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Examiners' report

A LEVEL

FURTHER MATHEMATICS A

OCR Level 3 Advanced GCE in Further Mathematics A

H245

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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 responses 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 Teach Cambridge.

Paper Y545 series overview

Overall, candidate performance improved on this paper compared to last year. There were some very well-answered questions, for instance Question 2 on using the vector product to calculate the area of a triangle and the scalar triple product to calculate the volume of a tetrahedron, and Question 7 on calculating the area of the surface of revolution for a curve defined in parametric form. It is encouraging to see that these topics which were introduced in the recent reform into the A Level Further Mathematics A specification are now firmly established in students' knowledge and abilities. Other questions which showed solid performances were Question 5, on (simultaneous) linear congruences (again a newer topic) and Question 8 on modelling, demonstrating that candidates are becoming increasingly familiar with this strand of the specification.

As is often the case, candidates found problem-solving questions and proofs challenging, especially Questions 1 and 3 on number theory and the second part of Question 6, with a group of matrices whose elements were elements of a modular group themselves.

It was apparent that the vast majority of candidates managed to complete the paper in the time allocated.

Candidates who did well on this paper generally:	Candidates who did less well on this paper generally:
• read the questions carefully to make sure that they used the requested method and that they had satisfied all the requirements • were able to use and apply standard techniques with confidence • demonstrated familiarity with topics that are regularly assessed, which could be due to their practice using past paper questions • communicated well using mathematical language correctly • used their calculator efficiently.	• made arithmetic/algebraic errors which prevented them from gaining straightforward marks in the paper • produced unclear explanations or incomplete mathematical arguments • struggled with problem-solving elements of questions • could not start/complete proofs • did not answer questions with the right level of detail, as signposted by specific command words.

Question 1 (a)

1 (a) A student claims that the order of 5 modulo 37 is 5.

Without calculation, explain why this student's claim must be incorrect. **[1]**

Approximately three quarters of candidates did not gain the available mark in this question, demonstrating lack of knowledge of Ref. 8.02n of the Specification: know that the order of a number modulo p, is a factor of $p-1$. In this question, AO2.3 (assess the validity of mathematical arguments) is tested.

Misconception

The most common response to this question was that, since 5 and 37 are coprime, then Fermat's little theorem holds and 'therefore' 5 cannot be the order of 5 mod 37. Another frequently observed response was that $5 \nmid 37$, followed by the same conclusion.

Question 1 (b)

(b) Show that the order of 5 modulo 37 is 36. **[3]**

This question part was completed incorrectly by the majority of candidates. A significant minority did not attempt it. Many found this question part to be very challenging. Below is an example of a response gaining all 3 marks. In this part question, AO2.1 (construct rigorous mathematical arguments, including proofs) and AO2.2a (make deductions) are assessed.

Exemplar 1

1(b)	by Fermat's little theorem: $5^{36} \equiv 1 \pmod{37}$
	but we must check that this is the smallest such integer.
	by Lagrange's theorem, order of 5 could be 2, 3, 6, 12, 4, 9
	or 18
	$5^2 \equiv 25 \not\equiv 1 \pmod{37}$ $\quad$ $5^{18} \equiv 6 \times 6 \equiv -1 \not\equiv 1 \pmod{37}$
	$5^3 \equiv 125 \equiv 14 \not\equiv 1 \pmod{37}$ $\quad$ hence order of 5 is 36
	$5^4 \equiv 14 \times 5 \equiv 33 \not\equiv 1 \pmod{37}$ $\quad$ modulo 37.
	$5^6 \equiv 14 \times 14 \equiv 11 \not\equiv 1 \pmod{37}$
	$5^9 \equiv 11 \times 14 \equiv 6 \not\equiv 1 \pmod{37}$
	$5^{12} \equiv 11 \times 11 \equiv 10 \not\equiv 1 \pmod{37}$

This response gains full marks in part (b). The candidate recognises that only powers of 5 to a factor of 36 (mod 37) need to be checked and duly lists all the factors of 36 (excluding 1 and 36). Then evaluating the first of these powers, $5^2 \equiv 25 \pmod{37}$, gains the first M mark. A B mark follows for correct evaluation of the second power $5^3 \equiv 14 \pmod{37}$, and finally the A mark is awarded for correct evaluation of all the remaining powers, thus concluding that the order of 5 mod 37 is 36.

