

Markscheme

November 2025

Mathematics: analysis and approaches

Higher level

Paper 2

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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”.

Section A

1. (a) (i) 1.25663...

$$\theta = 1.26 \left(= \frac{2\pi}{5} \right)$$

A1

(ii) $\frac{2\pi}{5} \times r = 12$ or equivalent

(A1)

9.54929...

$$r = 9.55 \text{ (cm)} \left(= \frac{60}{2\pi} = \frac{30}{\pi} \right)$$

A1

[3 marks]

(b) **METHOD 1**

attempt to find area of at least one shaded segment

(M1)

$$\frac{1}{2}r^2\theta - \frac{1}{2}r^2 \sin \theta \quad \text{OR} \quad \frac{1}{2}r^2(\theta - \sin \theta)$$

$$\frac{1}{2}(9.54929\dots)^2 \times 1.25663\dots - \frac{1}{2}(9.54929\dots)^2 \sin 1.25663\dots \quad \text{(or equivalent)}$$

(A1)

$$\text{shaded area} = 5 \times (57.2957\dots - 43.3629\dots) (= 5 \times 13.9328\dots)$$

69.6640...

$$= 69.7 \text{ (cm}^2\text{)}$$

A1

[3 marks]

METHOD 2

attempt to find area of one triangle

(M1)

$$\frac{1}{2} \times (9.54929\dots)^2 \times \sin 1.25663\dots$$

attempt to subtract five times their triangle area from their circle area

(M1)

$$\pi \times (9.54929\dots)^2 - 5 \times \frac{1}{2} \times (9.54929\dots)^2 \times \sin 1.25663\dots$$

69.6640...

$$= 69.7 \text{ (cm}^2\text{)}$$

A1

[3 marks]

Total [6 marks]

2. ${}^{10}P_3$ OR $10 \times 9 \times 8$ OR ${}^{10}C_3 \times 3!$ OR ${}^{10}C_7 \times 3!$ (= 720) (A1)

correct number of ways the remaining four members can be selected

7C_4 OR 35 (A1)

Note: The first two **A1** marks are to be awarded independently.

attempt to use the multiplication principle with their values (M1)

720×35

25200

A1

Total [4 marks]

3. (a) attempt to find mean of x -values **(M1)**
 $\bar{x} = 6.45$ **A1**
[2 marks]

- (b) (i) attempt to substitute their \bar{x} into regression equation **(M1)**
 $\bar{y} = 0.014375 + 2.1625 \times 6.45$
 $\bar{y} = 14.0$ (13.9625 exact) **A1**

- (ii) attempt to use formula for the mean **(M1)**

$$\sum_{i=1}^8 y_i = 8 \times 13.9625 \dots (\Rightarrow p + 93.2 = 111.7)$$
 $p = 18.5$ **A1**

Note: Accept $p = 18.8$ from the use of 3 sf in part (b)(i).

Some candidates are attempting part (b)(ii) before (b)(i), and substitute 8.9 into the given regression equation to find p . They then use their value of p to find \bar{y} . In this case, do not award any marks in this part. Allow **FT** from their incorrect p in part (c).

[4 marks]

- (c) 0.953958... **A1**
 $r = 0.954$ **[1 mark]**

Total [7 marks]

4. (a) (i) $a = -5$ **A1**

(ii) **EITHER**
 period = 32 **(A1)**

OR
 correct substitution of a point on the graph of g and their a **(A1)**
 $2 = -5 \cos(b \times 16) - 3$ **OR** $-3 = -5 \cos(b \times 8) - 3$

Note: Award **A0** if candidate substitutes $x = 0, y = -8$.

THEN
 0.196349...
 $b = 0.196 \left(= \frac{2\pi}{32} = \frac{\pi}{16} \right)$ **A1**

[3 marks]

(b) $k = 32$ **A1**
[1 mark]

(c) (i) **EITHER**
 attempt to use a horizontal translation **(M1)**
 $24 - q = 16$ **OR** $16 - q = 8$

OR
 substituting a point on the graph of g into $f(x) = p \sin(b(x - q)) - 3$ **(M1)**
 $-8 = p \sin\left(\frac{\pi}{16}(0 - q)\right) - 3$ **OR** $-3 = p \sin\left(\frac{\pi}{16}(8 - q)\right) - 3$ **OR** $2 = p \sin\left(\frac{\pi}{16}(16 - q)\right) - 3$

