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Examiners' report

FURTHER MATHEMATICS A

H245

For first teaching in 2017

Y541/01 Summer 2024 series

Version 1

Contents

Introduction

Our examiners' reports are produced to offer constructive feedback on candidates' performance in the examinations. They provide useful guidance for future candidates.

The reports will include a general commentary on candidates' performance, identify technical aspects examined in the questions and highlight good performance and where performance could be improved. A selection of candidate answers is also provided. The reports will also explain aspects which caused difficulty and why the difficulties arose, whether through a lack of knowledge, poor examination technique, or any other identifiable and explainable reason.

Where overall performance on a question/question part was considered good, with no particular areas to highlight, these questions have not been included in the report.

A full copy of the question paper and the mark scheme can be downloaded from OCR.

Paper Y541/01 series overview

This paper, along with Y540, assesses the compulsory core content of the A Level Further Mathematics qualification. Compared to previous years, the quality of the responses received was very promising indeed.

Some questions produced a particularly strong response, for instance Question 3 on matrix addition and multiplication, matrix algebra and solution of simultaneous equations using an inverse matrix; Question 5 on vector and scalar product and the significance of $\mathbf{a} \times \mathbf{b} \cdot \mathbf{c} = 0$; question 7 (a) on hyperbolic functions expressed in terms of exponentials. Parts of the modelling question were also very accessible, and candidates answered them well, while they found other parts challenging, especially those requiring an explanation, a justification or supporting reasoning. Other questions that candidates found challenging were Question 6 on properties of a curve in polar coordinates, also requiring explanations and justifications, Question 2(b) on de Moivre's theorem and Question 9, on the roots of unity and the geometrical effect of multiplying two complex numbers, due to its problem-solving nature and perhaps lack of familiarity.

There was some evidence that some candidates rushed through Question 9 or even omitted parts of it.

Candidates who did well on this paper generally:	Candidates who did less well on this paper generally:
• were able to use and apply standard techniques with confidence • knew the command words well and provided commensurate detail in their responses • could draw accurate diagrams and used them to support their explanations or calculations • had practised past paper questions on topics which are regularly assessed • Were able to use their problem-solving skills aptly • used their calculator efficiently.	• made arithmetic/algebraic errors which prevented them from gaining straightforward marks in the paper • did not provide enough detail in 'Detailed Reasoning' or 'Show that' questions • struggled with problem solving (for example with the start of Question 4 and in Question 9) • struggled with proofs (for example in Question 6 and in Question 9) • lacked rigour in their notation.

Question 1 (a)

1 **(a)** Use the method of differences to show that $\sum_{r=1}^{n}\left(\frac{1}{r}-\frac{1}{r+1}\right)=1-\frac{1}{n+1}$. **[1]**

Although this was the first question in the paper, a relatively large proportion of candidates did not gain the mark here as they were not rigorous enough in their explanations and their response lacked consistent logical notation.

Assessment for learning

Candidates should be reminded that the command word 'Show detailed reasoning' requires them to give a solution showing a detailed and complete analytical method and containing sufficient detail to allow the line of their argument to be followed.

A full list of command words can be found on pages 9-11 in the specification. There is also a poster that can be printed and displayed in the classroom https://www.ocr.org.uk/Images/533967-a-level-maths-command-words-poster-a4-size.pdf

Question 1 (b) (ii)

(b) Hence determine the following sums.

(ii) $\sum_{r=100}^{\infty}\frac{1}{r}-\frac{1}{r+1}$ **[3]**

Approximately one third of the candidates achieved full marks in part (b) (ii) and the vast majority gained at least 1 mark. Some candidates lost the B mark for missing limit to infinity (of the series) or for incorrect limit notation, while others did not show enough detail of their method.

Assessment for learning

Candidates should be reminded of the importance of correct limit notation.

