. For longer questions where all but the answer marks are implied this rule applies but may be overwritten by a **Note** in the Markscheme.

- Within a question part, once an **error** is made, no further **A** marks can be awarded for work which uses the error, but **M** marks may be awarded if appropriate.
- If the question becomes much simpler because of an error then use discretion to award fewer **FT** marks, by reflecting on what each mark is for and how that maps to the simplified version.
- If the error leads to an inappropriate value (e.g. probability greater than 1, $\sin \theta = 1.5$, non-integer value where integer required), do not award the mark(s) for the final answer(s).
- The markscheme may use the word “their” in a description, to indicate that candidates may be using an incorrect value.
- If the candidate’s answer to the initial question clearly contradicts information given in the question, it is not appropriate to award any **FT** marks in the subsequent parts. This includes when candidates fail to complete a “show that” question correctly, and then in subsequent parts use their incorrect answer rather than the given value.
- Exceptions to these **FT** rules will be explicitly noted on the markscheme.
- If a candidate makes an error in one part but gets the correct answer(s) to subsequent part(s), award marks as appropriate, unless the command term was “Hence”.

5 Mis-read

If a candidate incorrectly copies values or information from the question, this is a mis-read (**MR**). A candidate should be penalized only once for a particular misread. Use the **MR** stamp to indicate that this has been a misread and do not award the first mark, even if this is an **M** mark, but award all others as appropriate.

- If the question becomes much simpler because of the **MR**, then use discretion to award fewer marks.
- If the **MR** leads to an inappropriate value (e.g. probability greater than 1, $\sin \theta = 1.5$, non-integer value where integer required), do not award the mark(s) for the final answer(s).
- Miscopying of candidates' own work does **not** constitute a misread, it is an error.
- If a candidate uses a correct answer, to a "show that" question, to a higher degree of accuracy than given in the question, this is NOT a misread and full marks may be scored in the subsequent part.
- **MR** can only be applied when work is seen. For calculator questions with no working and incorrect answers, examiners should **not** infer that values were read incorrectly.

6 Alternative methods

Candidates will sometimes use methods other than those in the markscheme. Unless the question specifies a method, other correct methods should be marked in line with the markscheme. If the command term is 'Hence' and not 'Hence or otherwise' then alternative methods are not permitted unless covered by a note in the mark scheme.

- Alternative methods for complete questions are indicated by **METHOD 1**, **METHOD 2**, etc.
- Alternative solutions for parts of questions are indicated by **EITHER . . . OR**.

7 Alternative forms

Unless the question specifies otherwise, **accept** equivalent forms.

- As this is an international examination, accept all alternative forms of **notation** for example 1.9 and 1,9 or 1000 and 1,000 and 1.000.
- Do not accept final answers written using calculator notation. However, **M** marks and intermediate **A** marks can be scored, when presented using calculator notation, provided the evidence clearly reflects the demand of the mark.
- In the markscheme, equivalent **numerical** and **algebraic** forms will generally be written in brackets immediately following the answer.
- In the markscheme, some **equivalent** answers will generally appear in brackets. Not all equivalent notations/answers/methods will be presented in the markscheme and examiners are asked to apply appropriate discretion to judge if the candidate work is equivalent.

8 Format and accuracy of answers

If the level of accuracy is specified in the question, a mark will be linked to giving the answer to the required accuracy. If the level of accuracy is not stated in the question, the general rule applies to final answers: *unless otherwise stated in the question all numerical answers must be given exactly or correct to three significant figures*.

Where values are used in subsequent parts, the markscheme will generally use the exact value, however candidates may also use the correct answer to 3 sf in subsequent parts. The markscheme will often explicitly include the subsequent values that come “*from the use of 3 sf values*”.

Simplification of final answers: Candidates are advised to give final answers using good mathematical form. In general, for an **A** mark to be awarded, arithmetic should be completed, and

any values that lead to integers should be simplified; for example, $\sqrt{\frac{25}{4}}$ should be written as $\frac{5}{2}$.

An exception to this is simplifying fractions, where lowest form is not required (although the numerator and the denominator must be integers); for example, $\frac{10}{4}$ may be left in this form or written as $\frac{5}{2}$. However, $\frac{10}{5}$ should be written as 2, as it simplifies to an integer.

Algebraic expressions should be simplified by completing any operations such as addition and multiplication, e.g. $4e^{2x} \times e^{3x}$ should be simplified to $4e^{5x}$, and $4e^{2x} \times e^{3x} - e^{4x} \times e^x$ should be simplified to $3e^{5x}$. Unless specified in the question, expressions do not need to be factorized, nor do factorized expressions need to be expanded, so $x(x+1)$ and $x^2 + x$ are both acceptable.

Please note: intermediate **A** marks do NOT need to be simplified.

9 Calculators

A GDC is required for this paper, but if you see work that suggests a candidate has used any calculator not approved for IB DP examinations (eg CAS enabled devices), please follow the procedures for malpractice.