Assessment for learning

Candidates should be reminded that the command word **'Show that'** signposts that explanations have to be sufficiently detailed to cover every step of their working.

Misconception

A significant number of candidates did not demonstrate knowledge of the fact that $p - 1$ (with p prime) is not necessarily the least positive integer for which $a^n \equiv 1 \pmod{p}$ (hcf(a, p)=1). Many just quoted Fermat's little theorem, stating that because 37 is prime and hcf $(5,37) = 1$, then $5^{37-1} \equiv 1 \pmod{37}$ and therefore the order of 5 mod 37 had to be 36.

OCR support

For support material on number theory, see Delivery Guide: Section 8.02 Number Theory.

Question 3 (a)

3 Let $N = 10a + b$ and $M = a - 3b$, where a and b are positive integers and $0 \leqslant b \leqslant 9$.

(a) By considering $3N + M$, prove that $31 \mid N$ if and only if $31 \mid M$. **[4]**

In this question approximately one third of the candidates gained either 3 or 4 marks. Here a variety of AOs are tested:

- AO2.1 construct rigorous mathematical arguments, including proofs
- AO2.2a make deductions
- AO2.4 explain their reasoning.

Candidates were required to prove an equivalence statement on divisibility of two (positive) integers (N and M) by 31. Some scaffolding was provided, namely they were invited to consider a linear combination of the two numbers, which yields a multiple of 31 (the first M mark). Subsequently, they had to prove that if $31|N$, then $31|M$ (proof in one direction) and that if $31|M$, then $31|N$ (proof in the other direction), each for a M mark. Complete proof with statement on a required hcf would then gain the final A mark.

While the almost all the candidates obtained the first M mark for the linear combination, a significant proportion did not know how to start the proof or only attempted the proof in one direction. Proofs are part of A Level Mathematics Specification (Ref. 1.01) and should be revised/practised in the context of Number Theory in Additional Pure. Questions like 3 (a) have often featured in Y535 past papers (see e.g. June 2022 Question 4, June 2023 Question 5 (c), so candidates may find it useful to practise AS past papers too in preparation for their assessment.

Exemplar 2

3(a)	$N = 10a + b \qquad M = a - 3b$
	$3N + M = 3(10a + b) + a - 3b$
	$= 30a + \cancel{3b} + a \cancel{-3b}$
	$= \cancel{30}\ \cancel{33a}\ 31a$
	~~if 31~~ $31 \mid 31a \Rightarrow 31 \mid (3N+M)$
	if $31 \mid N \Rightarrow N = 31k \qquad$ if $31 \mid M \Rightarrow M = 31k$
	$M = 31a - 31k \times 3 \qquad 3N = 31a - 31k$
	$M = 31(a - 3k) \qquad 3N = 31(a - k)$
	$\Rightarrow 31 \mid M \qquad \Rightarrow 31 \mid N$ since
	$\therefore 31 \mid N \Leftrightarrow 31 \mid M \qquad \text{hcf}(31, 3) = 1$

This response gains full marks in part (a). The candidate works out the suggested linear combination (first M mark); they then divide the space in two columns, on the left is the proof that if $31|N$, then $31|M$ (proof in one direction) and on the right is the proof in the other direction (if $31|M$, then $31|N$), each for a M mark. Conclusion of equivalence (with required hcf) follows and gains the A mark.

Assessment for learning

Candidates would benefit from practising AS Level past papers, as well as A Level past papers, in preparation for their assessment.

Assessment for learning

Candidates should be reminded that the command word 'Prove' instructs them to provide a formal mathematical argument to demonstrate the validity of a statement.

More information about command words can be found in section 2b of the specification. OCR have also produced a poster which can be used in the classroom.