Question 2 (a)

2 In this question you must show detailed reasoning.

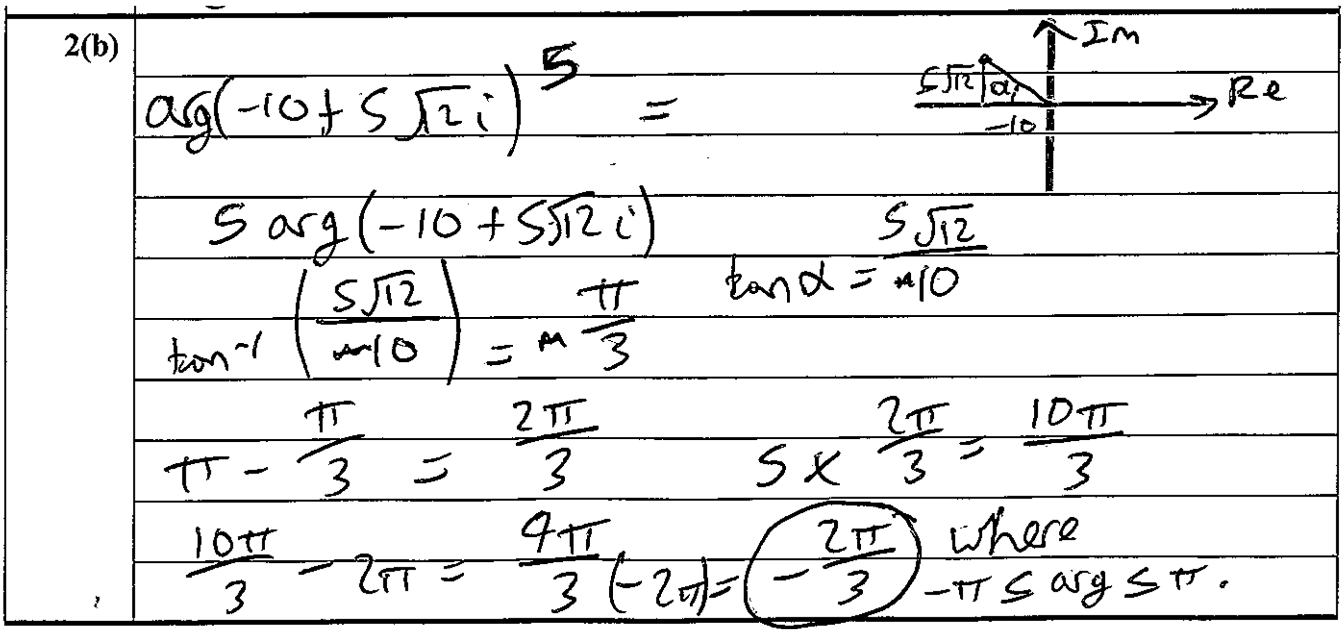
(a) Solve the equation $x^2 - 6x + 58 = 0$. Give your solutions in the form $a + b\mathrm{i}$ where a and b are real numbers. **[3]**

Given that this was a detailed reasoning question, in which assessment objective (AO) 2.5 is assessed (use mathematical language and notation correctly) all steps of the candidates' working needed to be shown to obtain full marks, including the crucial step of square rooting a negative number to produce an imaginary one. Completing the square featured quite prominently as a valid method. The majority of candidates gained full marks, while about one third did not have enough detail.

Question 2 (b)

(b) Determine, in exact form, $\arg(-10 + (5\sqrt{12})\mathrm{i})^5$. **[3]**

Exemplar 1



2(b)

$\arg(-10+5\sqrt{12}i)^5 =$

$5\arg(-10+5\sqrt{12}i)$ $\tan\alpha = \frac{5\sqrt{12}}{10}$

$\tan^{-1}\left(\frac{5\sqrt{12}}{10}\right) = \frac{\pi}{3}$

$\pi - \frac{\pi}{3} = \frac{2\pi}{3}$ $5 \times \frac{2\pi}{3} = \frac{10\pi}{3}$

$\frac{10\pi}{3} - 2\pi = \frac{4\pi}{3}(-2\pi) = -\frac{2\pi}{3}$ where $-\pi \le \arg \le \pi$.

Exemplar 1 received full marks. The correct formula/method for finding the argument of a complex number (with non-zero real and imaginary parts) is used and given (first M mark), followed by the use of de Moivre's theorem (second M mark) and finally the angle found is reduced to a principal argument lying in either of the intervals [0, 2 π) or (-π, π], gaining the accuracy mark.

Approximately one quarter of the candidates gained full marks in this question; the majority either obtained 1 or 2 marks. Candidates showed good understanding of the relationship between arg and tan, although some seemed less clear on what to do when the complex number does not lie in the first quadrant and how to deal with negative signs. Use of de Moivre's theorem was mostly as expected, although some candidates raised their initial answer to the power of 5. More than a few did not recognise the need to give a value for the required argument within the range (-π, π].