10. Presentation of candidate work

Crossed out work: If a candidate has drawn a line through work on their examination script, or in some other way crossed out their work, do not award any marks for that work unless an explicit note from the candidate indicates that they would like the work to be marked.

More than one solution: Where a candidate offers two or more different answers to the same question, an examiner should only mark the first response unless the candidate indicates otherwise. If the layout of the responses makes it difficult to judge, examiners should apply appropriate discretion to judge which is “first”.

1. (a) (i) $141 - 88$
 $= 53$ **A1**
AG
[1 mark]
- (ii) $(120 - 53 - 54 =) 13$ **A1**
[1 mark]
- (b) Restricting the size of the sample space to 150 ($54 + 96$) **(M1)**
 $= 0.36 \left(\frac{54}{150}, \frac{9}{25} \right)$ **A1**
[2 marks]
- (c) (i) H_0 : The development of cracks and the technique used are independent
 H_1 : The development of cracks and the technique used are not independent **A1**
- Note:** Condone equivalent statements such as ‘not dependent’ but do not accept “uncorrelated” or “not related” in place of “independent”.
- [1 mark]**
- (ii) $(p\text{-value} =) 0.0170$ (0.0169864...) **(M1)A1**
[2 marks]
- (iii) $0.0170 < 0.05$ **R1**
- hence there is sufficient evidence to reject the null hypothesis that the development of cracks and the technique used are independent. **A1**
- Note:** Do not award **R0A1**.
- [2 marks]**
- (d) $\frac{96 + 56}{240} \left(= \frac{152}{240} \right)$ **A1**
 $\frac{19}{30}$ **AG**
[1 mark]
- continued...

Question 1 continued.

(e) **EITHER**

the probability of each component developing cracks is independent of all the other components in the sample.

R1

Note: Do not accept the word “independence” on its own. Appropriate context must be seen.

OR

the development of cracks can be partitioned into two clear groups

R1

Note: Do not accept ‘the samples are representative of the population’.

[1 mark]

(f) 67 seen

(A1)

EITHER

attempt to find a probability ≤ 67 (condone strict inequality for **(M1)**)
 $(P(X \leq 67) =) 0.0549$ (0.0549093...)

(M1)
A1

Note: Award **(A1)(M1)A0** for an unsupported $p = 0.0372$, from use of strict inequality.

$0.0549 > 0.05$

R1

OR

attempt to find the critical region

(M1)

critical region is $X \leq 66$

A1

$66 < 67$ or ‘67 is not in the critical region’

R1

THEN

EITHER

do not reject the null hypothesis (as there is insufficient evidence that the new technique reduces the number of cracks).

A1

OR

do not accept the alternative hypothesis (as there is insufficient evidence that the new technique reduces the number of cracks).

A1

continued...

Question 1 continued.

Note: Do not award **R0A1**.
 Only follow through within part (f) for final **R1A1** if the **(M1)** has been awarded.
 Do not condone “accept the null hypothesis”.

[5 marks]

- (g) (i) the test for a proportion is directional and so considers whether the new treatment reduces the number of components developing cracks. **R1**

[1 mark]

(ii) **EITHER**

there could be variation in the value of p chosen for the null hypothesis /
 the value of p from the sample might not be a representative of
 the current technique

R1

OR

the test in (f) does not treat minor and major cracks as different attributes /
 the test in (c) does treat minor and major cracks as different attributes

R1

OR

the test in (f) has to make an additional assumption (for example ‘independence’) **R1**

[1 mark]

continued...

Question 1 continued.

(h) **EITHER**

let μ_1 be the mean length of time before cracks appear with the new technique
and μ_2 be the mean length with the current technique

$H_0: \mu_1 = \mu_2$

A1

$H_1: \mu_1 > \mu_2$

A1

Note: Award **A1A0** for correct hypotheses in which the two population means are not clearly defined (e.g. unsupported μ_1 and μ_2).

OR

H_0 : the POPULATION mean length of time before cracks appear is the same for both groups

A1

H_1 : the new technique increases the POPULATION mean length of time before cracks appear.

A1

OR

H_0 : the mean length of time before cracks appear in ALL components made with the new technique is the same as for ALL components made with the current technique.

A1

H_1 : the mean length of time before cracks appear in ALL components made with the new technique is greater than the mean for ALL components made with the current technique.

A1

Note: Award **A1A0** if “population” (or equivalent, such as “all”) is omitted from an otherwise correct answer.

THEN

recognition of the need to use of a two-sample test

(M1)

p -value = 0.0162 (0.0162328...)

A2

Note: If not pooled, answer is 0.0164368... award **(M1)A2**.

$0.0162 < 0.05$

R1

reject the null hypothesis (**OR** accept the alternative hypothesis)
(there is sufficient evidence to that the new technique increases the mean length of time before the cracks appear)

A1

Note: Do not award **R0A1**.

