Mathematics: analysis and approaches

Higher level and Standard level

Specimen papers 1, 2 and 3

First examinations in 2021
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Mathematics: analysis and approaches
Higher level
Paper 1

Specimen paper

Candidate session number

2 hours

Instructions to candidates

• Write your session number in the boxes above.
• Do not open this examination paper until instructed to do so.
• You are not permitted access to any calculator for this paper.
• Section A: answer all questions. Answers must be written within the answer boxes provided.
• Section B: answer all questions in the answer booklet provided. Fill in your session number on the front of the answer booklet, and attach it to this examination paper and your cover sheet using the tag provided.
• Unless otherwise stated in the question, all numerical answers should be given exactly or correct to three significant figures.
• A clean copy of the mathematics: analysis and approaches formula booklet is required for this paper.
• The maximum mark for this examination paper is [110 marks].
Full marks are not necessarily awarded for a correct answer with no working. Answers must be supported by working and/or explanations. Where an answer is incorrect, some marks may be given for a correct method, provided this is shown by written working. You are therefore advised to show all working.

Section A

Answer all questions. Answers must be written within the answer boxes provided. Working may be continued below the lines, if necessary.

1. [Maximum mark: 5]

Let $A$ and $B$ be events such that $P(A) = 0.5$, $P(B) = 0.4$ and $P(A \cup B) = 0.6$.

Find $P(A \mid B)$.

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2. [Maximum mark: 5]

(a) Show that \((2n - 1)^2 + (2n + 1)^2 = 8n^2 + 2\), where \(n \in \mathbb{Z}\). [2]

(b) Hence, or otherwise, prove that the sum of the squares of any two consecutive odd integers is even. [3]
3. [Maximum mark: 5]

Let \( f'(x) = \frac{8x}{\sqrt{2x^2 + 1}} \). Given that \( f(0) = 5 \), find \( f(x) \).
4. [Maximum mark: 5]

The following diagram shows the graph of $y = f(x)$. The graph has a horizontal asymptote at $y = -1$. The graph crosses the $x$-axis at $x = -1$ and $x = 1$, and the $y$-axis at $y = 2$.

On the following set of axes, sketch the graph of $y = [f(x)]^2 + 1$, clearly showing any asymptotes with their equations and the coordinates of any local maxima or minima.
5. [Maximum mark: 5]

The functions $f$ and $g$ are defined such that $f(x) = \frac{x + 3}{4}$ and $g(x) = 8x + 5$.

(a) Show that $(g \circ f)(x) = 2x + 11$. [2]

(b) Given that $(g \circ f)^{-1}(a) = 4$, find the value of $a$. [3]
6. [Maximum mark: 8]

(a) Show that \( \log_3 (\cos 2x + 2) = \log_3 \sqrt{\cos 2x + 2} \).  

(b) Hence or otherwise solve \( \log_3 (2 \sin x) = \log_3 (\cos 2x + 2) \) for \( 0 < x < \frac{\pi}{2} \).
7. [Maximum mark: 7]

A continuous random variable $X$ has the probability density function $f$ given by

$$f(x) = \begin{cases} \frac{\pi x}{36} \sin\left(\frac{\pi x}{6}\right), & 0 \leq x \leq 6 \\ 0, & \text{otherwise} \end{cases}$$

Find $P(0 \leq X \leq 3)$. 

...
8. [Maximum mark: 7]

The plane \( \Pi \) has the Cartesian equation \( 2x + y + 2z = 3 \).

The line \( L \) has the vector equation \( \mathbf{r} = \begin{pmatrix} 3 \\ -5 \\ 1 \end{pmatrix} + \mu \begin{pmatrix} 1 \\ -2 \\ p \end{pmatrix}, \mu, p \in \mathbb{R} \). The acute angle between the line \( L \) and the plane \( \Pi \) is 30°.

Find the possible values of \( p \).
9. [Maximum mark: 8]

The function $f$ is defined by $f(x) = e^{2x} - 6e^x + 5$, $x \in \mathbb{R}$, $x \leq a$. The graph of $y = f(x)$ is shown in the following diagram.

(a) Find the largest value of $a$ such that $f$ has an inverse function. [3]

(b) For this value of $a$, find an expression for $f^{-1}(x)$, stating its domain. [5]

(This question continues on the following page)
Section B

Answer all questions in the answer booklet provided. Please start each question on a new page.

10. [Maximum mark: 16]

Let \( f(x) = \frac{\ln 5x}{kx} \) where \( x > 0 \), \( k \in \mathbb{R}^+ \).

(a) Show that \( f'(x) = \frac{1 - \ln 5x}{kx^2} \). [3]

The graph of \( f \) has exactly one maximum point \( P \).

(b) Find the \( x \)-coordinate of \( P \). [3]

The second derivative of \( f \) is given by \( f''(x) = \frac{2 \ln 5x - 3}{kx^3} \). The graph of \( f \) has exactly one point of inflexion \( Q \).

(c) Show that the \( x \)-coordinate of \( Q \) is \( \frac{1}{5} \sqrt{e^2} \). [3]

The region \( R \) is enclosed by the graph of \( f \), the \( x \)-axis, and the vertical lines through the maximum point \( P \) and the point of inflexion \( Q \).

(d) Given that the area of \( R \) is 3, find the value of \( k \). [7]
Do not write solutions on this page.

11. [Maximum mark: 18]

   (a) Express \(-3 + \sqrt{3}i\) in the form \(re^{i\theta}\), where \(r > 0\) and \(-\pi < \theta \leq \pi\). \[5\]

   Let the roots of the equation \(z^3 = -3 + \sqrt{3}i\) be \(u\), \(v\) and \(w\).

   (b) Find \(u\), \(v\) and \(w\) expressing your answers in the form \(re^{i\theta}\), where \(r > 0\) and \(-\pi < \theta \leq \pi\). \[5\]

   On an Argand diagram, \(u\), \(v\) and \(w\) are represented by the points \(U\), \(V\) and \(W\) respectively.

   (c) Find the area of triangle \(UVW\). \[4\]

   (d) By considering the sum of the roots \(u\), \(v\) and \(w\), show that

\[
\cos \frac{5\pi}{18} + \cos \frac{7\pi}{18} + \cos \frac{17\pi}{18} = 0. \[4\]

12. [Maximum mark: 21]

   The function \(f\) is defined by \(f(x) = e^{\sin x}\).

   (a) Find the first two derivatives of \(f(x)\) and hence find the Maclaurin series for \(f(x)\) up to and including the \(x^3\) term. \[8\]

   (b) Show that the coefficient of \(x^3\) in the Maclaurin series for \(f(x)\) is zero. \[4\]

   (c) Using the Maclaurin series for \(\arctan x\) and \(e^{3x} - 1\), find the Maclaurin series for \(\arctan(e^{3x} - 1)\) up to and including the \(x^3\) term. \[6\]

   (d) Hence, or otherwise, find \(\lim_{x \to 0} \frac{f(x) - 1}{\arctan(e^{3x} - 1)}\). \[3\]
Please do not write on this page.

Answers written on this page will not be marked.
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Answers written on this page will not be marked.
Markscheme

Specimen paper

Mathematics: analysis and approaches

Higher level

Paper 1
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.

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 M2, N3, etc., do not split the marks, unless there is a note.

- Once a correct answer to a question or part-question is seen, ignore further correct working. However, if further working indicates a lack of mathematical understanding do not award the final A1. An exception to this may be in numerical answers, where a correct exact value is followed by an incorrect decimal. However, if the incorrect decimal is carried through to a subsequent part, and correct FT working shown, award FT marks as appropriate but do not award the final A1 in that part.

Examples

<table>
<thead>
<tr>
<th>Correct answer seen</th>
<th>Further working seen</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. $8\sqrt{2}$</td>
<td>5.65685... (incorrect decimal value)</td>
<td>Award the final A1 (ignore the further working)</td>
</tr>
<tr>
<td>2. $\frac{1}{4}\sin 4x$</td>
<td>$\sin x$</td>
<td>Do not award the final A1</td>
</tr>
<tr>
<td>3. $\log a - \log b$</td>
<td>$\log (a - b)$</td>
<td>Do not award the final A1</td>
</tr>
</tbody>
</table>
3 Implied marks

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

- Normally the correct work is seen or implied in the next line.
- Marks without brackets can only be awarded for work that is seen.

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) or subpart(s). 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 the only marks awarded in a subpart are for the answer (i.e. there is no working expected), then FT marks should be awarded if appropriate.

- 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.
- If the error leads to an inappropriate value (e.g. probability greater than 1, use of \( r > 1 \) for the sum of an infinite GP, \( \sin \theta = 1.5 \), non integer value where integer required), do not award the mark(s) for the final answer(s).
- The mark scheme may use the word “their” in a description, to indicate that candidates may be using an incorrect value.
- Exceptions to this rule will be explicitly noted on the mark scheme.
- 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 question says hence. It is often possible to use a different approach in subsequent parts that does not depend on the answer to previous parts.

5 Mis-read

If a candidate incorrectly copies information from the question, this is a mis-read (MR). Apply a MR penalty of 1 mark to that question.

- 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.
- The MR penalty 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.

- Alternative methods for complete questions are indicated by METHOD 1, METHOD 2, etc.
- Alternative solutions for part-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.
- In the markscheme, equivalent numerical and algebraic forms will generally be written in brackets immediately following the answer.
- In the markscheme, simplified answers, (which candidates often do not write in examinations), will generally appear in brackets. Marks should be awarded for either the form preceding the bracket or the form in brackets (if it is seen).

8 **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. There are two types of accuracy errors, and the final answer mark should not be awarded if these errors occur.

- **Rounding errors**: only applies to final answers not to intermediate steps.
- **Level of accuracy**: when this is not specified 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.

9 **Calculators**

No calculator is allowed. The use of any calculator on paper 1 is malpractice, and will result in no grade awarded. If you see work that suggests a candidate has used any calculator, please follow the procedures for malpractice. Examples: finding an angle, given a trig ratio of 0.4235.
Section A

1. attempt to substitute into \( P(A \cup B) = P(A) + P(B) - P(A \cap B) \) \((M1)\)

Note: Accept use of Venn diagram or other valid method.

0.6 = 0.5 + 0.4 - P(A \cap B) \((A1)\)

\( P(A \cap B) = 0.3 \) (seen anywhere) \( A1 \)

attempt to substitute into \( P(A | B) = \frac{P(A \cap B)}{P(B)} \) \((M1)\)

= \frac{0.3}{0.4}

\( P(A | B) = 0.75 \left( \frac{3}{4} \right) \) \( A1 \)

Total [5 marks]

2. (a) attempting to expand the LHS \((M1)\)

\( \text{LHS} = \left( 4n^2 - 4n + 1 \right) + \left( 4n^2 + 4n + 1 \right) \) \( A1 \)

= \( 8n^2 + 2 (= \text{RHS}) \) \( AG \)

[2 marks]

(b) \textbf{METHOD 1}

recognition that \( 2n - 1 \) and \( 2n + 1 \) represent two consecutive odd integers (for \( n \in \mathbb{Z} \)) \( R1 \)

\( 8n^2 + 2 = 2 \left( 4n^2 + 1 \right) \) \( A1 \)

valid reason \( eg \) divisible by 2 (2 is a factor) \( R1 \)

so the sum of the squares of any two consecutive odd integers is even \( AG \)

[3 marks]

\textbf{METHOD 2}

recognition, \( eg \) that \( n \) and \( n + 2 \) represent two consecutive odd integers (for \( n \in \mathbb{Z} \)) \( R1 \)

\( n^2 + (n + 2)^2 = 2 \left( n^2 + 2n + 2 \right) \) \( A1 \)

valid reason \( eg \) divisible by 2 (2 is a factor) \( R1 \)

so the sum of the squares of any two consecutive odd integers is even \( AG \)

[3 marks]

Total [5 marks]
3. attempt to integrate

\[ u = 2x^2 + 1 \Rightarrow \frac{du}{dx} = 4x \]

\[ \int \frac{8x}{\sqrt{2x^2 + 1}} \, dx = \int \frac{2}{\sqrt{u}} \, du \]  \hspace{1cm} (A1)

**EITHER**

\[ = 4\sqrt{u} (+C) \] \hspace{1cm} A1

**OR**

\[ = 4\sqrt{2x^2 + 1} (+C) \] \hspace{1cm} A1

**THEN**

correct substitution into their integrated function (must have \( C \))  \hspace{1cm} (M1)

\[ 5 = 4 + C \Rightarrow C = 1 \]

\[ f(x) = 4\sqrt{2x^2 + 1} + 1 \] \hspace{1cm} A1

Total [5 marks]
4. no $y$ values below 1
horizontal asymptote at $y = 2$ with curve approaching from below as $x \to \pm \infty$
(±1, 1) local minima
(0, 5) local maximum
smooth curve and smooth stationary points

5. (a) attempt to form composition
    correct substitution $g\left(\frac{x+3}{4}\right) = 8\left(\frac{x+3}{4}\right) + 5$
    $(g \circ f)(x) = 2x + 11$

(b) attempt to substitute 4 (seen anywhere)
correct equation $a = 2 \times 4 + 11$
    $a = 19$