Question 4 (a)

4 In this question you must show detailed reasoning.

The surface S is given by the equation $z = 4x^2y - 3xy^2 - 5x$ for all real values of x and y.

(a) The point $P(1, 1, -4)$ lies on S.

Find the equation of the tangent plane to S at P. **[4]**

Question 4 (b) (i)

(b) The point Q is a stationary point of S with positive x- and y-coordinates.

(i) Find, in exact form, the coordinates of Q. **[5]**

Candidates answered part (a) of Question 4 extremely well in general. They also tackled part (b) with high degree of success. The main error made by candidates was to failing to exclude $x = 0$ as a solution of $\frac{\partial z}{\partial x} = 0$ (or to divide the equation by x without even considering the possibility of $x = 0$ as a solution), followed by not calculating the z-coordinate of the stationary point, once they had found x and y.

In this question, AO3.1a (translate problems in mathematical contexts into mathematical processes) and AO2.1 (construct rigorous mathematical arguments, including proofs) were assessed.

Assessment for learning

Candidates should be reminded that stationary points of 3-D surfaces need to be stated as points in three dimensions, by means of three coordinates.

Question 4 (b) (ii)

(ii) Find the value of the determinant of $\mathbf{H}$, the Hessian matrix of S, at Q. **[4]**

The '**DR**' requirement (detailed reasoning) was particularly relevant in this part of Question 4, as explicit substitution of the x and y coordinate of the stationary point into the second partial derivatives or into the candidates' algebraic expression of the determinant of the Hessian matrix was required to gain full marks. Indeed, one half of the responses obtained all the available marks here, demonstrating that candidates are, in general, fully aware of the level of detail and clarity required by the **DR** command word.

Assessment for learning

Even though the **'show detailed reasoning'** command word is familiar to most candidates, it is still useful to remind them that their response should show a detailed and complete analytical method, allowing the line of their argument to be followed.

Question 5 (a) (b)

5 **(a)** Determine the solution of the linear congruence $3x \equiv 7 \pmod{13}$. Give your answer in the form $x \equiv a \pmod{13}$, where $0 \leqslant a < 13$. **[2]**

(b) Hence or otherwise, determine the solution of the simultaneous linear congruences $3x \equiv 7 \pmod{13}$, $7x \equiv 3 \pmod{31}$. **[4]**

Almost all the candidates dealt with the linear modular congruence in part (a) swiftly and efficiently. Two lines of working were generally enough, the first line to show the method adopted (mostly finding an equivalent to 7 mod 13 which is divisible by 3 or multiplying through by 9, the multiplicative inverse of 3 mod 13) and the second line with the solution. Only a few did not provide a justification for the result found, not appreciating that this is what the command word '**determine'** entails. In this scenario, responses without any working scored 0 marks.

The simultaneous linear congruences in part (b) allowed for a rich variety of methods, which are difficult to encapsulate in commonly observed responses. Salient features were combining two bases into one variable, which the vast majority of candidates accomplished. In the mark scheme, justification in terms of hcf was required, to make sure the existence of a solution, but it was often omitted. A few candidates chose to use the Chinese Remainder Theorem. Arithmetic errors were frequent but not too costly in this scenario. This part question assessed the following:

- AO2.1 - construct rigorous mathematical arguments, including proofs
- AO2.2a - make deductions
- AO2.4 - explain their reasoning.

Question 6 (a) (i), (ii) and (iii)

6 In this question, the set S is $\{2, 4, 6, 8\}$, and $\times_{10}$ is the operation of multiplication modulo 10.

(a) The group G consists of the set S, under the operation $\times_{10}$.

(i) Complete the Cayley table for G given in the Printed Answer Booklet. **[1]**

(ii) State the identity element of G. **[1]**

(iii) State the order of each non-identity element of G. **[2]**

Almost all the candidates dealt with part (a) successfully, demonstrating knowledge of and skills in finite groups based on modular arithmetic.