Assessment for learning

Candidates who took the route of writing z in the cartesian form and used the binomial expansion to find z^5, rarely obtained any marks.

Misconception

A significant number of candidates thought that $\arg(z^5) = (\arg z)^5$ instead of $5\arg z$.

Question 3 (b)

(b) Write down the matrix **C** such that **AC** = 2**A**. **[1]**

Although the vast majority of candidates earned the mark available here, many did far too much work for this question and did not recognise that the algebraic use of inverses immediately gives the answer required. In this question, a strand of AO2 (make deductions) is assessed.

Question 4

4 In this question you must show detailed reasoning.

The series S is defined as being the sum of the squares of all positive **odd** integers from 1^2 to 779^2.

Determine the value of S. **[5]**

This problem-solving question (AO 3.1a: translate problems in mathematical contexts into mathematical processes) had a strong response, with the majority of candidates receiving full marks. Of these, most used the main method shown in the mark scheme, while a smaller proportion wrote *S* as the difference between two sums of squares. Among the less successful responses, a common feature was to write *S* as the sum of the squares of all integers from zero (or 1) to 779.

Assessment for learning

Quite a few candidates read 799 instead of 779 and proceeded to calculate the sum of squares of odd integers up to 799. Remind them (many times) to read the questions carefully as it is essential.

Misconception

A significant number of candidates added all the squares of odd numbers up to 779, neglecting to subtract the sum of the squares of even integers.

Question 5

5 Vectors, $\mathbf{a}$, $\mathbf{b}$ and $\mathbf{c}$, are given by $\mathbf{a} = \mathbf{i} + (1-p)\mathbf{j} + (p+2)\mathbf{k}$, $\mathbf{b} = 2\mathbf{i} + \mathbf{j} + \mathbf{k}$ and $\mathbf{c} = \mathbf{i} + 14\mathbf{j} + (p-3)\mathbf{k}$ where p is a constant.

You are given that $\mathbf{a} \times \mathbf{b}$ is perpendicular to $\mathbf{c}$.

Determine the possible values of p. **[6]**

More than a half of the candidates gained full marks in this question on the vector product and its geometric interpretation. Almost all candidates were able to find a vector product, then to form a scalar product of **c** and their vector product, setting it to zero to and solve a quadratic equation. There were some slips in algebra with vector product and scalar product seen, but the question was generally accessible.

Question 6 (a)

6 In polar coordinates, the equation of a curve, C, is $r = 6\sin(2\theta)\sinh\left(\frac{1}{3}\theta\right)$ for $0 \leqslant \theta \leqslant \frac{1}{2}\pi$.

The pole of the polar coordinate system corresponds to the origin of the cartesian system and the initial line corresponds to the positive x-axis.

(a) Explain how you can tell that C comprises a single loop in the first quadrant, passing through the pole. **[3]**

Candidates generally found this question on properties of curves in polar coordinates rather challenging. Only around one in ten candidates gained full marks; the vast majority gained either 1 or 2 marks. The AOs tested here are all strands of AO2 (Reason, interpret and communicate mathematically):

2.1 Construct rigorous mathematical arguments (including proofs)

2.2a Make deductions

2.4 Explain their reasoning

Therefore, addressing the key points in the question and providing clear, rigorous explanations was paramount. Exemplar 2 does just that for two of the three key points.

Assessment for learning

A common issue observed was that candidates often did not link the solution to the first quadrant.

Exemplar 2

6(a)

$0 = 6\sin(2\theta)\sinh\left(\frac{\theta}{3}\right)$

$\sin 2\theta = 0$ $\qquad$ $\sinh\left(\frac{\theta}{3}\right) = 0$

$2\theta = \sin^{-1}(0) = 0, \pi$ $\qquad$ $\frac{\theta}{3} = 0$

$\theta = 0, \frac{\pi}{2}$ $\qquad$ $\theta = 0$

r is only 0 at 2 values (0 and $\frac{\pi}{2}$) ∴ must be a single loop when $0 \leq \theta \leq \frac{\pi}{2}$

Exemplar 2 earns the first B mark for finding the values of θ for which $r = 0$. The third B mark is also earned for a clear explanation that there are no more values of θ for which $r = 0$ and therefore there is only a single loop. Finally, the second B mark was withheld as there is no reference to the loop being in the first quadrant.

Question 6 (c)

The point on C which is furthest away from the pole is denoted by A and the value of θ at A is denoted by ϕ.