Total [5 marks]
6. (a) attempting to use the change of base rule
\[ \log_3(\cos 2x + 2) = \frac{\log_3(\cos 2x + 2)}{\log_3 9} \]
\[ = \frac{1}{2} \log_3(\cos 2x + 2) \]
\[ = \log_3 \sqrt{\cos 2x + 2} \]
\[ \text{[3 marks]} \]

(b) \[ \log_3(2 \sin x) = \log_3 \sqrt{\cos 2x + 2} \]
\[ 2 \sin x = \sqrt{\cos 2x + 2} \]
\[ 4 \sin^2 x = \cos 2x + 2 \quad \text{(or equivalent)} \]
use of \( \cos 2x = 1 - 2 \sin^2 x \)
\[ 6 \sin^2 x = 3 \]
\[ \sin x = (\pm) \frac{1}{\sqrt{2}} \]
\[ x = \frac{\pi}{4} \]
\[ \text{[5 marks]} \]

Note: Award \textit{A0} if solutions other than \( x = \frac{\pi}{4} \) are included.

\[ \text{Total [8 marks]} \]
7. attempting integration by parts, eg
\[ u = \frac{\pi x}{36}, \quad du = \frac{\pi}{36} \, dx, \quad dv = \sin\left(\frac{\pi x}{6}\right) \, dx, \quad v = -\frac{6}{\pi} \cos\left(\frac{\pi x}{6}\right) \]  

\[ P\left(0 \leq X \leq 3\right) = \frac{\pi}{36} \left[-\frac{6x}{\pi} \cos\left(\frac{\pi x}{6}\right)\right]_0^3 + \frac{6}{\pi} \int_0^3 \cos\left(\frac{\pi x}{6}\right) \, dx \]  

(or equivalent)  

\[ M1 \]

Note: Award \( A1 \) for a correct \( uv \) and \( A1 \) for a correct \( \int v \, du \).

\[ A1A1 \]

attempting to substitute limits
\[ \frac{\pi}{36} \left[-\frac{6x}{\pi} \cos\left(\frac{\pi x}{6}\right)\right]_0^3 = 0 \]  

(or equivalent)  

\[ A1 \]

\[ \frac{1}{\pi} \]  

Total [7 marks]

8. recognition that the angle between the normal and the line is 60° (seen anywhere)  

\[ R1 \]

attempt to use the formula for the scalar product
\[ \cos 60° = \frac{\left(\begin{array}{cc} 2 & 1 \\ 1 & -2 \end{array}\right) \cdot \left(\begin{array}{c} p \\ 2 \end{array}\right)}{\sqrt{9 \times 1 + 4 + p^2}} \]  

\[ A1 \]

\[ \frac{1}{2} = \frac{2p}{3\sqrt{5 + p^2}} \]  

\[ A1 \]

\[ 3\sqrt{5 + p^2} = 4|p| \]  

attempt to square both sides
\[ 9(5 + p^2) = 16p^2 \Rightarrow 7p^2 = 45 \]  

\[ p = \pm 3\sqrt{\frac{5}{7}} \]  

(or equivalent)  

\[ A1A1 \]

Total [7 marks]
9. (a) attempt to differentiate and set equal to zero
   \[ f'(x) = 2e^{2x} - 6e^x = 2e^x(e^x - 3) = 0 \]
   minimum at \( x = \ln 3 \)
   \( a = \ln 3 \)

   \[ \text{[3 marks]} \]

(b) **Note:** Interchanging \( x \) and \( y \) can be done at any stage.

\[ y = (e^x - 3)^2 - 4 \]
\[ e^x - 3 = \pm \sqrt{y + 4} \]

as \( x \leq \ln 3 \), \( x = \ln(3 - \sqrt{y + 4}) \)

so \( f^{-1}(x) = \ln(3 - \sqrt{x + 4}) \)

domain of \( f^{-1} \) is \( x \in \mathbb{R}, -4 \leq x < 5 \)

\[ \text{[5 marks]} \]

**Total [8 marks]**
Section B

10. (a) attempt to use quotient rule
   correct substitution into quotient rule

   \[ f'(x) = \frac{5kx \left( \frac{1}{5x} \right) - k \ln 5x}{(kx)^2} \]  
   (or equivalent)  
   \[ A1 \]

   \[ = \frac{k - k \ln 5x}{k^2 x^2}, \quad (k \in \mathbb{R}^+) \]  
   \[ A1 \]

   \[ = \frac{1 - \ln 5x}{kx^2} \]  
   \[ AG \]

   [3 marks]

(b) \( f'(x) = 0 \)
   \[ 1 - \ln 5x \]  
   \[ \frac{kx^2}{k} = 0 \]  
   \[ \ln 5x = 1 \]  
   \[ x = e^{\frac{1}{5}} \]  
   \[ A1 \]

   [3 marks]

(c) \( f''(x) = 0 \)
   \[ 2 \ln 5x - 3 \]  
   \[ \frac{3kx^3}{k} = 0 \]  
   \[ \ln 5x = \frac{3}{2} \]  
   \[ 5x = e^{\frac{3}{2}} \]  
   \[ A1 \]

   so the point of inflexion occurs at \( x = \frac{1}{5} e^{\frac{3}{2}} \)  
   \[ AG \]

   [3 marks]

continued…
Question 10 continued

(d) attempt to integrate \( u = \ln 5x \Rightarrow \frac{du}{dx} = \frac{1}{x} \)  
\[
\int \frac{\ln 5x}{kx} \, dx = \frac{1}{k} \int u \, du \quad \text{(A1)}
\]

**EITHER**

\[
e = \frac{u^2}{2k} \quad \text{A1}
\]

so \[
\frac{1}{k} \int u \, du = \left[ \frac{u^2}{2k} \right] \quad \text{A1}
\]

**OR**

\[
e = \frac{(\ln 5x)^2}{2k} \quad \text{A1}
\]

so \[
\frac{1}{k} \int_{\frac{5}{3}}^{\frac{5}{3}} \frac{\ln 5x}{kx} \, dx = \left[ \frac{(\ln 5x)^2}{2k} \right]_{\frac{5}{3}}^{\frac{5}{3}} \quad \text{A1}
\]

**THEN**

\[
e = \frac{1}{2k} \left( \frac{9}{4} - 1 \right) = \frac{5}{8k} \quad \text{A1}
\]

setting their expression for area equal to 3  \( M1 \)

\[
\frac{5}{8k} = 3 \quad \text{A1}
\]

\[
k = \frac{5}{24} \quad [7 \text{ marks}]
\]

Total [16 marks]
11. (a) attempt to find modulus
   \[ r = 2\sqrt{3} \left( = \sqrt{12} \right) \]
   attempt to find argument in the correct quadrant
   \[ \theta = \pi + \arctan \left( -\frac{\sqrt{3}}{3} \right) \]
   \[ = \frac{5\pi}{6} \]
   \[-3 + \sqrt{3}i = \sqrt{12}e^{\frac{5\pi}{6}} = 2\sqrt{3}e^{\frac{5\pi}{6}} \]

   \[ [5 \text{ marks}] \]

(b) attempt to find a root using de Moivre’s theorem
   \[ \frac{1}{12}e^{\frac{5\pi}{18}} \]
   attempt to find further two roots by adding and subtracting \( \frac{2\pi}{3} \) to the argument
   \[ \frac{1}{12}e^{\frac{7\pi}{18}} \]
   \[ \frac{1}{12}e^{\frac{17\pi}{18}} \]

   \[ [5 \text{ marks}] \]

\textbf{Note:} Ignore labels for \( u, v \) and \( w \) at this stage.

\textit{continued…}
**Question 11 continued**

(c) **METHOD 1**

attempting to find the total area of (congruent) triangles \( UOV, VOW \)

and \( UOW \)

\[
\text{Area} = 3 \left( \frac{1}{2} \left( \frac{1}{2} \right) \left( \frac{1}{2} \right) \right) \text{sin} \frac{2\pi}{3}
\]

\[
= \frac{3\sqrt{3}}{4} \left( \frac{1}{2} \right) \text{ (or equivalent)}
\]

**Note:** Award \( A1 \) for \( \left( \frac{1}{2} \right) \left( \frac{1}{2} \right) \left( \frac{1}{2} \right) \) and \( A1 \) for \( \text{sin} \frac{2\pi}{3} \).

[4 marks]

**METHOD 2**

\[
U^2 = \left( \frac{1}{2} \right)^2 + \left( \frac{1}{2} \right)^2 - 2 \left( \frac{1}{2} \right) \left( \frac{1}{2} \right) \cos \frac{2\pi}{3}
\]

\[
= \frac{3\sqrt{3}}{4} \left( \frac{1}{2} \right)
\]

\[
\text{area} = \frac{1}{2} \times UV \times VW \times \text{sin} \alpha
\]

\[
= \frac{1}{2} \left( \sqrt{3} \times \frac{1}{2} \right) \left( \sqrt{3} \times \frac{1}{2} \right) \text{sin} \frac{\pi}{3}
\]

\[
= \frac{3\sqrt{3}}{4} \left( \frac{1}{2} \right)
\]

[4 marks]

(d) \( u + v + w = 0 \)

\[
12^\frac{1}{6} \left( \cos \left( \frac{-7\pi}{18} \right) + i \sin \left( \frac{-7\pi}{18} \right) + \cos \frac{5\pi}{18} + i \sin \frac{5\pi}{18} + \cos \frac{17\pi}{18} + i \sin \frac{17\pi}{18} \right) = 0
\]

consideration of real parts

\[
12^\frac{1}{6} \left( \cos \left( \frac{-7\pi}{18} \right) + \cos \frac{5\pi}{18} + \cos \frac{17\pi}{18} \right) = 0
\]

\[
\cos \left( \frac{-7\pi}{18} \right) = \cos \frac{7\pi}{18}
\]

explicitly stated

\[
\cos \frac{5\pi}{18} + \cos \frac{7\pi}{18} + \cos \frac{17\pi}{18} = 0
\]

[4 marks]

Total [18 marks]
12. (a) attempting to use the chain rule to find the first derivative

\[ f'(x) = (\cos x)e^{\sin x} \]

\[ f''(x) = e^{\sin x} \left( \cos^2 x - \sin x \right) \] (or equivalent)  

attempting to use the product rule to find the second derivative

\[ f''(x) = e^{\sin x} \left( \cos^2 x - \sin x \right) \] (or equivalent)  

attempting to find \( f(0), f'(0) \) and \( f''(0) \)

\[ f(0) = 1; \; f'(0) = (\cos 0)e^{\sin 0} = 1; \; f''(0) = e^{\sin 0} \left( \cos^2 0 - \sin 0 \right) = 1 \]

substitution into the Maclaurin formula \( f(x) = f(0) + xf'(0) + \frac{x^2}{2!} f''(0) + \ldots \)

so the Maclaurin series for \( f(x) \) up to and including the \( x^2 \) term is \( 1 + x + \frac{x^2}{2} \)

[8 marks]

(b) \textbf{METHOD 1}

attempting to differentiate \( f''(x) \)

\[ f'''(x) = (\cos x)e^{\sin x} \left( \cos^2 x - \sin x \right) - (\cos x)e^{\sin x} \left( 2 \sin x + 1 \right) \] (or equivalent)

substituting \( x = 0 \) into their \( f'''(x) \)

\[ f'''(0) = 1(1 - 0) - 1(0 + 1) = 0 \]

so the coefficient of \( x^3 \) in the Maclaurin series for \( f(x) \) is zero

\textbf{METHOD 2}

substituting \( \sin x \) into the Maclaurin series for \( e^x \)

\[ e^{\sin x} = 1 + \sin x + \frac{\sin^2 x}{2!} + \frac{\sin^3 x}{3!} + \ldots \]

substituting Maclaurin series for \( \sin x \)

\[ e^{\sin x} = 1 + \left( x - \frac{x^3}{3!} + \ldots \right) + \left( x - \frac{x^3}{3!} + \ldots \right)^2 + \left( x - \frac{x^3}{3!} + \ldots \right)^3 + \ldots \]

\[ \frac{1}{2!} + \frac{1}{3!} = 0 \]

coefficient of \( x^3 \) is \( -\frac{1}{2!} + \frac{1}{3!} = 0 \)

so the coefficient of \( x^3 \) in the Maclaurin series for \( f(x) \) is zero

[4 marks]

continued...
Question 12 continued

(c) substituting $3x$ into the Maclaurin series for $e^x$

$$e^{3x} = 1 + 3x + \frac{(3x)^2}{2!} + \frac{(3x)^3}{3!} + \ldots$$

$A1$

substituting $(e^{3x} - 1)$ into the Maclaurin series for $\arctan x$

$$\arctan(e^{3x} - 1) = (e^{3x} - 1) - \frac{(e^{3x} - 1)^3}{3} + \frac{(e^{3x} - 1)^5}{5} - \ldots$$

$M1$

$$= \left(3x + \frac{(3x)^2}{2!} + \frac{(3x)^3}{3!} + \ldots\right) - \frac{3x + \frac{(3x)^2}{2!} + \frac{(3x)^3}{3!} + \ldots}{3} \ldots A1,$$

selecting correct terms from above

$$= 3x + \frac{9x^2}{2} - \frac{9x^3}{2}$$

$A1$

(d) **METHOD 1**

substitution of their series

$$\lim_{x \to 0} \frac{x + \frac{x^2}{2} + \ldots}{3x + \frac{9x^2}{2} + \ldots} = \lim_{x \to 0} \frac{1 + \frac{x}{2} + \ldots}{3 + \frac{9x}{2} + \ldots} = \frac{1}{3}$$

$A1$

**METHOD 2**

use of l'Hôpital’s rule

$$\lim_{x \to 0} \frac{(\cos x)e^{3x}}{3e^{3x}} = \lim_{x \to 0} \frac{1}{1 + (e^{3x} - 1)^2} = \frac{1}{3}$$

$A1$

[3 marks]

Total [21 marks]
Mathematics: analysis and approaches
Higher level
Paper 2

Specimen

Candidate session number

2 hours

Instructions to candidates

• Write your session number in the boxes above.
• Do not open this examination paper until instructed to do so.
• A graphic display calculator is required for this paper.
• Section A: answer all questions. Answers must be written within the answer boxes provided.
• Section B: answer all questions in the answer booklet provided. Fill in your session number
  on the front of the answer booklet, and attach it to this examination paper and your
  cover sheet using the tag provided.
• Unless otherwise stated in the question, all numerical answers should be given exactly or
  correct to three significant figures.
• A clean copy of the mathematics: analysis and approaches formula booklet is required for
  this paper.
• The maximum mark for this examination paper is [110 marks].
Full marks are not necessarily awarded for a correct answer with no working. Answers must be supported by working and/or explanations. Solutions found from a graphic display calculator should be supported by suitable working. For example, if graphs are used to find a solution, you should sketch these as part of your answer. Where an answer is incorrect, some marks may be given for a correct method, provided this is shown by written working. You are therefore advised to show all working.