Question 6 (b) (i), (ii) and (iii)

(b) The group H consists of all 2×2 matrices of the form $\begin{pmatrix} a & 0 \\ 0 & b \end{pmatrix}$, where $a,\ b \in S$, under the operation of matrix multiplication (using $\times_{10}$ to multiply elements of S).

(i) State, with justification, the order of H. **[2]**

(ii) State also the identity element of H. **[1]**

(iii) State all the elements of H of order 2. **[2]**

Part (b) of this question on groups presented some degree of challenge, as it contained a group of diagonal matrices whose elements are the elements of the original modular group in part (a). More than a half of the candidates were able to establish the order of the new group correctly and to explain their reasoning (AO2.4). A few candidates were under the misconception that the original modular group and the matrix group had to be isomorphic and therefore had the same order. Almost every candidate was able to deduce the identity element of the new group (AO2.2a - make deductions). Identifying one of the matrices of order 2 seemed to be straightforward for many candidates, while deducing the remaining two matrices of order 2 (again AO2.2a) proved more challenging. A few candidates added the identity element to the list of matrices of order 2, thereby not gaining one of the two B marks.

Question 6 (b) (iv)

(iv) Using the result of part **(a)(iii)**, or otherwise, explain why all the (non-identity) elements which do not have order 2 must have order 4. **[3]**

More than a half of the candidates did not answer part (b) (iv) correctly and did not give a reason to justify the desired result. Many candidates answered this part question essay-style, with extended responses often missing the point, rather than providing mathematical equations or expressions in their explanations.

Of those who answered the part question successfully, a good proportion of them arrived at the correct conclusion by considering $\begin{pmatrix} a & 0 \\ 0 & b \end{pmatrix}^2$ and equating it to $\begin{pmatrix} a^2 & 0 \\ 0 & b^2 \end{pmatrix}$, rather than considering the fourth power of the matrix element as per main scheme. This matrix identity (or an equivalent one) was enough for the B mark and was essential to evidence that candidates were really considering the order of the elements of group H (the matrix group) and not just the order of the elements of group G (the modular group). Often responses would contain reference to (element of) order (1,), 2 or 4, without specifying which group they belong to. While a generic statement like this would receive the M mark, only a complete argument, with explicit exclusion of the identity and the elements of order 2 from part (b) (iii), would gain the A mark.

In this part question, in which AO2 is assessed, constructing a rigorous mathematical argument to reach the desired conclusion was essential. AO3.1a (translate problems in mathematical contexts into mathematical processes) was also tested.

Exemplar 3

6) b) iv) $\begin{pmatrix} a & 0 \\ 0 & b \end{pmatrix}^2 = \begin{pmatrix} a^2 & 0 \\ 0 & b^2 \end{pmatrix}$

if $b^2, a^2 \not\equiv 6 \pmod{10}$

$a^2, b^2 \equiv 4 \pmod{10}$

from cayley table

$b^4, a^4 = 4^2 \equiv 6 \pmod{10}$

so if not order 2

then order 4

This response illustrates a concise, but complete explanation, which is structured around mathematical facts and uses as few words as possible. Firstly, the matrix identity gains the first (B) mark; then, consideration of quadratic residues mod 10 in S (6 or 4 only) and the statement that the square of elements of H of order (1,) 2 would yield $\begin{pmatrix} 6 & 0 \\ 0 & 6 \end{pmatrix}$, obtains the second (M) mark. Finally, the conclusion is drawn that all elements which are not (the identity nor) order 2, making the argument complete for the final A mark.

OCR support

For support material on groups, see Delivery Guide: Section 8.03 Groups.

A Level Maths: what makes a mathematical explanation?

Question 6 (b) (v)

(v) State whether or not H is cyclic. You must give a reason for your answer. **[1]**

This part question tests AO2.4, which requires an explanation of the candidate's reasoning. Approximately half of the candidates gave the correct statement (group H is not cyclic), supported by a valid reason, which usually was that there is no element of order 16. A general statement like 'not cyclic as there is no generator' was not given the single available mark.

Assessment for learning

Candidates may find it useful to have frequent exposure to problems involving group properties, including those set in unfamiliar contexts, with a strong emphasis on the importance of clear and logical reasoning when constructing proofs.