THEN
 $q = 8$ **A1**

(ii) $p = 5$ **A1**
[3 marks]

Total [7 marks]

5. (a) (i) 27.5 **A1**
- (ii) 6.26374...
6.26 **A1**
- [2 marks]**
- (b) 75th percentile = 31.7248... **(A1)**
25th percentile = 23.2751... **(A1)**
8.44965...
IQR = 8.4 **A1**
- [3 marks]**
- Total [5 marks]**

6. (a) $u_1 = \frac{53}{1000}$

$$r = \frac{1}{100}$$

$$\frac{\frac{53}{1000}}{1 - \frac{1}{100}}$$

(M1)(A1)

$$S_\infty = \frac{53}{990} (= 0.0\overline{53}) (= 0.0\dot{5}3)$$

A1

Note: Award **(M1)** for an attempt to use the sum to infinity formula.

[3 marks]

(b) $0.2 + \frac{53}{990}$

M1

$$\frac{251}{990}$$

A1

[2 marks]

Total [5 marks]

7. (a) recognition of binomial distribution **(M1)**

$$\binom{10}{2} (p)^2 (1-p)^8, B(10, p)$$

Note: The **(M1)** may be awarded for just stating 'binomial', parameters are not required, accept incorrect parameters. Do not award the **(M1)** if candidates only state np . Accept the use of calculator notation, such as binompdf.

attempt to consider both machines using $p = 0.1$ AND $p = 0.05$ **(M1)**

$0.5 \times (0.193710\dots) + 0.5 \times (0.0746347\dots)$ **(A1)**

0.134172...

0.134 **A1**

[4 marks]

continued...

Question 7 continued.

(b) recognition of conditional probability **(M1)**

$$P(A|2 \text{ defective}) \text{ OR } \frac{P(A \cap 2 \text{ defective})}{P(2 \text{ defective})}$$

Note: recognition must be shown in context, either in words or symbols, not just $P(A|B)$.

$$\frac{0.0968\dots}{0.134\dots} \quad \text{(A1)}$$

$$0.72187\dots$$

$$0.722 \quad \text{A1}$$

Note: Accept 0.723 or 0.724 from using 3 sf values from part (a).

[3 marks]

Total [7 marks]

8. attempt to write at least one function in terms of y (M1)

$x^2 = y^2 + 16$ OR $x^2 = 25y - 50$ (or equivalent) (A1)

one correct expression for volume

$\pi \int_0^3 y^2 + 16 \, dy$ OR $\pi \int_2^3 25y - 50 \, dy$ (A1)

attempt to subtract two volumes with limits for y (M1)

$\pi \int_0^3 (y^2 + 16) \, dy - \pi \int_2^3 (25y - 50) \, dy$ (A1)

Note: Award at most **M1A1A1M0A0A0** for a candidate who writes $\pi \int_0^3 (y^2 + 16) - (25y - 50) \, dy$.

179.0707... – 39.269908

139.8008...

$V = 140$ (cubic units) $\left(= \frac{89}{2} \pi \right)$ A1

Note: Ignore absence of π throughout if their final answer is correct. Otherwise award at most **M1A1A1M1A0A0**.

Total [6 marks]

9. attempt to find a relationship between x and θ using cosine rule (M1)

$$x^2 = 15^2 + 20^2 - 2(15)(20)\cos\theta, \quad x = \sqrt{625 - 600\cos\theta}$$

attempt to relate the rates (seen anywhere) (M1)

$$\frac{dx}{dt} = \frac{dx}{d\theta} \times \frac{d\theta}{dt}$$

$$\frac{dx}{d\theta} = \frac{1}{2}(625 - 600\cos\theta)^{-\frac{1}{2}} \times 600\sin\theta \quad \text{(A1)}$$

OR

Attempt to differentiate implicitly with respect to t (M1)

$$2x \frac{dx}{dt} = 600\sin\theta \cdot \frac{d\theta}{dt} \quad \text{OR} \quad \frac{dx}{dt} = \frac{1}{2}(625 - 600\cos\theta)^{-\frac{1}{2}} \times 600\sin\theta \cdot \frac{d\theta}{dt} \quad \text{(A1)}$$