Section A

Answer all questions. Answers must be written within the answer boxes provided. Working may be continued below the lines, if necessary.

1. [Maximum mark: 6]

The following diagram shows part of a circle with centre $O$ and radius 4 cm.

![Diagram of a circle with chord AB and angle $OAB = \theta$.]

Chord $AB$ has a length of 5 cm and $AOB = \theta$.

(a) Find the value of $\theta$, giving your answer in radians. [3]

(b) Find the area of the shaded region. [3]
2. [Maximum mark: 6]

On 1st January 2020, Laurie invests $P$ in an account that pays a nominal annual interest rate of 5.5\%, compounded quarterly.

The amount of money in Laurie’s account at the end of each year follows a geometric sequence with common ratio, \( r \).

(a) Find the value of \( r \), giving your answer to four significant figures. \([3]\)

Laurie makes no further deposits to or withdrawals from the account.

(b) Find the year in which the amount of money in Laurie’s account will become double the amount she invested. \([3]\)
3. [Maximum mark: 6]

A six-sided biased die is weighted in such a way that the probability of obtaining a “six” is \( \frac{7}{10} \).

The die is tossed five times. Find the probability of obtaining

(a) at most three “sixes”. [3]

(b) the third “six” on the fifth toss. [3]
4. [Maximum mark: 7]

The following table below shows the marks scored by seven students on two different mathematics tests.

<table>
<thead>
<tr>
<th>Test 1 (x)</th>
<th>15</th>
<th>23</th>
<th>25</th>
<th>30</th>
<th>34</th>
<th>34</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 2 (y)</td>
<td>20</td>
<td>26</td>
<td>27</td>
<td>32</td>
<td>35</td>
<td>37</td>
<td>35</td>
</tr>
</tbody>
</table>

Let \( L_1 \) be the regression line of \( x \) on \( y \). The equation of the line \( L_1 \) can be written in the form \( x = ay + b \).

(a) Find the value of \( a \) and the value of \( b \). \[2\]

Let \( L_2 \) be the regression line of \( y \) on \( x \). The lines \( L_1 \) and \( L_2 \) pass through the same point with coordinates \((p, q)\).

(b) Find the value of \( p \) and the value of \( q \). \[3\]

(c) Jennifer was absent for the first test but scored 29 marks on the second test. Use an appropriate regression equation to estimate Jennifer’s mark on the first test. \[2\]
5. [Maximum mark: 7]

The displacement, in centimetres, of a particle from an origin, O, at time \( t \) seconds, is given by \( s(t) = t^2 \cos t + 2t \sin t, \ 0 \leq t \leq 5 \).

(a) Find the maximum distance of the particle from O. [3]

(b) Find the acceleration of the particle at the instant it first changes direction. [4]
6. [Maximum mark: 6]

In a city, the number of passengers, $X$, who ride in a taxi has the following probability distribution.

<table>
<thead>
<tr>
<th>$x$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(X = x)$</td>
<td>0.60</td>
<td>0.30</td>
<td>0.03</td>
<td>0.05</td>
<td>0.02</td>
</tr>
</tbody>
</table>

After the opening of a new highway that charges a toll, a taxi company introduces a charge for passengers who use the highway. The charge is $2.40 per taxi plus $1.20 per passenger. Let $T$ represent the amount, in dollars, that is charged by the taxi company per ride.

(a) Find $E(T)$. [4]

(b) Given that $\text{Var}(X) = 0.8419$, find $\text{Var}(T)$. [2]
7. [Maximum mark: 5]

Two ships, A and B, are observed from an origin O. Relative to O, their position vectors at time \( t \) hours after midday are given by

\[
\mathbf{r}_A = \left( \frac{4}{3} \right) + t \left( \begin{array}{c} 5 \\ 8 \end{array} \right)
\]

\[
\mathbf{r}_B = \left( \frac{7}{-3} \right) + t \left( \begin{array}{c} 0 \\ 12 \end{array} \right)
\]

where distances are measured in kilometres.

Find the minimum distance between the two ships.
8. [Maximum mark: 7]

The complex numbers $w$ and $z$ satisfy the equations

$$\frac{w}{z} = 2i$$

$$z^* - 3w = 5 + 5i.$$ 

Find $w$ and $z$ in the form $a + bi$ where $a, b \in \mathbb{Z}$.
9. [Maximum mark: 5]

Consider the graphs of \( y = \frac{x^2}{x - 3} \) and \( y = m(x + 3), \ m \in \mathbb{R} \).

Find the set of values for \( m \) such that the two graphs have no intersection points.
Section B

Answer all questions in the answer booklet provided. Please start each question on a new page.

10. [Maximum mark: 15]

The length, $X$ mm, of a certain species of seashell is normally distributed with mean 25 and variance, $\sigma^2$.

The probability that $X$ is less than 24.15 is 0.1446.

(a) Find $P(24.15 < X < 25)$. [2]

(b) (i) Find $\sigma$, the standard deviation of $X$.

(ii) Hence, find the probability that a seashell selected at random has a length greater than 26 mm. [5]

A random sample of 10 seashells is collected on a beach. Let $Y$ represent the number of seashells with lengths greater than 26 mm.

(c) Find $E(Y)$. [3]

(d) Find the probability that exactly three of these seashells have a length greater than 26 mm. [2]

A seashell selected at random has a length less than 26 mm.

(e) Find the probability that its length is between 24.15 mm and 25 mm. [3]
11. [Maximum mark: 21]

A large tank initially contains pure water. Water containing salt begins to flow into the tank. The solution is kept uniform by stirring and leaves the tank through an outlet at its base. Let $x$ grams represent the amount of salt in the tank and let $t$ minutes represent the time since the salt water began flowing into the tank.

The rate of change of the amount of salt in the tank, $\frac{dx}{dt}$, is described by the differential equation $\frac{dx}{dt} = 10e^{-\frac{t}{4}} - \frac{x}{t + 1}$.

(a) Show that $t + 1$ is an integrating factor for this differential equation. [2]

(b) Hence, by solving this differential equation, show that $x(t) = \frac{200 - 40e^{-\frac{t}{4}}(t + 5)}{t + 1}$. [8]

(c) Sketch the graph of $x$ versus $t$ for $0 \leq t \leq 60$ and hence find the maximum amount of salt in the tank and the value of $t$ at which this occurs. [5]

(d) Find the value of $t$ at which the amount of salt in the tank is decreasing most rapidly. [2]

The rate of change of the amount of salt leaving the tank is equal to $\frac{x}{t + 1}$.

(e) Find the amount of salt that left the tank during the first 60 minutes. [4]

12. [Maximum mark: 19]

(a) Show that $\cot 2\theta = \frac{1 - \tan^2 \theta}{2 \tan \theta}$. [1]

(b) Verify that $x = \tan \theta$ and $x = -\cot \theta$ satisfy the equation $x^2 + (2 \cot 2\theta)x - 1 = 0$. [7]

(c) Hence, or otherwise, show that the exact value of $\tan \frac{\pi}{12} = 2 - \sqrt{3}$. [5]

(d) Using the results from parts (b) and (c) find the exact value of $\tan \frac{\pi}{24} - \cot \frac{\pi}{24}$.

Give your answer in the form $a + b\sqrt{3}$ where $a, b \in \mathbb{Z}$. [6]
Markscheme

Specimen paper

Mathematics: analysis and approaches

Higher level

Paper 2
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.

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 M2, N3, etc., do not split the marks, unless there is a note.

- Once a correct answer to a question or part-question is seen, ignore further correct working. However, if further working indicates a lack of mathematical understanding do not award the final A1. An exception to this may be in numerical answers, where a correct exact value is followed by an incorrect decimal. However, if the incorrect decimal is carried through to a subsequent part, and correct FT working shown, award FT marks as appropriate but do not award the final A1 in that part.

Examples

<table>
<thead>
<tr>
<th>Correct answer seen</th>
<th>Further working seen</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 8\sqrt{2}</td>
<td>5.65685... (incorrect decimal value)</td>
<td>Award the final A1 (ignore the further working)</td>
</tr>
<tr>
<td>2. 1/4 \sin 4x</td>
<td>\sin x</td>
<td>Do not award the final A1</td>
</tr>
<tr>
<td>3. \log a – \log b</td>
<td>\log (a – b)</td>
<td>Do not award the final A1</td>
</tr>
</tbody>
</table>
3 Implied marks

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

- Normally the correct work is seen or implied in the next line.
- Marks without brackets can only be awarded for work that is seen.

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) or subpart(s). 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 the only marks awarded in a subpart are for the answer (i.e. there is no working expected), then FT marks should be awarded if appropriate.

- 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.
- If the error leads to an inappropriate value (e.g. probability greater than 1, use of $r > 1$ for the sum of an infinite GP, $\sin \theta = 1.5$, 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.
- Exceptions to this rule 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 question says hence. It is often possible to use a different approach in subsequent parts that does not depend on the answer to previous parts.

5 Mis-read

If a candidate incorrectly copies information from the question, this is a mis-read (MR). Apply a MR penalty of 1 mark to that question

- 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.
- The MR penalty 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.

- Alternative methods for complete questions are indicated by METHOD 1, METHOD 2, etc.
- Alternative solutions for part-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.
- In the markscheme, equivalent numerical and algebraic forms will generally be written in brackets immediately following the answer.
- In the markscheme, simplified answers, (which candidates often do not write in examinations), will generally appear in brackets. Marks should be awarded for either the form preceding the bracket or the form in brackets (if it is seen).

8 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. There are two types of accuracy errors, and the final answer mark should not be awarded if these errors occur.

- Rounding errors: only applies to final answers not to intermediate steps.
- Level of accuracy: when this is not specified 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.

9 Calculators

A GDC is required for paper 2, but calculators with symbolic manipulation features/ CAS functionality are not allowed.

Calculator notation
The subject guide says:

Students must always use correct mathematical notation, not calculator notation.

Do not accept final answers written using calculator notation. However, do not penalize the use of calculator notation in the working.
Section A

1. (a) **METHOD 1**
   attempt to use the cosine rule
   \[ \cos \theta = \frac{4^2 + 4^2 - 5^2}{2 \times 4 \times 4} \] (or equivalent)
   \[ \theta = 1.35 \]
   \[ (M1) \quad A1 \quad [3 \text{ marks}] \]

   **METHOD 2**
   attempt to split triangle AOB into two congruent right triangles
   \[ \sin \left( \frac{\theta}{2} \right) = \frac{2.5}{4} \]
   \[ \theta = 1.35 \]
   \[ (M1) \quad A1 \quad [3 \text{ marks}] \]

   (b) attempt to find the area of the shaded region
   \[ \frac{1}{2} \times 4 \times 4 \times (2\pi - 1.35...) \]
   \[ = 39.5 \text{ (cm}^2) \]
   \[ (M1) \quad A1 \quad [3 \text{ marks}] \]

   Total [6 marks]

2. (a) \[ \left( 1 + \frac{5.5}{4 \times 100} \right)^4 \]
   \[ 1.056 \]
   \[ (M1)(A1) \quad A1 \quad [3 \text{ marks}] \]

   continued…
Question 2 continued

(b) EITHER

\[ 2P = P \times \left( 1 + \frac{5.5}{100 \times 4} \right)^n \]

OR

\[ 2P = P \times (\text{their } (a))^n \] \( (\text{M1})(\text{A1}) \)

Note: Award \((\text{M1})\) for substitution into loan payment formula. Award \((\text{A1})\) for correct substitution.