(c) Show that ϕ satisfies the equation $\phi = \frac{3}{2}\ln\left(\frac{6-\tan 2\phi}{6+\tan 2\phi}\right)$ **[4]**

Almost a half of the candidates achieved full marks in this part question. Candidates commonly secured the first 2 marks for finding the derivative correctly. Most candidates were able to proceed further and express the equation $\frac{dr}{d\theta} = 0$ in terms of tan and tanh only. Successful candidates were then able to express tanh in terms of a natural logarithm, using a known result from the formula book. They also remembered to replace θ with ϕ, which was necessary to earn the final accuracy mark. In this question the AOs assessed are:

AO 3.1a: translate problems in mathematical contexts into mathematical processes.

AO 2.2a: make deductions.

Assessment for learning

Some of the candidates who had achieved the third mark and thus expressed the equation $\frac{dr}{d\theta} = 0$ in terms of tan and tanh only, would rewrite tanh in terms of exponentials and venture into lengthy algebraic manipulation to derive the required equation for ϕ. This often led nowhere and resulted in the loss of the final mark.

OCR support

For support material on Polar coordinates, see OCR Delivery Guides Section 4.09 Polar coordinates, check-in tests and activities.

Question 7 (b)

A function is defined by $f(x) = \dfrac{1}{\sqrt{17\cosh x - 15\sinh x}}$. The region bounded by the curve $y = f(x)$, the x-axis, the y-axis and the line $x = \ln 3$ is rotated by 2π radians about the x-axis to form a solid of revolution S.

(b) In this question you must show detailed reasoning.

Use a suitable substitution, together with known results from the formula book, to show that the volume of S is given by $k\pi \tan^{-1} q$ where k and q are rational numbers to be determined. **[7]**

Although fewer than one in ten candidates gained the final mark in this part question, the other 6 marks proved to be fairly accessible and were gained by approximately a half of the candidates. Overall, they showed proficiency in using the formula for the volume of revolution correctly, though a few forgot to include the factor of π. They also effectively utilised their work from part (a) and identified useful substitutions for integration. Additionally, they correctly substituted the limits, although some incorrectly thought that e^0 is zero. On the other hand, some candidates did not show the early steps in their working, thereby losing marks, or did not heed the demand to 'use a suitable substitution', which is a standard technique in this specification.

Very rarely, candidates identified the formula for tan(A−B) as useful to complete their detailed working and so earned the final, problem-solving mark (AO 3.1a: translate problems in mathematical contexts into mathematical processes).

Exemplar 3

7(b)

$$f(x) = \frac{1}{\sqrt{17\cosh x - 15\sinh x}} = \frac{1}{\sqrt{e^{-x}(e^{2x}+16)}}$$

$$S = \pi \int_0^{\ln 3} (f(x))^2 \, dx = \pi \int_0^{\ln 3} \frac{1}{e^{-x}(e^{2x}+16)} \, dx$$

$$= \pi \int_0^{\ln 3} \frac{e^x}{e^{2x}+16} \, dx$$

7(b)	(continued)
	let $u = e^x$, $du = e^x\,dx$ $\therefore$ $dx = \frac{du}{u}$
	$x \to 0$, $u \to 1$
	$x \to \ln 3$; $u \to 3$
	$\therefore \; S = \pi \int_1^3 \frac{u}{u^2+16} \times \frac{du}{u}$
	$S = \pi \int_1^3 \frac{du}{u^2+16} = \pi \int_1^3 \frac{du}{u^2+4^2}$
	$= \pi \left[\frac{1}{4} \tan^{-1}\left(\frac{u}{4}\right) \right]_1^3$
	$= \frac{\pi}{4} \tan^{-1}\left(\frac{3}{4}\right) - \frac{\pi}{4} \tan^{-1}\left(\frac{1}{4}\right)$
	$= \frac{\pi}{4}\left[\tan^{-1}\left(\frac{(3)}{4}\right) - \tan^{-1}\left(\frac{1}{4}\right)\right]$
	~~$\tan\left(\frac{3}{4} + \frac{1}{4}\right) = \tan\left(\frac{3}{4}\right.$~~
	let $A = \tan^{-1}(3/4)$, $B = \tan^{-1}(1/4)$, $\tan A = 3/4$, $\tan B = 1/4$
	$\tan(A \mp B) = \frac{\tan A \mp \tan B}{1 \pm \tan A \tan B} = \frac{3/4 \mp 1/4}{1 + 3/4 \times 1/4} = \frac{16}{13}$ ~~13~~ $= \frac{8}{19}$
	$\tan^{-1}(3/4) - \tan^{-1}(1/4) = \tan^{-1}(8/19)$
	$\therefore \; S = \frac{\pi}{4} \tan^{-1}\left(\frac{8}{19}\right)$ /// $\quad r = \frac{1}{4}$, $q = \frac{8}{19}$

Exemplar 3 illustrates a fully correct response and contains all the details expected in a response to a 'Detailed Reasoning' question. The final step (AO3.1a) is very well articulated and explained.