Question 7

7 In this question you must show detailed reasoning.

A curve is defined parametrically by $x = \cos^3 t$, $y = \sin^3 t$, for $0 \leqslant t \leqslant \frac{1}{2}\pi$. When the curve is rotated through 2π about the x-axis, a surface of revolution is formed with surface area A.

Determine the exact value of A. **[8]**

Most candidates obtained full marks in this question, which required the implementation of multiple problem-solving steps, and candidates found each of them fairly accessible in isolation. Candidates who made a good start were those who used the chain rule to differentiate x and y with respect to t, whereas those who expressed $\cos^3 t$ as $\cos t \times \cos^2 t$ and then $\cos^2 t$ in terms of $\cos 2t$ (and similarly for $\sin^3 t$) before differentiating, usually made no progress. Another crucial problem-solving step was to factorise $\dot{x}^2 + \dot{y}^2$ as $9\cos^2 t \sin^2 t(\cos^2 t + \sin^2 t)$ and then use a trigonometric identity to replace the brackets with 1. Candidates who instead replaced either $\cos^2 t$ with $1 - \sin^2 t$ (or the other way round) in $\dot{x}^2 + \dot{y}^2$ ended up with long algebraic manipulations and were often unable to make the necessary simplifications to produce an integrable function. Finally, a small proportion of candidates were unable to devise a method to integrate $\sin^4 t \cos t$, neither substitution nor reverse chain rule. Only a handful of candidates did not have the correct factor of 2π in the area formula. There were plenty of AO3.1a marks, for translating problems in mathematical contexts into mathematical processes, featured in this question.

Assessment for learning

Students should be reminded that when a question opens with **show detailed reasoning,** their solution should lead to a conclusion showing a complete analytical method, by providing sufficient detail to allow the line of their argument to be followed. Calculators can still be used to offload numerical computations, allowing them to focus on problem-solving and conceptual understanding rather than arithmetic.

Questions 8 (a) (i) and (ii)

8 **(a)** The members of the family of the sequences $\{G_n\}$ satisfy the **first-order** recurrence relation $G_{n+1} = 1.25 - qG_n$, for $n \geqslant 0$,
where q is a positive constant.

(i) Determine, in terms of q, the general solution of the first-order recurrence relation. **[3]**

(ii) Hence explain why, when q is close to zero, G_n is approximately constant and equal to 1.25. **[2]**

This modelling question had overall solid responses from candidates. In part (a) (i), almost all candidates earned at least 1 mark. The majority interpreted the command word 'Determine' correctly, justifying how they arrived at the complementary and particular solutions. However, some did not gain full marks as the complementary solution was given without a general coefficient or as Aq^n or the particular solution as 1.25.

In part (b), about three quarters of the candidates gained both marks available. Given that one B mark was for stating that $q^n \to 0$ for large n and q small, even responses whose complementary solution did not contain a general coefficient or of the type Aq^n could earn this mark. AO2.1 (construct rigorous mathematical arguments, including proofs) and AO2.4 (explain their reasoning) were assessed in this part question.

Question 8 (a) (iii)

(iii) In the case where $G_1 = 1.22$ and $G_2 = 1.2378$, find the values of q and G_0. **[3]**

This problem-solving part question (AO3.1a - translate problems in mathematical contexts into mathematical processes) generated some interesting responses. Over a half of the candidates gained full marks. Those who realised that they could use the given recurrence relation for $n = 1$ (to find q) and then for $n = 0$ (to find G_0), answered this part question successfully and efficiently. If instead they started from their general solution G_n, substituted in $n = 1$ and $n = 2$, obtaining two (fairly complicated) simultaneous equations, they often were not able to gain full marks. In fact, in a significant number of cases, candidates would start off with the simultaneous equations method, only to abandon it halfway through having realised that there was a much more efficient method and switched to the latter. Therefore, most responses used a much larger space than the one available.