OR

PV = ±1
FV = 42
I% = 5.5
P/Y = 4
C/Y = 4
n = 50.756… \((\text{M1})(\text{A1})\)

OR

PV = ±1
FV = 42
I% = 100(\text{their } (a) - 1)
P/Y = 1
C/Y = 1 \((\text{M1})(\text{A1})\)

THEN

\( \Rightarrow 12.7 \) years
Laurie will have double the amount she invested during 2032 \( \text{A1} \)

[3 marks]

Total [6 marks]

3. (a) recognition of binomial

\( X \sim B(5, 0.7) \)

attempt to find \( P(X \leq 3) \)

\( = 0.472 \left( = 0.47178 \right) \) \( \text{M1} \)

\( \text{A1} \) [3 marks]

(b) recognition of 2 sixes in 4 tosses \( \text{M1} \)

\( P\left(\text{3rd six on the 5th toss}\right) = \left[ \binom{4}{2} \times (0.7)^2 \times (0.3)^2 \right] \times 0.7 = 0.2646 \times 0.7 \)

\( = 0.185 \left( = 0.18522 \right) \) \( \text{A1} \) [3 marks]

Total [6 marks]
4. (a) \( a = 1.29 \) and \( b = -10.4 \)

(b) recognising both lines pass through the mean point \( p = 28.7, \ q = 30.3 \)

(c) substitution into their \( x \) on \( y \) equation
\[ x = 1.29082(29) - 10.3793 \]
\[ x = 27.1 \]

Note: Accept 27.

[2 marks]

Total [7 marks]

5. (a) use of a graph to find the coordinates of the local minimum
\[ s = -16.513... \]
maximum distance is 16.5 cm (to the left of \( O \))

(b) attempt to find time when particle changes direction eg considering the first maximum on the graph of \( s \), or the first \( t \) – intercept on the graph of \( s' \).
\[ t = 1.51986... \]

attempt to find the gradient of \( s' \) for their value of \( t \), \( s''(1.51986...) \)
\[ = -8.92 \text{ (cm/s}^2\text{)} \]

Note: Accept 27.

Total [7 marks]
6. (a) **METHOD 1**

attempting to use the expected value formula

\[
E(X) = (1 \times 0.60) + (2 \times 0.30) + (3 \times 0.03) + (4 \times 0.05) + (5 \times 0.02)
\]

\[
E(X) = 1.59\text{($)}
\]

use of \(E(1.20X + 2.40) = 1.20E(X) + 2.40\)

\[
E(T) = 1.20(1.59) + 2.40
\]

\[= 4.31\text{($)}\]

**METHOD 2**

attempting to find the probability distribution for \(T\)

\[
\begin{array}{c|ccccc}
 t & 3.60 & 4.80 & 6.00 & 7.20 & 8.40 \\
P(T=t) & 0.60 & 0.30 & 0.03 & 0.05 & 0.02 \\
\end{array}
\]

attempting to use the expected value formula

\[
E(T) = (3.60 \times 0.60) + (4.80 \times 0.30) + (6.00 \times 0.03) + (7.20 \times 0.05) + (8.40 \times 0.02)
\]

\[= 4.31\text{($)}\]

\[\text{[4 marks]}\]

(b) **METHOD 1**

using \(\text{Var}(1.20X + 2.40) = (1.20)^2 \text{Var}(X)\) with \(\text{Var}(X) = 0.8419\)

\[\text{Var}(T) = 1.21\]

**METHOD 2**

finding the standard deviation for their probability distribution found in part (a)

\[\text{Var}(T) = (1.101...)^2\]

\[= 1.21\]

**Note:** Award M1A1 for \(\text{Var}(T) = (1.093...)^2 = 1.20\).

\[\text{[2 marks]}\]

Total [6 marks]
7. attempting to find \( \mathbf{r}_B - \mathbf{r}_A \) for example

\[
\mathbf{r}_B - \mathbf{r}_A = \begin{pmatrix} 3 \\ -6 \end{pmatrix} + t \begin{pmatrix} -5 \\ 4 \end{pmatrix}
\]

attempting to find \( |\mathbf{r}_B - \mathbf{r}_A| \)

distance \( d(t) = \sqrt{(3-5t)^2 + (4t-6)^2} \)

\( = \sqrt{41t^2 - 78t + 45} \)

using a graph to find the \( d \) coordinate of the local minimum

the minimum distance between the ships is 2.81 \( \text{km} \)

Total [5 marks]

8. substituting \( w = 2iz \) into \( z^* - 3w = 5 + 5i \)

\[
z^* - 6iz = 5 + 5i
\]

let \( z = x + yi \)

comparing real and imaginary parts of \( (x - yi) - 6i(x + yi) = 5 + 5i \)

to obtain \( x + 6y = 5 \) and \( -6x - y = 5 \)

attempting to solve for \( x \) and \( y \)

\( x = -1 \) and \( y = 1 \) and so \( z = -1 + i \)

hence \( w = -2 - 2i \)
9. **METHOD 1**

sketching the graph of \( y = \frac{x^2}{x-3} \) \( \frac{y = x + 3 + \frac{9}{x-3}}{x} \) \( M1 \)
the (oblique) asymptote has a gradient equal to 1
and so the maximum value of \( m \) is 1 \( R1 \)
consideration of a straight line steeper than the horizontal line joining
\((-3,0)\) and \((0,0)\) \( M1 \)
so \( m > 0 \) \( R1 \)
hence \( 0 < m \leq 1 \) \( A1 \)

**METHOD 2**

attempting to eliminate \( y \) to form a quadratic equation in \( x \) \( M1 \)
\( x^2 = m(x^2 - 9) \)
\( \Rightarrow (m-1)x^2 - 9m = 0 \) \( A1 \)

**EITHER**

attempting to solve \( -4(m-1)(-9m) < 0 \) for \( m \) \( M1 \)

**OR**

attempting to solve \( x^2 < 0 \) i.e. \( \frac{9m}{m-1} < 0 \) \( (m \neq 1) \) for \( m \) \( M1 \)

**THEN**

\( \Rightarrow 0 < m < 1 \) \( A1 \)
a valid reason to explain why \( m = 1 \) gives no solutions e.g. if \( m = 1 \),
\( (m-1)x^2 - 9m = 0 \) \( \Rightarrow -9 = 0 \) and so \( 0 < m \leq 1 \) \( R1 \)

Total [5 marks]
Section B

10. (a) attempt to use the symmetry of the normal curve
    eg diagram, 0.5 - 0.1446
    \[ P(24.15 < X < 25) = 0.3554 \]  
    \[ (M1) \]  
    \[ A1 \]  
    \[ 2 \text{ marks} \]  

(b) (i) use of inverse normal to find \( z \) score
    \[ z = \frac{24.15 - 25}{\sigma} = -1.0598 \]  
    \[ (M1) \]  
    \[ (A1) \]  
    \[ A1 \]  
    \[ 5 \text{ marks} \]  

(ii) \( P(X > 26) = 0.106 \)  
    \[ (M1)A1 \]  

(c) recognizing binomial probability
    \[ E(Y) = 10 \times 0.10621 \]  
    \[ = 1.06 \]  
    \[ (M1) \]  
    \[ (A1) \]  
    \[ A1 \]  
    \[ 3 \text{ marks} \]  

(d) \( P(Y = 3) \)
    \[ = 0.0655 \]  
    \[ (M1) \]  
    \[ A1 \]  
    \[ 2 \text{ marks} \]  

(e) recognizing conditional probability
    \[ \frac{0.3554}{1 - 0.10621} = 0.398 \]  
    \[ (M1) \]  
    \[ A1 \]  
    \[ 3 \text{ marks} \]  

Total \[ 15 \text{ marks} \]
11. (a) **METHOD 1**

using \( I(t) = e^{\int I(t) dt} \)

\[ e^{\int \frac{1}{t+1} dt} \]
\[ = e^{\ln(t+1)} \]
\[ = t+1 \]

**METHOD 2**

attempting product rule differentiation on \( \frac{d}{dt}(x(t+1)) \)

\[ \frac{d}{dt}(x(t+1)) = \frac{dx}{dt}(t+1) + x \]
\[ = (t+1) \left( \frac{dx}{dt} + \frac{x}{t+1} \right) \]

so \( t+1 \) is an integrating factor for this differential equation

[2 marks]
Question 11 continued

(b) attempting to multiply through by \((t+1)\) and rearrange to give \((M1)\)

\[
(t+1)\frac{dx}{dt} + x = 10(t+1)e^{-\frac{t}{4}}
\]

\[
A1
\]

\[
\frac{d}{dt}(x(t+1)) = 10(t+1)e^{-\frac{t}{4}}
\]

\[
A1
\]

\[
x(t+1) = \int 10(t+1)e^{-\frac{t}{4}}
\]

\[
A1
\]

attempting to integrate the RHS by parts \(M1\)

\[
= -40(t+1)e^{-\frac{t}{4}} + 40\int e^{-\frac{t}{4}}
\]

\[
A1
\]

\[
= -40(t+1)e^{-\frac{t}{4}} - 160e^{-\frac{t}{4}} + C
\]

\[
Note: \text{Condone the absence of } C .\]

\[
EITHER
\]

substituting \(t = 0, x = 0 \Rightarrow C = 200 \) \(M1\)

\[
x = \frac{-40(t+1)e^{-\frac{t}{4}} - 160e^{-\frac{t}{4}} + 200}{t+1}
\]

\[
A1
\]

using \(-40e^{-\frac{t}{4}}\) as the highest common factor of \(-40(t+1)e^{-\frac{t}{4}}\) and \(-160e^{-\frac{t}{4}}\) \(M1\)

\[
OR
\]

using \(-40e^{-\frac{t}{4}}\) as the highest common factor of \(-40(t+1)e^{-\frac{t}{4}}\) and \(-160e^{-\frac{t}{4}}\) giving

\[
x(t+1) = -40e^{-\frac{t}{4}}(t + 5) + C \text{ (or equivalent)} \quad M1A1
\]

substituting \(t = 0, x = 0 \Rightarrow C = 200 \) \(M1\)

\[
THEN
\]

\[
x(t) = \frac{200 - 40e^{-\frac{t}{4}}(t + 5)}{t+1}
\]

\[
AG
\]

[8 marks]

\[
\text{continued…}
\]
Question 11 continued

(c) 

![Graph showing a local maximum at (6.60, 14.6)]

The graph starts at the origin and has a local maximum (coordinates not required) A1
sketched for $0 \leq t \leq 60$ A1
correct concavity for $0 \leq t \leq 60$ A1
maximum amount of salt is 14.6 (grams) at $t = 6.60$ (minutes) A1A1

[5 marks]

(d) using an appropriate graph or equation (first or second derivative) M1
amount of salt is decreasing most rapidly at $t = 12.9$ (minutes) A1

[2 marks]

(e) EITHER

attempting to form an integral representing the amount of salt that left the tank M1

$$\int_{0}^{60} \frac{x(t)}{t+1} \, dt$$

$$\int_{0}^{60} \left(200 - 40e^{-\frac{t}{4}}(t+5)\right) \frac{1}{(t+1)^2} \, dt$$ A1

OR

attempting to form an integral representing the amount of salt that entered the tank minus the amount of salt in the tank at $t = 60$ (minutes) M1

amount of salt that left the tank is $\int_{0}^{60} 10e^{-\frac{t}{4}} \, dt - x(60)$ A1

THEN

= 36.7 (grams) A2

[4 marks]

Total [21 marks]
12. (a) Stating the relationship between \( \cot 2\theta \) and \( \tan \theta \) and stating the identity for \( \tan 2\theta \):

\[
\cot 2\theta = \frac{1}{\tan 2\theta} \quad \text{and} \quad \tan 2\theta = \frac{2\tan \theta}{1 - \tan^2 \theta}
\]

\[
\Rightarrow \cot 2\theta = \frac{1 - \tan^2 \theta}{2\tan \theta}
\]

[1 mark]

(b) \textbf{METHOD 1}

Attempting to substitute \( \tan \theta \) for \( x \) and using the result from (a):

\[
\text{LHS} = \tan^2 \theta + 2\tan \theta \left( \frac{1 - \tan^2 \theta}{2\tan \theta} \right) - 1
\]

\[
\tan^2 \theta + 1 - \tan^2 \theta - 1 = 0 (= \text{RHS})
\]

So \( x = \tan \theta \) satisfies the equation.

Attempting to substitute \( -\cot \theta \) for \( x \) and using the result from (a):

\[
\text{LHS} = \cot^2 \theta - 2\cot \theta \left( \frac{1 - \tan^2 \theta}{2\tan \theta} \right) - 1
\]

\[
= \frac{1}{\tan^2 \theta} - \left( \frac{1 - \tan^2 \theta}{\tan \theta} \right) - 1
\]

\[
\frac{1}{\tan^2 \theta} - \frac{1}{\tan^2 \theta} + 1 - 1 = 0 (= \text{RHS})
\]

So \( x = -\cot \theta \) satisfies the equation.

\textbf{METHOD 2}

Let \( \alpha = \tan \theta \) and \( \beta = -\cot \theta \)

Attempting to find the sum of roots:

\[
\alpha + \beta = \tan \theta - \frac{1}{\tan \theta}
\]

\[
= \frac{\tan^2 \theta - 1}{\tan \theta}
\]

\[
= -2\cot 2\theta \quad \text{(from part (a))}
\]

Attempting to find the product of roots:

\[
\alpha\beta = \tan \theta \times (-\cot \theta)
\]

\[
= -1
\]

The coefficient of \( x \) and the constant term in the quadratic are \( 2\cot 2\theta \) and \( -1 \) respectively.