Follow through within part (h) for the last **R1A1**, provided their p -value is between 0 and 1 inclusive.

[7 marks]

continued...

Question 1 continued.

(i) **EITHER**

(though statistically significant) the new technique only seems to increase the time before cracks appear by 1 hour out of 250, so it is not a significant increase (i.e. the effect size is small) **R1**

OR

the minimum time (not mean time) before cracks appear should be considered given the context / An appropriate confidence interval should be considered, and not simply the mean. **R1**

Note: If a not significant p -value was seen in part (h), do not award **R1** for an answer of “the result is not significant” in part (i).

[1 mark]

[Total 26 marks]

- 2 (a) (i) (34, 4.1) A1A1
[2 marks]
- (ii) recognizing the sequence is arithmetic, with a common difference of 0.5 and 1.0 (M1)
 $(30 + (n - 1), 2.1 + (n - 1)0.5)$ A1A1
 $(= (29 + n, 1.6 + 0.5n))$ [3 marks]
- (b) (i) evidence of integration of the acceleration vector **OR** use of $v = u + at$ (M1)

$$\begin{pmatrix} \dot{x} \\ \dot{y} \end{pmatrix} = \begin{pmatrix} c_1 \\ -9.8t + c_2 \end{pmatrix}$$

$$\begin{pmatrix} \dot{x} \\ \dot{y} \end{pmatrix} = \begin{pmatrix} 29.4 \cos \theta \\ 29.4 \sin \theta - 9.8t \end{pmatrix}$$
 A1A1
- Note:** The first **A1** is for \dot{x} and the second is for \dot{y} .
- [3 marks]
- (ii) $\theta = 90^\circ$ (A1)
 $29.4 - 9.8t = 0$ M1A1
- Note:** Award **M1** for setting their \dot{y} to zero (may still include θ), **A1** for correct equation, leading to given result.
 If they substitute $t = 3$ award at most **(A1)M0A0**.
- maximum point when $t = \frac{29.4}{9.8}$
 $= 3$ (seconds) AG
[3 marks]
- (c) correct substitution OR use of correct graph (M1)
 maximum height is $29.4 \times 3 - 4.9 \times 3^2$
 $= 44.1$ (m) A1
[2 marks]

continued...

Question 2 continued.

(d) (i) $29.4 \sin \theta t - 4.9t^2 = 0$
 $t = 6 \sin \theta$ (or $t = 0$)

M1

A1

$$x = 29.4 \cos \theta \times 6 \sin \theta$$

$$= 176.4 \cos \theta \sin \theta$$

A1

AG

[3 marks]

- (ii) valid method to find maximum (e.g. sketch graph, find derivative)
 maximum value of x is 88.2 (m)

(M1)

A1

Note: Award **(M1)A0** for an unsupported answer of “45” or $\frac{\pi}{4}$ (0.785398...).

[2 marks]

(e) (i) ($c =$) 44.1

A1

Note: follow through from 2c

[1 mark]

- (ii) **EITHER**

$$\frac{dy}{dx} = 0 \Rightarrow 2a \times 0 + b = 0$$

(M1)

OR

$$\text{vertex is at } x = -\frac{b}{2a} = 0$$

(M1)

THEN

$$\Rightarrow b = 0$$

A1

[2 marks]

- (iii) point (88.2, 0) used

(A1)

$$0 = a \times 88.2^2 + 44.1$$

(M1)

$$\Rightarrow a = -\frac{44.1}{88.2^2}$$

$$= -\frac{5}{882} = -0.0056689...$$

A1

[3 marks]

Note: The method for finding the parameters might appear in a different part, for example use of (88.2, 0) might appear in part (ii), or the parts might not be clearly numbered. Accept any correct working wherever it is seen, and ascribe the marks to the correct part.

continued...

Question 2 continued.

- (f) use of their arithmetic sequence from (a)(ii) with $n = 40$ (M1)
 coordinates of seat $A_{40} = (69, 21.6)$ (A1)

EITHER

substitution of their 69 into their $y = -\frac{5}{882}x^2 + 44.1$ from part (e) (M1)

$$y = -\frac{5}{882} \times 69^2 + 44.1$$

$$= 17.1 \text{ (17.1102...)} \quad \text{A1}$$

$$21.6 > 17.1 \quad \text{R1}$$

OR

substitution of their $y=21.6$ into their $y = -\frac{5}{882}x^2 + 44.1$ from part (e) (M1)

$$21.6 = -\frac{5}{882}x^2 + 44.1$$

$$x = 63 \quad \text{A1}$$

$$69 > 63 \quad \text{R1}$$

Note: Accept equivalent justification in words, provided both values are seen.

Award **R1** for correct reasoning only if **M1** has been awarded and their seat coordinates lie outside their equation for the curve.

so the T-shirt cannot reach seat A_{40} AG
 [5 marks]

[Total 29 marks]