OR

Using GDC to find $\frac{dx}{d\theta}$ (M1)

$$\frac{dx}{d\theta} = 13.835110... \quad \text{(A1)}$$

attempt to find $\cos\theta$ or $\sin\theta$ or θ when area is 140 (M1)

$$\sin\theta = \frac{14}{15} \quad \text{or} \quad \cos\theta = \frac{\sqrt{29}}{15} \quad \text{or} \quad \theta = 1.20358... \quad \text{(seen anywhere)} \quad \text{(A1)}$$

(accept 68.9605...°)

$$\frac{1}{2} \left(625 - 600 \left(\frac{\sqrt{29}}{15} \right) \right)^{\left(\frac{1}{2} \right)} \left(600 \times \frac{280}{300} \right) \times \left(-\frac{\pi}{60} \right) \quad \text{(A1)}$$

$$-0.724402...$$

$$\frac{dx}{dt} = -0.724 \quad (\text{cm min}^{-1}) \quad \text{A1}$$

Note: Award (M1)(M1)(A1)(M1)(A1)(A1)A0 for $\frac{dx}{dt} = 0.724 \text{ (cm min}^{-1}\text{)}$.

Total [7 marks]

Section B

10. (a) (i) speed of airplane = 60 (ms⁻¹) **A1**
- (ii) speed of car = 0 (ms⁻¹) **A1**
- [2 marks]**

- (b) (i) recognizing $v_{\text{air}} = v_{\text{car}}$ when speeds are the same **(M1)**
 6.35564...
 $t = 6.36$ (s) **A1**

- (ii) 31.7782...
 speed = 31.8 (ms⁻¹) **A1**
- [3 marks]**

- (c) let $s_{\text{air}}(t)$ be the displacement of the airplane and $s_{\text{car}}(t)$ be the displacement of the car at time t
- recognizing to integrate either velocity function **(M1)**
- $\int 60e^{-0.1t} dt, \int 5t dt$
- correct integration **(A1)(A1)**
- $-600e^{-0.1t}, \frac{5}{2}t^2 (+C)$ (award **A1** for each term)
- recognize to subtract displacements (seen anywhere) **(M1)**

EITHER

substituting initial condition into their $d(t)$ **(M1)**

$100 = -600e^{-1(0)} - \frac{5}{2} \times 0^2 + C$ OR $-100 = 600e^{-1(0)} + \frac{5}{2} \times 0^2 + C$ (or equivalent)

OR

substituting initial condition into their $s_{\text{air}}(t)$ **(M1)**

$(s_{\text{car}}(0) = 0 \Rightarrow) 100 = -600e^{-1(0)} + C$

continued...

Question 10 continued.

THEN

$$C = 700 \text{ (or } -700) \quad \text{(A1)}$$

$$d(t) = -600e^{-0.1t} - \frac{5}{2}t^2 + 700 \text{ (accept } d(t) = \left| 600e^{-0.1t} + \frac{5}{2}t^2 - 700 \right|) \quad \text{A1}$$

[7 marks]

(d) recognizing to solve their $d(t) = 0$ (M1)

15.0586...

$$t = 15.1 \text{ (s)} \quad \text{A1}$$

[2 marks]

(e) attempt to find the distance travelled by the car (M1)

$$\int_0^{15.0586} 5t \, dt, \frac{5}{2}(15.0586)^2 \quad \text{(A1)}$$

566.904...

$$567 \text{ (m) (accept } 570 \text{ (m) from 3 sf answer in (d))} \quad \text{A1}$$

Note: Award **(M1)(A1FT)A0**, where appropriate, if the candidate has an incorrect $d(t)$ and/or incorrect value of t which leads to their distance travelled by the car to be less than 100 (m).

For example, where the candidate finds $d(t) = 600e^{-0.1t} - \frac{5}{2}t^2 - 500$ in part (c), award

(M1)(A1FT)A0 to 7.08, or 7.06 from using 3 sf value.

[3 marks]

Total [17 marks]

11. (a) **METHOD 1**

attempt to use integration by parts

M1

$$u = \arccos x, \frac{dv}{dx} = 1, \frac{du}{dx} = -\frac{1}{\sqrt{1-x^2}}, v = x$$

$$x \arccos x + \int \frac{x}{\sqrt{1-x^2}} dx$$

(A1)

attempt to integrate $\frac{x}{\sqrt{1-x^2}}$ by substitution or inspection

(M1)

$$-\frac{1}{2} \times 2u^{\frac{1}{2}}, -\sqrt{1-x^2}$$

$$x \arccos x - \sqrt{1-x^2} + C$$

A1

Note: Do not award the final **A1** if $+C$ is missing.