Hence the two roots are \( \alpha = \tan \theta \) and \( \beta = -\cot \theta \)

[7 marks]

continued…
(c) **METHOD 1**

\[ x = \tan \frac{\pi}{12} \quad \text{and} \quad x = -\cot \frac{\pi}{12} \]

are roots of \( x^2 + \left(2 \cot \frac{\pi}{6}\right)x - 1 = 0 \) \( \text{R1} \)

**Note:** Award \( \text{R1} \) if only \( x = \tan \frac{\pi}{12} \) is stated as a root of \( x^2 + \left(2 \cot \frac{\pi}{6}\right)x - 1 = 0 \).

\[ x^2 + 2\sqrt{3}x - 1 = 0 \] \( \text{A1} \)

attempting to solve their quadratic equation \( \text{M1} \)

\[ x = -\sqrt{3} \pm 2 \] \( \text{A1} \)

\[ \tan \frac{\pi}{12} > 0 \quad (-\cot \frac{\pi}{12} < 0) \] \( \text{R1} \)

so \( \tan \frac{\pi}{12} = 2 - \sqrt{3} \) \( \text{AG} \)

**METHOD 2**

attempting to substitute \( \theta = \frac{\pi}{12} \) into the identity for \( \tan 2\theta \) \( \text{M1} \)

\[ \tan \frac{\pi}{6} = \frac{2 \tan \frac{\pi}{12}}{1 - \tan^2 \frac{\pi}{12}} \]

\[ \tan^2 \frac{\pi}{12} + 2\sqrt{3} \tan \frac{\pi}{12} - 1 = 0 \] \( \text{A1} \)

attempting to solve their quadratic equation \( \text{M1} \)

\[ \tan \frac{\pi}{12} = -\sqrt{3} \pm 2 \] \( \text{A1} \)

\[ \tan \frac{\pi}{12} > 0 \] \( \text{R1} \)

so \( \tan \frac{\pi}{12} = 2 - \sqrt{3} \) \( \text{AG} \)

[d] \( \tan \frac{\pi}{24} - \cot \frac{\pi}{24} \) is the sum of the roots of \( x^2 + \left(2 \cot \frac{\pi}{12}\right)x - 1 = 0 \) \( \text{R1} \)

\[ \tan \frac{\pi}{24} - \cot \frac{\pi}{24} = -2 \cot \frac{\pi}{12} \] \( \text{A1} \)

\[ = \frac{-2}{2 - \sqrt{3}} \] \( \text{A1} \)

attempting to rationalise their denominator \( \text{(M1)} \)

\[ = -4 - 2\sqrt{3} \] \( \text{A1A1} \)

[6 marks]

**Total [19 marks]**
Mathematics: analysis and approaches
Higher level
Paper 3

Specimen

1 hour

Instructions to candidates

• Do not open this examination paper until instructed to do so.
• A graphic display calculator is required for this paper.
• Answer all the questions in the answer booklet provided.
• Unless otherwise stated in the question, all numerical answers should be given exactly or correct to three significant figures.
• A clean copy of the mathematics: analysis and approaches formula booklet is required for this paper.
• The maximum mark for this examination paper is [55 marks].
Answer all questions in the answer booklet provided. Please start each question on a new page. Full marks are not necessarily awarded for a correct answer with no working. Answers must be supported by working and/or explanations. Solutions found from a graphic display calculator should be supported by suitable working. For example, if graphs are used to find a solution, you should sketch these as part of your answer. Where an answer is incorrect, some marks may be given for a correct method, provided this is shown by written working. You are therefore advised to show all working.

1. [Maximum mark: 30]

This question asks you to investigate regular \( n \)-sided polygons inscribed and circumscribed in a circle, and the perimeter of these as \( n \) tends to infinity, to make an approximation for \( \pi \).

(a) Consider an equilateral triangle \( ABC \) of side length, \( x \) units, inscribed in a circle of radius 1 unit and centre \( O \) as shown in the following diagram.

The equilateral triangle \( ABC \) can be divided into three smaller isosceles triangles, each subtending an angle of \( \frac{2\pi}{3} \) at \( O \), as shown in the following diagram.

Using right-angled trigonometry or otherwise, show that the perimeter of the equilateral triangle \( ABC \) is equal to \( 3\sqrt{3} \) units. [3]

(b) Consider a square of side length, \( x \) units, inscribed in a circle of radius 1 unit. By dividing the inscribed square into four isosceles triangles, find the exact perimeter of the inscribed square. [3]

(This question continues on the following page)
(Question 1 continued)

(c) Find the perimeter of a regular hexagon, of side length, \( x \) units, inscribed in a circle of radius 1 unit. \([2]\)

Let \( P_i(n) \) represent the perimeter of any \( n \)-sided regular polygon inscribed in a circle of radius 1 unit.

(d) Show that \( P_i(n) = 2n \sin \left( \frac{\pi}{n} \right) \). \([3]\)

(e) Use an appropriate Maclaurin series expansion to find \( \lim_{n \to \infty} P_i(n) \) and interpret this result geometrically. \([5]\)

Consider an equilateral triangle \( \triangle ABC \) of side length, \( x \) units, circumscribed about a circle of radius 1 unit and centre \( O \) as shown in the following diagram.

Let \( P_c(n) \) represent the perimeter of any \( n \)-sided regular polygon circumscribed about a circle of radius 1 unit.

(f) Show that \( P_c(n) = 2n \tan \left( \frac{\pi}{n} \right) \). \([4]\)

(g) By writing \( P_c(n) \) in the form \( \frac{2 \tan \left( \frac{\pi}{n} \right)}{\frac{1}{n}} \), find \( \lim_{n \to \infty} P_c(n) \). \([5]\)

(h) Use the results from part (d) and part (f) to determine an inequality for the value of \( \pi \) in terms of \( n \). \([2]\)

The inequality found in part (h) can be used to determine lower and upper bound approximations for the value of \( \pi \).

(i) Determine the least value for \( n \) such that the lower bound and upper bound approximations are both within 0.005 of \( \pi \). \([3]\)
2. [Maximum mark: 25]

This question asks you to investigate some properties of the sequence of functions of the form 
\[ f_n(x) = \cos(n \arccos x), \quad -1 \leq x \leq 1 \quad \text{and} \quad n \in \mathbb{Z}^+. \]

**Important:** When sketching graphs in this question, you are **not** required to find the coordinates of any axes intercepts or the coordinates of any stationary points unless requested.

(a) On the same set of axes, sketch the graphs of 
\[ y = f_1(x) \quad \text{and} \quad y = f_3(x) \]
for \(-1 \leq x \leq 1\). [2]

(b) For odd values of \( n > 2 \), use your graphic display calculator to systematically vary the value of \( n \). Hence suggest an expression for odd values of \( n \) describing, in terms of \( n \), the number of

(i) local maximum points;

(ii) local minimum points. [4]

(c) On a new set of axes, sketch the graphs of 
\[ y = f_2(x) \quad \text{and} \quad y = f_4(x) \]
for \(-1 \leq x \leq 1\). [2]

(d) For even values of \( n > 2 \), use your graphic display calculator to systematically vary the value of \( n \). Hence suggest an expression for even values of \( n \) describing, in terms of \( n \), the number of

(i) local maximum points;

(ii) local minimum points. [4]

(e) Solve the equation \( f'_n(x) = 0 \) and hence show that the stationary points on the graph of 
\[ y = f_n(x) \]
occur at 
\[ x_k = \cos \frac{k\pi}{n}, \quad 0 < k < n. \] [4]

The sequence of functions, \( f_n(x) \), defined above can be expressed as a sequence of polynomials of degree \( n \).

(f) Use an appropriate trigonometric identity to show that 
\[ f_2(x) = 2x^2 - 1. \] [2]

Consider \( f_{n+1}(x) = \cos((n + 1) \arccos x). \)

(g) Use an appropriate trigonometric identity to show that 
\[ f_{n+1}(x) = \cos(n \arccos x) \cos(\arccos x) - \sin(n \arccos x) \sin(\arccos x). \] [2]

(h) Hence

(i) show that \( f_{n+1}(x) + f_{n-1}(x) = 2xf_n(x), \ n \in \mathbb{Z}^+; \)

(ii) express \( f_3(x) \) as a cubic polynomial. [5]
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.

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 M2, N3, etc., do not split the marks, unless there is a note.

- Once a correct answer to a question or part-question is seen, ignore further correct working. However, if further working indicates a lack of mathematical understanding do not award the final A1. An exception to this may be in numerical answers, where a correct exact value is followed by an incorrect decimal. However, if the incorrect decimal is carried through to a subsequent part, and correct FT working shown, award FT marks as appropriate but do not award the final A1 in that part.

Examples

<table>
<thead>
<tr>
<th>Correct answer seen</th>
<th>Further working seen</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. (8\sqrt{2})</td>
<td>5.65685... (incorrect decimal value)</td>
<td>Award the final A1 (ignore the further working)</td>
</tr>
<tr>
<td>2. (\frac{1}{4}\sin 4x)</td>
<td>(\sin x)</td>
<td>Do not award the final A1</td>
</tr>
<tr>
<td>3. (\log a - \log b)</td>
<td>(\log (a - b))</td>
<td>Do not award the final A1</td>
</tr>
</tbody>
</table>
3 Implied marks

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

- Normally the correct work is seen or implied in the next line.
- Marks without brackets can only be awarded for work that is seen.

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) or subpart(s). 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 the only marks awarded in a subpart are for the answer (i.e. there is no working expected), then FT marks should be awarded if appropriate.

- 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.
- If the error leads to an inappropriate value (e.g. probability greater than 1, use of $r > 1$ for the sum of an infinite GP, $\sin \theta = 1.5$, 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.
- Exceptions to this rule 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 question says hence. It is often possible to use a different approach in subsequent parts that does not depend on the answer to previous parts.

5 Mis-read

If a candidate incorrectly copies information from the question, this is a mis-read (MR). Apply a MR penalty of 1 mark to that question.

- 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.
- The MR penalty 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.

- Alternative methods for complete questions are indicated by METHOD 1, METHOD 2, etc.
- Alternative solutions for part-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.
- In the markscheme, equivalent numerical and algebraic forms will generally be written in brackets immediately following the answer.
- In the markscheme, simplified answers, (which candidates often do not write in examinations), will generally appear in brackets. Marks should be awarded for either the form preceding the bracket or the form in brackets (if it is seen).

8 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. There are two types of accuracy errors, and the final answer mark should not be awarded if these errors occur.

- Rounding errors: only applies to final answers not to intermediate steps.
- Level of accuracy: when this is not specified 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.

9 Calculators

A GDC is required for paper 3, but calculators with symbolic manipulation features/ CAS functionality are not allowed.

Calculator notation
The subject guide says:

Students must always use correct mathematical notation, not calculator notation.

Do not accept final answers written using calculator notation. However, do not penalize the use of calculator notation in the working.
1. (a) **METHOD 1**

consider right-angled triangle OCX where \( CX = \frac{x}{2} \)

\[
\sin \frac{\pi}{3} = \frac{x}{2} \quad M1A1
\]

\[
\Rightarrow \frac{x}{2} = \frac{\sqrt{3}}{2} \Rightarrow x = \sqrt{3} \quad A1
\]

\[
P_i = 3 \times x = 3\sqrt{3} \quad AG
\]

**METHOD 2**

eg use of the cosine rule

\[
x^2 = l^2 + l^2 - 2(l)(1)\cos \frac{2\pi}{3} \quad M1A1
\]

\[
x = \sqrt{3} \quad A1
\]

\[
P_i = 3 \times x = 3\sqrt{3} \quad AG
\]

**Note:** Accept use of sine rule. [3 marks]

(b) \[ \sin \frac{\pi}{4} = \frac{1}{x} \] where \( x \) = side of square \[ M1 \]

\[
x = \sqrt{2} \quad A1
\]

\[
P_i = 4\sqrt{2} \quad A1
\]

[3 marks]

(c) 6 equilateral triangles \( \Rightarrow x = 1 \)

\[ P_i = 6 \quad A1 \]

[2 marks]

(d) in right-angled triangle \[ \sin \left( \frac{\pi}{n} \right) = \frac{x}{2} \]

\[
\Rightarrow x = 2 \sin \left( \frac{\pi}{n} \right) \quad A1
\]

\[
P_i = n \times x \quad A1
\]

\[
P_i = n \times 2 \sin \left( \frac{\pi}{n} \right) \quad M1
\]

\[
P_i = 2n \sin \left( \frac{\pi}{n} \right) \quad AG
\]

[3 marks]

continued…
Question 1 continued

(e) consider \( \lim_{n \to \infty} 2n \sin \left( \frac{\pi}{n} \right) \)

use of \( \sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \ldots \)

\[
2n \sin \left( \frac{\pi}{n} \right) = 2n \left( \frac{\pi}{n} - \frac{\pi^3}{6n^3} + \frac{\pi^5}{120n^5} - \ldots \right)
\]

\[
= 2 \left( \frac{\pi}{6n^2} + \frac{\pi^5}{120n^4} - \ldots \right)
\]