Question 8 (b) (i)

(b) The population of a species of fish F_n is being modelled by the **second-order** recurrence relation

$$F_{n+2} = 1.25F_{n+1} - rF_{n+1}F_n,$$

where r is a positive constant and n is the number of weeks since the start of the breeding season.

You are given that the value of r is such that the model predicts that the population approaches a limiting value, L.

(i) Determine L in terms of r. **[2]**

Approximately three quarters of the responses used the mathematical model (AO 3.4) to produce a quadratic equation, gaining the first M mark, and then to obtain the correct limiting value L, gaining the second available mark. The most common source of error, for the quarter of the candidates who earned no marks, was to set $F_n = x^0$, $F_{n+1} = x^1$, $F_{n+2} = x^2$ in the recurrence relation to produce a 'limiting value' of $1.25r$, trying to solve a the second-order recurrence relation as if it was linear and not understanding the concept of limit of a sequence.

Question 8 (b) (ii)

(ii) Determine what happens if a term of the sequence is greater than $\frac{5}{4r}$. **[2]**

This part question proved challenging for most of the candidates, as is often the case when modelling AOs are tested (3.3 Translate situations in context into mathematical models and 3.5a Evaluate the outcomes of modelling in context). Over a half of the candidates just gave an explanation in words which was not sufficient in this case, as the command word '**Determine**' was in the question stem. Approximately one third of the responses earned the first M mark for substituting either $F_n > \frac{5}{4r}$ or $F_n = \frac{5}{4r}$ into the second-order recurrence relation. In order to achieve the accuracy mark, candidates needed to evaluate the outcome of the model in context. Therefore, besides stating that the number of fish becomes negative or zero, the interpretation that 'the fish become extinct' was required. Few candidates reached this conclusion.

Assessment for learning

Students should be reminded that the command word **Determine** signposts that justification should be given for any results found, including working where appropriate.

Question 8 (b) (iii) and (iv)

(iii) Explain why the modified recurrence relation $F_{n+2} = \mathrm{INT}(1.25F_{n+1} - rF_{n+1}F_n)$ may be preferable when modelling this fish population. **[1]**

(iv) When $r = 0.0001$, both $F_{n+2} = 1.25F_{n+1} - rF_{n+1}F_n$ and $F_{n+2} = \mathrm{INT}(1.25F_{n+1} - rF_{n+1}F_n)$ predict that the fish population approaches a limiting value.

By finding the limiting value for each model, when $F_0 = 2450$ and $F_1 = 2475$, compare the two models for the fish population. **[3]**

Most of the candidates earned the available mark in part (b) (iii), recognising the limitation of the model and explaining why the modified recurrence relation with INT was preferable (AO3.5b Recognise the limitations of models).

Most of the responses to part (b) (iv) contained the correct value of the limit for the unmodified recurrence relation (AO2.2a make deductions), even though a number of candidates arrived at it starting anew by iterating the recurrence relation (by calculator) rather than substituting the given value of r into the expression $L = \frac{1}{4r}$ derived in part (b) (i). The second B mark (3.1b Translate problems in non-mathematical contexts into mathematical processes) proved harder to achieve and indeed just a minority of candidates achieved it by providing the correct limit of the modified recurrence relation (2497). A common error here was a 'limit' of 2487, obtained by calculating $F_2 = 2487.375$ with the original recurrence formula for the given values of F_0 and F_1 and then rounding it down applying INT. Another common error was to iterate the recurrence relation without INT and then rounding down the values obtained at each step. Moreover, some candidates thought that the limit of the recurrence relation with INT was also 2500, since it is an integer value. Finally, very few responses gained the third B mark of AO3.2a (interpret solutions to problems in their original context) for analysing the models and concluding that they are similar.

Misconception

A common error when comparing the values of sequences described via a recurrence relation without INT and the same with INT, was that u_n for the latter was obtained by rounding down the corresponding value of the former, rather than substituting u_{n-1} and u_{n-2} into the recurrence relation with INT.

OCR support

For support material on sequences and series, see OCR Delivery Guide: Section 8.01 Sequences and Series.

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