METHOD 2

attempt to use substitution

(M1)

$$\cos \theta = x$$

$$\theta = \arccos x$$

$$\frac{d\theta}{dx} = -\frac{1}{\sqrt{1-x^2}}, \sin \theta = \sqrt{1-x^2}$$

$$-\int \theta \sin \theta d\theta$$

(A1)

attempt to use integration by parts

M1

$$u = \theta, \frac{du}{d\theta} = 1, \frac{dv}{d\theta} = \sin \theta, v = -\cos \theta$$

$$\theta \cos \theta - \sin \theta$$

$$x \arccos x - \sqrt{1-x^2} + C$$

A1

Note: Do not award the final **A1** if $+C$ is missing.

[4 marks]

continued...

Question 11 continued.

(b) (i) $\int_0^k 3x \arccos(x^2) dx = 1$ (seen anywhere) **M1**

attempt to integrate **(M1)**

$$\frac{3}{2} \int \arccos u \, du$$

$$\frac{3}{2} \left[u \arccos u - \sqrt{1-u^2} \right]_0^{k^2} (=1) , \quad \frac{3}{2} \left[x^2 \arccos x^2 - \sqrt{1-x^4} \right]_0^k (=1) \quad \textbf{A1}$$

Note: Condone incorrect or absent limits up to this point.

$$\frac{3}{2} \left(k^2 \arccos(k^2) - \sqrt{1-k^4} - (0-1) \right) = 1 \quad \textbf{OR} \quad k^2 \arccos(k^2) - \sqrt{1-k^4} - (0-1) = \frac{2}{3} \quad \textbf{A1}$$

$$k^2 \arccos(k^2) - \sqrt{1-k^4} + \frac{1}{3} = 0 \quad \textbf{AG}$$

(ii) $k = 0.713250$ **A2**

[6 marks]

continued...

Question 11 continued.

- (c) (i) attempt to substitute their value of k into the formula for $E(X)$ **(M1)**

$$\int_0^k 3x^2 \arccos(x^2) dx$$

0.456309...

$$E(X) = 0.456$$

A1

- (ii) **METHOD 1**

$$E(X^2) = 0.237 \quad (0.237198)$$

(A1)

attempt to use formula for variance **(M1)**

$$E(X^2) - [E(X)]^2$$

0.0289805...

$$\text{Var}(X) = 0.0290$$

A1

[5 marks]

METHOD 2

$$\text{Var}(X) = \int_0^{0.713250} (x - 0.456309\dots)^2 f(x) dx$$

(M1)(A1)

$$\text{Var}(X) = 0.0290$$

(A1)

[5 marks]

continued...

Question 11 continued.

(d) $\sigma = 0.170236\dots$ (seen anywhere)

(A1)

$$\int_{0.28607\dots}^{0.626549\dots} f(x) dx$$

(A1)

0.620012...

0.620

A1

[3 marks]

Total [18 marks]

12. (a) attempt to set up a system of equations with at least one correct equation **M1**

$$5 + s = -1 + 2t, 4 - s = 7 + t, 2 + s = -5 + 3t$$

$$t = 1 \text{ OR } s = -4 \quad \text{A1}$$

$$\begin{pmatrix} 5 \\ 4 \\ 2 \end{pmatrix} - 4 \begin{pmatrix} 1 \\ -1 \\ 1 \end{pmatrix} \text{ OR } \begin{pmatrix} -1 \\ 7 \\ -5 \end{pmatrix} + \begin{pmatrix} 2 \\ 1 \\ 3 \end{pmatrix} \quad \text{A1}$$

point of intersection $\begin{pmatrix} 1 \\ 8 \\ -2 \end{pmatrix}$ **AG**

[3 marks]

(b) (i) $r = \begin{pmatrix} 5 \\ 4 \\ 2 \end{pmatrix} + \lambda \begin{pmatrix} 1 \\ -1 \\ 1 \end{pmatrix} + \mu \begin{pmatrix} 2 \\ 1 \\ 3 \end{pmatrix}$ OR $r = \begin{pmatrix} 1 \\ 8 \\ -2 \end{pmatrix} + \lambda \begin{pmatrix} 1 \\ -1 \\ 1 \end{pmatrix} + \mu \begin{pmatrix} 2 \\ 1 \\ 3 \end{pmatrix}$

OR $r = \begin{pmatrix} -1 \\ 7 \\ -5 \end{pmatrix} + \lambda \begin{pmatrix} 1 \\ -1 \\ 1 \end{pmatrix} + \mu \begin{pmatrix} 2 \\ 1 \\ 3 \end{pmatrix}$ **A1**

Note: $r =$ must be seen.

continued...