\( \Rightarrow \lim_{n \to \infty} 2n \sin \left( \frac{\pi}{n} \right) = 2\pi \)

as \( n \to \infty \) polygon becomes a circle of radius 1 and \( P_i = 2\pi \)

[f 5 marks]

(f) consider an \( n \)-sided polygon of side length \( x \)

\( 2n \) right-angled triangles with angle \( \frac{2\pi}{2n} = \frac{\pi}{n} \) at centre

M1A1

opposite side \( \frac{x}{2} = \tan \left( \frac{\pi}{n} \right) \Rightarrow x = 2 \tan \left( \frac{\pi}{n} \right) \)

M1A1

Perimeter \( P_e = 2n \tan \left( \frac{\pi}{n} \right) \)

AG

[4 marks]

(g) consider \( \lim_{n \to \infty} 2n \tan \left( \frac{\pi}{n} \right) = \lim_{n \to \infty} \left( \frac{2 \tan \left( \frac{\pi}{n} \right)}{\frac{1}{n}} \right) \)

\[
= \lim_{n \to \infty} \left( \frac{2 \tan \left( \frac{\pi}{n} \right)}{\frac{1}{n}} \right) = 0
\]

R1

attempt to use L’Hopital’s rule

M1

\[
\lim_{n \to \infty} \left( \frac{-2\pi sec^2 \left( \frac{\pi}{n} \right)}{-\frac{1}{n^2}} \right)
\]

A1A1

A1

[5 marks]

continued…
Question 1 continued

(h) \( P_i < 2\pi < P_c \)
\[
2n \sin\left(\frac{\pi}{n}\right) < 2\pi < 2n \tan\left(\frac{\pi}{n}\right)
\]

\[
n \sin\left(\frac{\pi}{n}\right) < \pi < n \tan\left(\frac{\pi}{n}\right)
\]

(M1)  

A1

[2 marks]

(i) attempt to find the lower bound and upper bound approximations within 0.005 of \( \pi \)
\( n = 46 \)

(M1)

A2  

[3 marks]

Total [30 marks]

2. (a) correct graph of \( y = f_1(x) \)

(b) (i) graphical or tabular evidence that \( n \) has been systematically varied

\( eg \)

\( n = 3, \) 1 local maximum point and 1 local minimum point

\( n = 5, \) 2 local maximum points and 2 local minimum points

\( n = 7, \) 3 local maximum points and 3 local minimum points

(A1)

(A1)

[2 marks]

(ii) \( \frac{n-1}{2} \) local maximum points

\( n = 46 \)

(A1)

(A1)

Note: Allow follow through from an incorrect local maximum formula expression.

[4 marks]

continued…
Question 2 continued

(c) correct graph of \( y = f_2(x) \) \( A1 \)
correct graph of \( y = f_4(x) \) \( A1 \)

(d) (i) graphical or tabular evidence that \( n \) has been systematically varied \( M1 \)

\[ eg \quad n = 2, \quad 0 \text{ local maximum point and } 1 \text{ local minimum point} \]
\[ n = 4, \quad 1 \text{ local maximum points and } 2 \text{ local minimum points} \]
\[ n = 6, \quad 2 \text{ local maximum points and } 3 \text{ local minimum points} \] \( (A1) \)

\[ \frac{n-2}{2} \text{ local maximum points} \quad A1 \]

(ii) \( \frac{n}{2} \) local minimum points \( A1 \)

[4 marks]

(e) \( f_n(x) = \cos(\arccos(x)n) \)
\( f_n'(x) = \frac{n\sin(n\arccos(x))}{\sqrt{1-x^2}} \) \( M1A1 \)

Note: Award \( M1 \) for attempting to use the chain rule.

\( f_n'(x) = 0 \Rightarrow n\sin(n\arccos(x)) = 0 \) \( M1 \)
\( n\arccos(x) = k\pi \quad (k \in \mathbb{Z}^+) \) \( A1 \)

leading to
\( x = \cos \frac{k\pi}{n} \quad (k \in \mathbb{Z}^+ \text{ and } 0 < k < n) \) \( AG \)

[4 marks]

continued…
Question 2 continued

(f) \( f_2(x) = \cos(2 \arccos x) \)
    \( = 2\left(\cos(\arccos x)\right)^2 - 1 \)
    stating that \( \left(\cos(\arccos x)\right) = x \)
    so \( f_2(x) = 2x^2 - 1 \)
    \( \text{AG} \)

[2 marks]

(g) \( f_{n+1}(x) = \cos((n+1)\arccos x) \)
    \( = \cos(n \arccos x + \arccos x) \)
    use of \( \cos(A + B) = \cos A \cos B - \sin A \sin B \) leading to
    \( = \cos(n \arccos x) \cos(\arccos x) - \sin(n \arccos x) \sin(\arccos x) \)
    \( \text{AG} \)

[2 marks]

(h) (i) \( f_{n-1}(x) = \cos((n-1)\arccos x) \)
    \( = \cos(n \arccos x) \cos(\arccos x) + \sin(n \arccos x) \sin(\arccos x) \)
    \( f_{n+1}(x) + f_{n-1}(x) = 2\cos(n \arccos x) \cos(\arccos x) \)
    \( = 2xf_n(x) \)
    \( \text{AG} \)

(ii) \( f_3(x) = 2xf_2(x) - f_1(x) \)
    \( = 2x(2x^2 - 1) - x \)
    \( = 4x^3 - 3x \)
    \( \text{A1} \)

[5 marks]

Total [25 marks]
Mathematics: analysis and approaches  
Standard level  
Paper 1

Specimen  

Candidate session number  

1 hour 30 minutes

Instructions to candidates

• Write your session number in the boxes above.
• Do not open this examination paper until instructed to do so.
• You are not permitted access to any calculator for this paper.
• Section A: answer all questions. Answers must be written within the answer boxes provided.
• Section B: answer all questions in the answer booklet provided. Fill in your session number on the front of the answer booklet, and attach it to this examination paper and your cover sheet using the tag provided.
• Unless otherwise stated in the question, all numerical answers should be given exactly or correct to three significant figures.
• A clean copy of the mathematics: analysis and approaches formula booklet is required for this paper.
• The maximum mark for this examination paper is [80 marks].
Section A

Answer all questions. Answers must be written within the answer boxes provided. Working may be continued below the lines, if necessary.

1. [Maximum mark: 5]

   The following diagram shows triangle ABC, with $AB = 6$ and $AC = 8$.

   \[ \text{diagram not to scale} \]

   \[ \begin{array}{c}
   \text{A} \\
   \text{6} \\
   \text{B} \\
   \text{C} \\
   \text{8}
   \end{array} \]

   \( \text{(a)} \) Given that $\cos A = \frac{5}{6}$, find the value of $\sin A$. \hspace{1cm} [3]

   \( \text{(b)} \) Find the area of triangle ABC. \hspace{1cm} [2]
2. [Maximum mark: 5]

Let \( A \) and \( B \) be events such that \( P(A) = 0.5 \), \( P(B) = 0.4 \) and \( P(A \cup B) = 0.6 \).

Find \( P(A \mid B) \).
3. [Maximum mark: 5]

(a) Show that \((2n - 1)^2 + (2n + 1)^2 = 8n^2 + 2\), where \(n \in \mathbb{Z}\). \[2\]

(b) Hence, or otherwise, prove that the sum of the squares of any two consecutive odd integers is even. \[3\]
4. [Maximum mark: 5]

Let \( f'(x) = \frac{8x}{\sqrt{2x^2 + 1}} \). Given that \( f(0) = 5 \), find \( f(x) \).
5. [Maximum mark: 5]

The functions \( f \) and \( g \) are defined such that \( f(x) = \frac{x + 3}{4} \) and \( g(x) = 8x + 5 \).

(a) Show that \((g \circ f)(x) = 2x + 11\).  \[2\]

(b) Given that \((g \circ f)^{-1}(a) = 4\), find the value of \(a\).  \[3\]
6. [Maximum mark: 8]

(a) Show that \( \log_9 (\cos 2x + 2) = \log_3 \sqrt[3]{\cos 2x + 2} \). \[3\]

(b) Hence or otherwise solve \( \log_3 (2 \sin x) = \log_9 (\cos 2x + 2) \) for \( 0 < x < \frac{\pi}{2} \). \[5\]
Section B

Answer all questions in the answer booklet provided. Please start each question on a new page.

7. [Maximum mark: 15]

A large company surveyed 160 of its employees to find out how much time they spend traveling to work on a given day. The results of the survey are shown in the following cumulative frequency diagram.

(This question continues on the following page)
Do not write solutions on this page.

(Question 7 continued)

(a) Find the median number of minutes spent traveling to work. [2]

(b) Find the number of employees whose travelling time is within 15 minutes of the median. [3]

Only 10% of the employees spent more than $k$ minutes traveling to work.

(c) Find the value of $k$. [3]

The results of the survey can also be displayed on the following box-and-whisker diagram.

```
travelling times (minutes)
```

(d) Write down the value of $b$. [1]

(e) (i) Find the value of $a$. 
(ii) Hence, find the interquartile range. [4]

Travelling times of less than $p$ minutes are considered outliers.

(f) Find the value of $p$. [2]

8. [Maximum mark: 16]

Let $f(x) = \frac{1}{3}x^3 + x^2 - 15x + 17$.

(a) Find $f'(x)$. [2]

The graph of $f$ has horizontal tangents at the points where $x = a$ and $x = b$, $a < b$.

(b) Find the value of $a$ and the value of $b$. [3]

(c) (i) Sketch the graph of $y = f'(x)$.
(ii) Hence explain why the graph of $f$ has a local maximum point at $x = a$. [2]

(d) (i) Find $f''(b)$.
(ii) Hence, use your answer to part (d)(i) to show that the graph of $f$ has a local minimum point at $x = b$. [4]

The normal to the graph of $f'$ at $x = a$ and the tangent to the graph of $f'$ at $x = b$ intersect at the point $(p, q)$.

(e) Find the value of $p$ and the value of $q$. [5]
9. [Maximum mark: 16]

Let \( f(x) = \frac{\ln 5x}{kx} \) where \( x > 0, \ k \in \mathbb{R}^+ \).

(a) Show that \( f'(x) = \frac{1 - \ln 5x}{kx^2} \). [3]

The graph of \( f \) has exactly one maximum point \( P \).

(b) Find the \( x \)-coordinate of \( P \). [3]

The second derivative of \( f \) is given by \( f''(x) = \frac{2\ln 5x - 3}{kx^3} \). The graph of \( f \) has exactly one point of inflexion \( Q \).

(c) Show that the \( x \)-coordinate of \( Q \) is \( \frac{1}{5} e^{\frac{3}{5}} \). [3]

The region \( R \) is enclosed by the graph of \( f \), the \( x \)-axis, and the vertical lines through the maximum point \( P \) and the point of inflexion \( Q \).

(d) Given that the area of \( R \) is 3, find the value of \( k \). [7]
Please **do not** write on this page.

Answers written on this page will not be marked.
Please do not write on this page.

Answers written on this page will not be marked.
Markscheme

Specimen paper

Mathematics: analysis and approaches

Standard level

Paper 1
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.

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 M2, N3, etc., do not split the marks, unless there is a note.
- Once a correct answer to a question or part-question is seen, ignore further correct working. However, if further working indicates a lack of mathematical understanding do not award the final A1. An exception to this may be in numerical answers, where a correct exact value is followed by an incorrect decimal. However, if the incorrect decimal is carried through to a subsequent part, and correct FT working shown, award FT marks as appropriate but do not award the final A1 in that part.

Examples

<table>
<thead>
<tr>
<th>Correct answer seen</th>
<th>Further working seen</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.  $8\sqrt{2}$</td>
<td>5.65685... (incorrect decimal value)</td>
<td>Award the final A1 (ignore the further working)</td>
</tr>
<tr>
<td>2.  $\frac{1}{4}\sin 4x$</td>
<td>$\sin x$</td>
<td>Do not award the final A1</td>
</tr>
<tr>
<td>3.  $\log a - \log b$</td>
<td>$\log (a - b)$</td>
<td>Do not award the final A1</td>
</tr>
</tbody>
</table>
3 Implied marks

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

- Normally the correct work is seen or implied in the next line.
- Marks without brackets can only be awarded for work that is *seen*.

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) or subpart(s). 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 the only marks awarded in a subpart are for the answer (i.e. there is no working expected), then FT marks should be awarded if appropriate.*

- 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.
- If the error leads to an inappropriate value (e.g. probability greater than 1, use of $r > 1$ for the sum of an infinite GP, $\sin \theta = 1.5$, 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.
- Exceptions to this rule 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 question says hence. It is often possible to use a different approach in subsequent parts that does not depend on the answer to previous parts.

5 Mis-read

*If a candidate incorrectly copies information from the question, this is a mis-read (MR). Apply a MR penalty of 1 mark to that question*

- 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.
- The MR penalty 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.

- Alternative methods for complete questions are indicated by METHOD 1, METHOD 2, etc.
- Alternative solutions for part-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.
- In the markscheme, equivalent numerical and algebraic forms will generally be written in brackets immediately following the answer.
- In the markscheme, simplified answers, (which candidates often do not write in examinations), will generally appear in brackets. Marks should be awarded for either the form preceding the bracket or the form in brackets (if it is seen).