Questions 8 (a) and (b)

8 A children's play centre has two rooms, a room full of bouncy castles and a room full of ball pits. At any given instant, each child in the centre is playing either on the bouncy castles or in the ball pits. Each child can see one room from the other room and can decide to change freely between the two rooms. It is assumed that such changes happen instantaneously.

The number of children playing on the bouncy castles at time t hours, is denoted by C and the corresponding number of children playing in the ball pits is P. Because the number of children is large for most of the time, C and P are modelled as being continuous.

When there is a different number of children in each room, some children will move from the room with more children to the room with fewer children. A researcher therefore decides to model C and P with the following coupled differential equations.

$$\frac{\mathrm{d}P}{\mathrm{d}t} = \alpha(P - C) + \gamma t$$

$$\frac{\mathrm{d}C}{\mathrm{d}t} = \alpha(C - P)$$

(a) Explain why α must be negative. **[1]**

After examining data, the researcher chooses $\alpha = -2$ and $\gamma = 32$.

(b) Show that P satisfies the second order differential equation $\frac{\mathrm{d}^2P}{\mathrm{d}t^2} + 4\frac{\mathrm{d}P}{\mathrm{d}t} = 64t + 32$. **[2]**

In Question 8 part (a), the majority of candidates did not gain the available mark of AO2.4, explain their reasoning. They generally found explaining their reasoning challenging. Besides addressing the sign of the rate of change of C and the sign of $C - P$, their explanation also needed to be in the context of children moving between rooms.

In part (b), the majority gained full marks. Typically, those who correctly began with differentiating dP/dt or C, successfully reached the expected equation. However, some candidates got lost during the process of substituting for C. In part (b) AO2.4 (explain their reasoning) and AO3.4 (use mathematical models) were tested.

Questions 8 (c) (i), (ii), (iii), (d) and (e)

(c) **(i)** Find the complementary function for the differential equation from part **(b)**. **[1]**

(ii) Explain why a particular integral of the form $P = at + b$ will not work in this situation. **[1]**

(iii) Using a particular integral of the form $P = at^2 + bt$, find the general solution of the differential equation from part **(b)**. **[3]**

At a certain time there are 55 children playing in the ball pits and 24 children per hour are arriving at the ball pits.

(d) Use the model, starting from this time, to estimate the number of children in the ball pits 30 minutes later. **[4]**

(e) Explain why the model becomes unreliable as t gets very large. **[1]**

In part (c) (i) the majority of candidates gained the available mark by finding the complementary function using the auxiliary equation. However, some of them solved $m^2 + 4 = 0$ instead, which led to incorrect solutions.

Part (c) (ii) was less well answered. Successful candidates recognised that there was already a constant in the complementary function. Although most observed this, their answers were often too vague to be accepted (AO2.4, explain their reasoning).

In part (c) (iii), where AO3.4 (use mathematical models) is tested, many candidates successfully used the particular integral to find the coefficients and understood that the final solution for P should be expressed as a sum of the particular integral and the complementary function. This showed a good grasp of the method required to solve such differential equations.

In part (d), approximately one third of the candidates achieved full marks, while roughly three quarters obtained at least 1 mark. A common cause of error was incorrectly equating the values of 55 and 24 to the function and its derivative, respectively, without substituting t=0. Those who earned 1 mark often did so by finding dP/dt. Those who gained the first 2 method marks and went on to calculate P after 30 minutes, usually rounded their decimal answer down correctly to represent the number of children accurately. In part (d), AO3.3 (translate situations in context into mathematical models) and AO3.4 (use mathematical models) were assessed.

Finally, in part (e) the majority of candidates gained the available mark of AO3.5b (recognise the limitations of models). Correct responses commonly addressed the unrealistic nature of the model, namely the fact that the number of children cannot increase indefinitely. Only a few referred to the context and limitations, such as the physical space or time constraints. Some responses presented the term 'unreliable,' which was provided in the question, but better ones referred to the likelihood of the situation.