Question 12 continued.

(ii) **METHOD 1**

attempt to write equation of the plane in the form $r \cdot n = a \cdot n$

M1

$$r \cdot \begin{pmatrix} -4 \\ -1 \\ 3 \end{pmatrix} = \begin{pmatrix} 5 \\ 4 \\ 2 \end{pmatrix} \cdot \begin{pmatrix} -4 \\ -1 \\ 3 \end{pmatrix} (= -18)$$

$$-4x - y + 3z = -18$$

A1

$$4x + y - 3z = 18$$

AG

Note: Students may use $\begin{pmatrix} 1 \\ 8 \\ -2 \end{pmatrix}$ or $\begin{pmatrix} -1 \\ 7 \\ -5 \end{pmatrix}$ in place of $\begin{pmatrix} 5 \\ 4 \\ 2 \end{pmatrix}$ or other points from lines L_1 or L_2 .

METHOD 2

recognizing that $b \times c$ is normal to the plane.

M1

$$-4x - y + 3z = k$$

correct substitution of one of the points to find k

A1

$$k = 18$$

$$4x + y - 3z = 18$$

AG

[3 marks]

(c) (i) $q = 18$

A1

(ii) $r = -6$

A1

[2 marks]

continued...

Question 12 continued.

(d) $\vec{PQ} = \begin{pmatrix} -4.5 \\ 18 \\ 0 \end{pmatrix}$ **OR** $\vec{PR} = \begin{pmatrix} -4.5 \\ 0 \\ -6 \end{pmatrix}$ seen anywhere **(A1)**

attempt to find a vector product **(M1)**

$$\vec{PQ} \times \vec{PR}$$

$$\vec{PQ} \times \vec{PR} = \begin{pmatrix} -108 \\ -27 \\ 81 \end{pmatrix} \quad \text{A1}$$

attempt to find magnitude of their cross product **(M1)**

$$\sqrt{(-108)^2 + (-27)^2 + 81^2}, \sqrt{18954}, 137.673$$

$$\text{Area} = 68.8 \quad \left(= \frac{1}{2} \sqrt{18954} \right) \left(= \frac{27\sqrt{26}}{2} \right) \quad \text{A1}$$

[5 marks]

(e) $r_3 = \begin{pmatrix} 1 \\ 8 \\ -2 \end{pmatrix} + \gamma \begin{pmatrix} -4 \\ -1 \\ 3 \end{pmatrix}$ **A2**

Note: Accept any multiple of the direction vector.

Award **A1A0** if $r_3 =$ is not seen.

Accept $r =$

[2 marks]

continued...

Question 12 continued.

- (f) attempt to set their r_3 equal to the vector $\begin{pmatrix} -11 \\ 5 \\ 7 \end{pmatrix}$ **(M1)**

$$-11 = 1 - 4\gamma, \quad 5 = 8 - \gamma, \quad 7 = -2 + 3\gamma$$

$$\gamma = 3$$

A1

Note: Accept any correct value of γ for their direction vector. For example accept $\gamma = -3$ for a

direction vector of $\begin{pmatrix} 4 \\ 1 \\ -3 \end{pmatrix}$.

[2 marks]

- (g) attempt to subtract appropriate vectors (in any order) OR consider $3n$ **(M1)**

$$\begin{pmatrix} -11 \\ 5 \\ 7 \end{pmatrix} - \begin{pmatrix} 1 \\ 8 \\ -2 \end{pmatrix}, \quad \begin{pmatrix} -12 \\ -3 \\ 9 \end{pmatrix}$$

(height of pyramid =) $\sqrt{(-12)^2 + (-3)^2 + 9^2}, \quad \sqrt{234}, \quad 3\sqrt{26}, \quad 15.2970\dots$ **A1**

attempt to substitute their values into the formula for the volume of a pyramid **(M1)**

$$\frac{1}{3} \times \frac{1}{2} \sqrt{18954} \times \sqrt{234}$$

$$V = 351 \text{ (exact) (cubic units)}$$

A1

[4 marks]

Total [21 marks]