8 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. There are two types of accuracy errors, and the final answer mark should not be awarded if these errors occur.

- Rounding errors: only applies to final answers not to intermediate steps.
- Level of accuracy: when this is not specified 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.

9 Calculators

No calculator is allowed. The use of any calculator on paper 1 is malpractice, and will result in no grade awarded. If you see work that suggests a candidate has used any calculator, please follow the procedures for malpractice. Examples: finding an angle, given a trig ratio of 0.4235.
Section A

1. (a) valid approach using Pythagorean identity
\[
\sin^2 A + \left(\frac{5}{6}\right)^2 = 1 \quad \text{(or equivalent)}
\]
\[
\sin A = \frac{\sqrt{11}}{6}
\]
\[\text{(A1)}\]
\[\text{[3 marks]}\]

(b) \[\frac{1}{2} \times 8 \times 6 \times \frac{\sqrt{11}}{6} \quad \text{(or equivalent)}\]
\[
\text{area} = 4 \sqrt{11}
\]
\[\text{(A1)}\]
\[\text{[2 marks]}\]

Total [5 marks]

2. attempt to substitute into \( P( A \cup B) = P( A) + P( B) - P( A \cap B) \)
\[\text{(M1)}\]

\[\text{Note: Accept use of Venn diagram or other valid method.}\]

\[
P(A \cap B) = 0.3 \quad \text{(seen anywhere)}
\]
\[\text{(A1)}\]

\[P(A \mid B) = \frac{P( A \cap B)}{P( B)}\]
\[= \frac{0.3}{0.4}\]
\[
P(A \mid B) = 0.75\left(= \frac{3}{4}\right)
\]
\[\text{(A1)}\]

Total [5 marks]
3. (a) attempting to expand the LHS
   \[ \text{LHS} = (4n^2 - 4n + 1) + (4n^2 + 4n + 1) = 8n^2 + 2 (= \text{RHS}) \]
   \[ (M1) \]
   \[ A1 \]
   \[ AG \]
   \[ [2 \text{ marks}] \]

(b) \textbf{METHOD 1}

recognition that \(2n - 1\) and \(2n + 1\) represent two consecutive odd integers (for \(n \in \mathbb{Z}\))
   \[ R1 \]
   \[ A1 \]
valid reason \(eg\) divisible by 2 (2 is a factor)
   \[ R1 \]
so the sum of the squares of any two consecutive odd integers is even
   \[ AG \]
   \[ [3 \text{ marks}] \]

\textbf{METHOD 2}

recognition, \(eg\) that \(n\) and \(n + 2\) represent two consecutive odd integers (for \(n \in \mathbb{Z}\))
   \[ R1 \]
   \[ A1 \]
valid reason \(eg\) divisible by 2 (2 is a factor)
   \[ R1 \]
so the sum of the squares of any two consecutive odd integers is even
   \[ AG \]
   \[ [3 \text{ marks}] \]

Total \[5 \text{ marks}\]

4. attempt to integrate
   \[ u = 2x^2 + 1 \Rightarrow \frac{du}{dx} = 4x \]
   \[ (M1) \]
   \[ \int \frac{8x}{\sqrt{2x^2 + 1}} \, dx = \int \frac{2}{\sqrt{u}} \, du \]
   \[ (A1) \]

\textbf{EITHER}

\[ = 4\sqrt{u} \left(+C\right) \]
   \[ A1 \]

\textbf{OR}

\[ = 4\sqrt{2x^2 + 1} \left(+C\right) \]
   \[ A1 \]

\textbf{THEN}

correct substitution into \textbf{their} integrated function (must have \(C\))
   \[ (M1) \]
   \[ 5 = 4 + C \Rightarrow C = 1 \]
   \[ f(x) = 4\sqrt{2x^2 + 1} + 1 \]
   \[ A1 \]

Total \[5 \text{ marks}\]
5. (a) attempt to form composition

Correct substitution \( g \left( \frac{x+3}{4} \right) = 8 \left( \frac{x+3}{4} \right) + 5 \)

\( (g \circ f)(x) = 2x + 11 \)

(b) attempt to substitute 4 (seen anywhere)

Correct equation \( a = 2 \times 4 + 11 \)

\( a = 19 \)

6. (a) attempting to use the change of base rule

\[ \log_x (\cos 2x + 2) = \frac{\log_9 (\cos 2x + 2)}{\log_3 9} \]

\[ = \frac{1}{2} \log_3 (\cos 2x + 2) \]

\[ = \log_3 \sqrt{\cos 2x + 2} \]

(b) \( \log_3 (2\sin x) = \log_3 \sqrt{\cos 2x + 2} \)

\[ 2\sin x = \sqrt{\cos 2x + 2} \]

\[ 4 \sin^2 x = \cos 2x + 2 \quad (\text{or equivalent}) \]

Use of \( \cos 2x = 1 - 2 \sin^2 x \)

\[ 6 \sin^2 x = 3 \]

\[ \sin x = \left( \pm \right) \frac{1}{\sqrt{2}} \]

\[ x = \frac{\pi}{4} \]

**Note:** Award A0 if solutions other than \( x = \frac{\pi}{4} \) are included.

Total [5 marks]

Total [8 marks]
Section B

7. (a) evidence of median position
     80th employee
     40 minutes
     \( (M1) \)  
     \( \text{A1} \)  
     [2 marks]

(b) valid attempt to find interval \((25-55)\)
    18 (employees), 142 (employees)
    124
    \( (M1) \)  
    \( \text{A1} \)  
    \( \text{A1} \)  
    [3 marks]

(c) recognising that there are 16 employees in the top 10%
    144 employees travelled more than \( k \) minutes
    \( k = 56 \)
    \( (M1) \)  
    \( \text{A1} \)  
    [3 marks]

(d) \( b = 70 \)
    \( \text{A1} \)  
    [1 mark]

(e) (i) recognizing \( a \) is first quartile value
    40 employees
    \( a = 33 \)
    \( (M1) \)  
    \( \text{A1} \)  

(ii) \( 47 - 33 \)
    \( \text{IQR} = 14 \)
    \( (M1) \)  
    \( \text{A1} \)  
    [4 marks]

(f) attempt to find \( 1.5 \times \text{their} \text{ IQR} \)
    \( 33 - 21 \)
    \( 12 \)
    \( (M1) \)  
    \( \text{A1} \)  
    [2 marks]

[Total 15 marks]

8. (a) \( f'(x) = x^2 + 2x - 15 \)
    \( (M1) \text{A1} \)  
    [2 marks]

(b) correct reasoning that \( f'(x) = 0 \) (seen anywhere)
    \( x^2 + 2x - 15 = 0 \)
    valid approach to solve quadratic
    \( (x - 3)(x + 5) \), quadratic formula
    correct values for \( x \)
    \( 3, -5 \)
    correct values for \( a \) and \( b \)
    \( a = -5 \) and \( b = 3 \)
    \( (M1) \)  
    \( \text{A1} \)  
    [3 marks]

continued…
Question 8 continued

(c) (i)

(ii) first derivative changes from positive to negative at \( x = a \)
so local maximum at \( x = a \)

(d) (i) \( f''(x) = 2x + 2 \)

substituting their \( b \) into their second derivative
\( f''(3) = 2 \times 3 + 2 \)
\( f''(b) = 8 \)

(ii) \( f''(b) \) is positive so graph is concave up
so local minimum at \( x = b \)

(e) normal to \( f \) at \( x = a \) is \( x = -5 \) (seen anywhere)
attempt to find \( y \)-coordinate at their value of \( b \)
\( f(3) = -10 \)
tangent at \( x = b \) has equation \( y = -10 \) (seen anywhere)
intersection at \( (-5, -10) \)
\( p = -5 \) and \( q = -10 \)

[Total 16 marks]
9. (a) attempt to use quotient rule
   correct substitution into quotient rule
   
   \[ f'(x) = \frac{5kx \left( \frac{1}{5x} \right) - k \ln 5x}{(kx)^2} \] (or equivalent)
   
   \[ = \frac{k - k \ln 5x}{k^2x^2}, \quad (k \in \mathbb{R}^+) \]
   
   \[ = \frac{1 - \ln 5x}{kx^2} \]

   \[A1\]

   \[M1\]

   \[AG\]

   \[3\] marks

(b) \[ f''(x) = 0 \]

   \[ \frac{1 - \ln 5x}{kx^2} = 0 \]

   \[ \ln 5x = 1 \]
   
   \[ x = \frac{e}{5} \]

   \[A1\]

   \[A1\]

   \[3\] marks

(c) \[ f'''(x) = 0 \]

   \[ \frac{2 \ln 5x - 3}{kx^3} = 0 \]

   \[ \ln 5x = \frac{3}{2} \]

   \[ 5x = \frac{3}{2} \]

   \[5x = e^{\frac{3}{2}} \]

   so the point of inflexion occurs at \[ x = \frac{1}{5} e^{\frac{3}{2}} \]

   \[AG\]

   \[3\] marks

continued…
Question 9 continued

(d) attempt to integrate 
\[ u = \ln 5x \Rightarrow \frac{du}{dx} = \frac{1}{x} \] 
\[ \int \frac{\ln 5x}{kx} \, dx = \frac{1}{k} \int u \, du \] 

(Either)
\[ \frac{u^2}{2k} \]
so \[ \frac{1}{k} \int u \, du = \left[ \frac{u^2}{2k} \right] \]

(Or)
\[ \frac{(\ln 5x)^2}{2k} \]
so \[ \int \frac{\ln 5x}{kx} \, dx = \left[ \frac{(\ln 5x)^2}{2k} \right] \]

(Then)
\[ \frac{1}{2k} \left( \frac{9}{4} - 1 \right) \]
\[ = \frac{5}{8k} \]
setting their expression for area equal to 3
\[ \frac{5}{8k} = 3 \]
\[ k = \frac{5}{24} \]

[7 marks]

Total [16 marks]
Instructions to candidates

• Write your session number in the boxes above.
• Do not open this examination paper until instructed to do so.
• A graphic display calculator is required for this paper.
• Section A: answer all questions. Answers must be written within the answer boxes provided.
• Section B: answer all questions in the answer booklet provided. Fill in your session number on the front of the answer booklet, and attach it to this examination paper and your cover sheet using the tag provided.
• Unless otherwise stated in the question, all numerical answers should be given exactly or correct to three significant figures.
• A clean copy of the mathematics: analysis and approaches formula booklet is required for this paper.
• The maximum mark for this examination paper is [80 marks].
Full marks are not necessarily awarded for a correct answer with no working. Answers must be supported by working and/or explanations. Solutions found from a graphic display calculator should be supported by suitable working. For example, if graphs are used to find a solution, you should sketch these as part of your answer. Where an answer is incorrect, some marks may be given for a correct method, provided this is shown by written working. You are therefore advised to show all working.

Section A

Answer all questions. Answers must be written within the answer boxes provided. Working may be continued below the lines, if necessary.

1. [Maximum mark: 6]

A metal sphere has a radius 12.7 cm.

(a) Find the volume of the sphere expressing your answer in the form \(a \times 10^k\), \(1 \leq a < 10\) and \(k \in \mathbb{Z}\). [3]

The sphere is to be melted down and remoulded into the shape of a cone with a height of 14.8 cm.

(b) Find the radius of the base of the cone, correct to 2 significant figures. [3]
2. [Maximum mark: 6]

The following diagram shows part of a circle with centre \( O \) and radius 4 cm.

Chord \( AB \) has a length of 5 cm and \( A\hat{O}B = \theta \).

(a) Find the value of \( \theta \), giving your answer in radians. [3]

(b) Find the area of the shaded region. [3]
3. [Maximum mark: 6]

On 1st January 2020, Laurie invests $P$ in an account that pays a nominal annual interest rate of 5.5%, compounded quarterly.

The amount of money in Laurie’s account at the end of each year follows a geometric sequence with common ratio, $r$.

(a) Find the value of $r$, giving your answer to four significant figures. [3]

Laurie makes no further deposits to or withdrawals from the account.

(b) Find the year in which the amount of money in Laurie’s account will become double the amount she invested. [3]
4. [Maximum mark: 6]

A six-sided biased die is weighted in such a way that the probability of obtaining a “six” is \( \frac{7}{10} \).

The die is tossed five times. Find the probability of obtaining

(a) at most three “sixes”. \([3]\)

(b) the third “six” on the fifth toss. \([3]\)
5. [Maximum mark: 5]

The following table below shows the marks scored by seven students on two different mathematics tests.

<table>
<thead>
<tr>
<th>Test 1 (x)</th>
<th>15</th>
<th>23</th>
<th>25</th>
<th>30</th>
<th>34</th>
<th>34</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 2 (y)</td>
<td>20</td>
<td>26</td>
<td>27</td>
<td>32</td>
<td>35</td>
<td>37</td>
<td>35</td>
</tr>
</tbody>
</table>

Let $L_1$ be the regression line of $x$ on $y$. The equation of the line $L_1$ can be written in the form $x = ay + b$.