Assessment for learning

Candidates should routinely be exposed to modelling questions, to appreciate the need for clarity of explanations and precise terminology.

Question 9 (a)

9 In this question, the argument of a complex number is defined as being in the range $[0, 2\pi)$.

You are given that ω_k, where $k = 0, 1, 2, ..., n-1$, are the n n^{th} roots of unity for some integer n, $n \geqslant 3$, and that these are given in order of increasing argument (so that $\omega_0 = 1$).

(a) With the help of a diagram explain why $\omega_k = (\omega_1)^k$ for $k = 2, ..., n-1$. **[3]**

Approximately one third of the candidates gained no marks in part (a) and a small proportion achieved full marks. Although in some cases it seemed that the candidate may have run out of time, in other cases it was clear that they did not understand the demand of the question. Candidates often drew diagrams for a specific *n*-gon, but these attempts were usually unsuccessful. Some tried to use induction, but their arguments lacked rigour.

The most successful responses used the alternative method provided in the mark scheme. This part question assessed AO2.1 (construct rigorous mathematical arguments, including proofs), AO2.2a (make deductions) and AO2.4 (explain their reasoning).

Question 9 (b)

(b) Using the identity given in part **(a)**, show that $\sum_{k=0}^{n-1} \omega_k = 0$. **[2]**

In Part (b), many candidates recognised the need to use a geometric sequence; however, common errors were to have $1 - \omega_1^{n-1}$ instead of the correct $1 - \omega_1^n$ at the numerator in their formula and/or using a generic ω instead of ω_1. This led to incorrect answers despite a sound understanding of the required method. In this part of the question, AO3.1a (translate problems in mathematical contexts into mathematical processes) and AO2.2a (make deductions) were tested.

Questions 9 (c), (d) and (e)

(c) Show that if z is a complex number then $z + z^* = 2\text{Re}(z)$. **[1]**

(d) Using the results from parts **(b)** and **(c)** show that $\sum_{k=0}^{n-1} \text{Re}(\omega_k) = 0$. **[1]**

(e) With the help of a diagram explain why $\text{Re}(\omega_k) = \text{Re}(\omega_{n-k})$ for $k = 1, 2, ..., n - 1$. **[1]**

In part (c), in which AO2.1 (construct rigorous mathematical arguments, including proofs) was tested, the vast majority of candidates secured the mark. Essentially only responses in which z was not properly defined, lost the mark.

In part (d) few candidates were able to obtain the available AO3.1a mark (translate problems in mathematical contexts into mathematical processes). Successful candidates were able to use the previous parts of the question correctly in their justification. For those who did not gain the mark, the main issue was with trying to obtain the required equation with no reference to the result of (c) and in some case with no reference to the result of (b) either.

In part (e), which again assessed AO2.1, not many responses received the available mark. Successful responses generally referenced the symmetry about the real axis and the concept of conjugate pairs, indicating a good understanding of the underlying geometric and algebraic principles.

Questions 9 (f) (i) and (ii)

You should now consider the case where $n = 5$.

(f) **(i)** Use parts **(d)** and **(e)** to deduce that $\cos\frac{4\pi}{5} = a + b\cos\frac{2\pi}{5}$, for some rational constants a and b. **[2]**

(ii) Hence determine the exact value of $\cos\frac{2\pi}{5}$. **[2]**

About one third of the candidates obtained full marks in part (f) (i). Most students successfully found the first argument. However, only a few managed to use parts (d) and (e) of the question to find the correct formula, as the command word 'hence' requested. This shows that while candidates could tackle parts of the problem in isolation, integrating information from different sections proved challenging (AO2.2a, make deductions).

In part (f) (ii), approximately one in ten candidates obtained both marks. Those who succeeded in part (f) (i) and had a formula to use, were generally successful in this part too. The main challenge for candidates was providing a valid argument for rejecting one of the solutions to the quadratic equation (AO2.3, assess the validity of mathematical arguments).

Assessment for learning

To improve performance, candidates should focus on:

- drawing accurate and relevant diagrams while ensuring they understand the mathematical concepts they represent
- clearly defining all variables and terms used in their solutions
- integrating information from various parts of the question to form cohesive and comprehensive responses
- providing rigorous and well-structured arguments, especially when justifying the rejection of solutions in problems involving equations.

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