(a) Find the value of $a$ and the value of $b$. [2]

Let $L_2$ be the regression line of $y$ on $x$. The lines $L_1$ and $L_2$ pass through the same point with coordinates $(p, q)$.

(b) Find the value of $p$ and the value of $q$. [3]
6. [Maximum mark: 7]

The displacement, in centimetres, of a particle from an origin, $O$, at time $t$ seconds, is given by $s(t) = t^2 \cos t + 2t \sin t$, $0 \leq t \leq 5$.

(a) Find the maximum distance of the particle from $O$. [3]

(b) Find the acceleration of the particle at the instant it first changes direction. [4]
Section B

Answer all questions in the answer booklet provided. Please start each question on a new page.

7. [Maximum mark: 16]

Adam sets out for a hike from his camp at point A. He hikes at an average speed of 4.2 km/h for 45 minutes, on a bearing of 035° from the camp, until he stops for a break at point B.

(a) Find the distance from point A to point B. [2]

Adam leaves point B on a bearing of 114° and continues to hike for a distance of 4.6 km until he reaches point C.

(b) (i) Show that \( \angle ABC \) is 101°.

(ii) Find the distance from the camp to point C. [5]

(c) Find \( \angle BCA \). [3]

Adam’s friend Jacob wants to hike directly from the camp to meet Adam at point C.

(d) Find the bearing that Jacob must take to point C. [3]

Jacob hikes at an average speed of 3.9 km/h.

(e) Find, to the nearest minute, the time it takes for Jacob to reach point C. [3]
8. [Maximum mark: 15]

The length, \(X\) mm, of a certain species of seashell is normally distributed with mean 25 and variance, \(\sigma^2\).

The probability that \(X\) is less than 24.15 is 0.1446.

(a) Find \(P(24.15 < X < 25)\). [2]

(b) (i) Find \(\sigma\), the standard deviation of \(X\).

(ii) Hence, find the probability that a seashell selected at random has a length greater than 26 mm. [5]

A random sample of 10 seashells is collected on a beach. Let \(Y\) represent the number of seashells with lengths greater than 26 mm.

(c) Find \(E(Y)\). [3]

(d) Find the probability that exactly three of these seashells have a length greater than 26 mm. [2]

A seashell selected at random has a length less than 26 mm.

(e) Find the probability that its length is between 24.15 mm and 25 mm. [3]
9. [Maximum mark: 13]

Consider a function \( f \), such that \( f(x) = \frac{\pi}{6} (x + 1) + b, \quad 0 \leq x \leq 10, \quad b \in \mathbb{R} \).

(a) Find the period of \( f \). \[2\]

The function \( f \) has a local maximum at the point \((2, 21.8)\), and a local minimum at \((8, 10.2)\).

(b) (i) Find the value of \( b \).

(ii) Hence, find the value of \( f(6) \). \[4\]

A second function \( g \) is given by \( g(x) = p \sin \left( \frac{2\pi}{9} (x - 3.75) \right) + q, \quad 0 \leq x \leq 10; \quad p, q \in \mathbb{R} \).

The function \( g \) passes through the points \((3, 2.5)\) and \((6, 15.1)\).

(c) Find the value of \( p \) and the value of \( q \). \[5\]

(d) Find the value of \( x \) for which the functions have the greatest difference. \[2\]
Please do not write on this page.

Answers written on this page will not be marked.
Markscheme

Specimen paper

Mathematics:
analysis and approaches

Standard level

Paper 2
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.

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 \(M2, N3, etc\.), do not split the marks, unless there is a note.

   - Once a correct answer to a question or part-question is seen, ignore further correct working.
     However, if further working indicates a lack of mathematical understanding do not award the final
     \(A1\). An exception to this may be in numerical answers, where a correct exact value is followed by
     an incorrect decimal. However, if the incorrect decimal is carried through to a subsequent part,
     and correct \(FT\) working shown, award \(FT\) marks as appropriate but do not award the final \(A1\) in
     that part.

Examples

<table>
<thead>
<tr>
<th>Correct answer seen</th>
<th>Further working seen</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. (8\sqrt{2})</td>
<td>5.65685... (incorrect decimal value)</td>
<td>Award the final (A1) (ignore the further working)</td>
</tr>
<tr>
<td>2. (\frac{1}{4} \sin 4x)</td>
<td>(\sin x)</td>
<td>Do not award the final (A1)</td>
</tr>
<tr>
<td>3. (\log a - \log b)</td>
<td>(\log (a - b))</td>
<td>Do not award the final (A1)</td>
</tr>
</tbody>
</table>
3 Implied marks

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

- Normally the correct work is seen or implied in the next line.
- Marks without brackets can only be awarded for work that is seen.

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) or subpart(s). 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 the only marks awarded in a subpart are for the answer (i.e. there is no working expected), then \(FT\) marks should be awarded if appropriate.

- 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.
- If the error leads to an inappropriate value (e.g. probability greater than 1, use of \(r > 1\) for the sum of an infinite GP, \(\sin \theta = 1.5\), 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.
- Exceptions to this rule 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 question says hence. It is often possible to use a different approach in subsequent parts that does not depend on the answer to previous parts.

5 Mis-read

If a candidate incorrectly copies information from the question, this is a mis-read \((MR)\). Apply a \(MR\) penalty of 1 mark to that question

- 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.
- The \(MR\) penalty 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.

- Alternative methods for complete questions are indicated by METHOD 1, METHOD 2, etc.
- Alternative solutions for part-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.
- In the markscheme, equivalent numerical and algebraic forms will generally be written in brackets immediately following the answer.
- In the markscheme, simplified answers, (which candidates often do not write in examinations), will generally appear in brackets. Marks should be awarded for either the form preceding the bracket or the form in brackets (if it is seen).

8 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. There are two types of accuracy errors, and the final answer mark should not be awarded if these errors occur.

- Rounding errors: only applies to final answers not to intermediate steps.
- Level of accuracy: when this is not specified 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.

9 Calculators

A GDC is required for paper 2, but calculators with symbolic manipulation features/ CAS functionality are not allowed.

Calculator notation
The subject guide says:
Students must always use correct mathematical notation, not calculator notation.

Do not accept final answers written using calculator notation. However, do not penalize the use of calculator notation in the working.
Section A

1. (a) \( \frac{4}{3} \pi (12.7)^3 \) (or equivalent) \( A1 \)

\[ V = 8.58 \times 10^3 \] \( A1 \)

(b) recognising volume of the cone is same as volume of their sphere \( M1 \)

\[ \frac{1}{3} \pi r^2 (14.8) = 8580.24 \] (or equivalent) \( A1 \)

\[ r = 23.529 \] \( A1 \)

\[ r = 24 \text{ (cm)} \] correct to 2 significant figures \( [3 \text{ marks}] \)

Total [6 marks]

2. (a) **METHOD 1**

attempt to use the cosine rule \( M1 \)

\[ \cos \theta = \frac{4^2 + 4^2 - 5^2}{2 \times 4 \times 4} \] (or equivalent) \( A1 \)

\[ \theta = 1.35 \] \( A1 \)

**METHOD 2**

attempt to split triangle AOB into two congruent right triangles \( M1 \)

\[ \sin \left( \frac{\theta}{2} \right) = \frac{2.5}{4} \] \( A1 \)

\[ \theta = 1.35 \] \( A1 \)

(b) attempt to find the area of the shaded region \( M1 \)

\[ \frac{1}{2} \times 4 \times 4 \times (2\pi - 1.35...) \] \( A1 \)

\[ = 39.5 \text{ (cm}^2) \] \( A1 \)

Total [6 marks]

3. (a) \( \left( 1 + \frac{5.5}{4 \times 100} \right)^4 \) \( M1)(A1) \)

1.056 \( A1 \)

[3 marks]

continued...
Question 3 continued

(b) EITHER

\[ 2P = P \times \left( 1 + \frac{5.5}{100 \times 4} \right)^n \quad \text{OR} \quad 2P = P \times \left( \text{their } (a) \right)^n \]

(M1)(A1)

Note: Award (M1) for substitution into loan payment formula. Award (A1) for correct substitution.

OR

\[ \text{PV} = \pm 1 \]
\[ \text{FV} = \mp 2 \]
\[ \text{I}\% = 5.5 \]
\[ \text{P/Y} = 4 \]
\[ \text{C/Y} = 4 \]
\[ n = 50.756 \ldots \]

\[ \text{PV} = \pm 1 \]
\[ \text{FV} = \mp 2 \]
\[ \text{I}\% = 100 \times \text{their } (a) - 1 \]
\[ \text{P/Y} = 1 \]
\[ \text{C/Y} = 1 \]

(M1)(A1)

THEN

\[ \Rightarrow 12.7 \text{ years} \]

Laurie will have double the amount she invested during 2032

[3 marks]

Total [6 marks]

4. (a) recognition of binomial

\[ X \sim B(5, 0.7) \]

attempt to find \( P(X \leq 3) \)

\[ = 0.472(= 0.47178) \]

(A1)

[3 marks]

Total [6 marks]

(b) recognition of 2 sixes in 4 tosses

\[ P(3 \text{rd six on the 5th toss}) = \left[ \left( \frac{4}{2} \right)^2 \times (0.7)^2 \times (0.3)^2 \right] \times 0.7(= 0.2646 \times 0.7) \]

\[ = 0.185(= 0.18522) \]

[3 marks]
5. (a) \( a = 1.29 \) and \( b = -10.4 \)

(b) recognising both lines pass through the mean point
\( p = 28.7 \), \( q = 30.3 \)

Total [5 marks]

6. (a) use of a graph to find the coordinates of the local minimum
\( s = -16.513... \)
maximum distance is 16.5 cm (to the left of \( O \))

(b) attempt to find time when particle changes direction \( \text{eg} \) considering the first maximum on the graph of \( s \) or the first \( t \) – intercept on the graph of \( s' \).
\( t = 1.51986... \)

attempt to find the gradient of \( s' \) for \textbf{their} value of \( t \), \( s''(1.51986...) \)
\( = -8.92 \) (cm/s²)

Total [7 marks]
Section B

7. (a) \[ \frac{4.2}{60} \times 45 \]
\[ AB = 3.15 \text{ (km)} \]
\[ A1 \]
\[ [2 \text{ marks}] \]

(b) (i) \[ 66' \text{ or } (180 - 114) \]
\[ 35 + 66 \]
\[ \hat{ABC} = 101' \]
\[ A1 \]
\[ A1 \]
\[ AG \]

(ii) attempt to use cosine rule
\[ AC^2 = 3.15^2 + 4.6^2 - 2 \times 3.15 \times 4.6 \cos 101^\circ \text{ (or equivalent)} \]
\[ AC = 6.05 \text{ (km)} \]
\[ A1 \]
\[ A1 \]
\[ [5 \text{ marks}] \]

(c) valid approach to find angle \( \hat{BCA} \)
\[ \text{eg sine rule} \]
\[ \text{correct substitution into sine rule} \]
\[ \frac{\sin(\hat{BCA})}{3.15} = \frac{\sin 101}{6.0507...} \]
\[ \hat{BCA} = 30.7^\circ \]
\[ A1 \]
\[ [3 \text{ marks}] \]

(d) \( \hat{BAC} = 48.267 \) (seen anywhere)
\[ \text{valid approach to find correct bearing} \]
\[ \text{eg } 48.267 + 35 \]
\[ \text{bearing} = 83.3^\circ \text{ (accept 083°)} \]
\[ A1 \]
\[ [3 \text{ marks}] \]

(e) attempt to use time = \[ \frac{\text{distance}}{\text{speed}} \]
\[ \frac{6.0507}{3.9} \text{ or } 0.065768 \text{ km/min} \]
\[ t = 93 \text{ (minutes)} \]
\[ A1 \]
\[ A1 \]
\[ [3 \text{ marks}] \]

Total [16 marks]
8. (a) attempt to use the symmetry of the normal curve

\[ P(24.15 < X < 25) = 0.3554 \]

(b) (i) use of inverse normal to find z score

\[ z = -1.0598 \]

\[ \sigma = 0.802 \]

(ii) \[ P(X > 26) = 0.106 \]

(c) recognizing binomial probability

\[ E(Y) = 10 \times 0.10621 = 1.06 \]

(d) \[ P(Y = 3) = 0.0655 \]

(e) recognizing conditional probability

\[ \frac{0.3554}{1 - 0.10621} = 0.398 \]

Total [15 marks]

9. (a) correct approach

\[ \frac{\pi}{6} = \frac{2\pi}{\text{period}} \]

period = 12

(b) (i) valid approach

\[ b = \frac{\text{max} + \text{min}}{2} \]

\[ b = 16 \]

continued…
Question 9 continued

(ii) attempt to substitute into their function
\[
5.8 \sin \left( \frac{\pi}{6} (6 + 1) \right) + 16
\]
\[f(6) = 13.1\]

(c) valid attempt to set up a system of equations
two correct equations
\[
p \sin \left( \frac{2\pi}{9} (3 - 3.75) \right) + q = 2.5, \quad p \sin \left( \frac{2\pi}{9} (6 - 3.75) \right) + q = 15.1
\]
valid attempt to solve system
\[p = 8.4; \quad q = 6.7\]

(d) attempt to use \(|f(x) - g(x)|\) to find maximum difference
\[x = 1.64\]

Total [13 marks]