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Examiners' report

A LEVEL

FURTHER MATHEMATICS B (MEI)

OCR Level 3 Advanced GCE in Further Mathematics B (MEI)

H645

For first teaching in 2017

Y435/01 Summer 2025 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 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 Y435/01 series overview

This was the fourth full summer sitting of this paper, which covers the Extra Pure option of A Level Further Mathematics B (MEI) – H645, since June 2019.

The paper comprised five compulsory questions, sampling content from almost every area of the specification. Almost all candidates attempted every part of each question and there was little evidence of time pressure. Overall standards were quite high and, although presentation was variable, solutions were generally set out well.

Throughout the paper it was expected that candidates were able to demonstrate a high level of understanding of the (sometimes abstract) topics. Several questions required proof of a given result, and the advice is that candidates should provide a detailed explanation of all their working; the examiner should not need to fill in any gaps of reasoning or calculation even if some of the steps appear obvious.

The following questions were answered well by most candidates:

Questions 1 (a), 1 (b), 1 (c), 2, 3 (b), 3 (c), 3 (d) (i), 4 (a), 4 (c), 5 (a) (i) and 5 (a) (ii).

The following questions proved to be more challenging:

Questions 1 (d), 3 (a), 3 (d) (ii), 4 (b), 4 (d), 5 (b) and 5 (c).

While most candidates appear to do well when tackling most of the specification subject areas, Group Theory still seems to represent a challenge to many. The highly abstract nature of the discipline presents a problem to candidates and most find the requirement to set out a detailed, rigorous explanation or proof, pitched at the correct level, very difficult indeed. Specifically, candidates are encouraged to learn and use notation and definitions precisely and to use these, within the context of the question, when answering such questions. Equally, candidates are advised against using exclusively word-based explanations since these are seldom rigorous; words should be supported by the appropriate symbols where possible.

Candidates who did well on this paper generally:	Candidates who did less well on this paper generally:
• set out their working neatly, clearly and logically • explained their reasoning rigorously and systematically • included every step, even seemingly trivial ones • used correct technical language and notation • answered the question asked in the specified manner • followed standard methodologies • made any necessary corrections to their work neatly and clearly • gave complete but concise explanations, citing known results or theorems in support, as required • did algebraic manipulation step by step • kept things as simple as possible.	• left out their working or presented it in a poorly or illogically structured way • skipped steps or explanations in their reasoning • lacked rigour in their explanations • used technical language or notation imprecisely or incorrectly • used incorrect or inappropriate methodology • did not answer the actual question asked or provide the answer in the required form • did not use the simplest approach to a question but instead overcomplicated • tried to do too much manipulation in one step • did not read the questions carefully enough.

Question 1 (a)

1 A binary operation, $\circ$, is defined on real numbers a and b by $a \circ b = 3ab$.

(a) Prove that $\circ$ is associative over the real numbers $\mathbb{R}$. **[2]**

Most candidates appreciated what was required here. However, simply finding that both $(a \circ b) \circ c = 9abc$ and $a \circ (b \circ c) = 9abc$ was not sufficient for full marks; it had to be noted that the two equalled each other and that this meant that the condition for associativity was met.

Those candidates that started with the statement $(a \circ b) \circ c = a \circ (b \circ c)$ and then reduced this, in effect, to $0 = 0$ gained no credit since this approach is not a proof.

Some candidates felt that it was appropriate to use their own notation, or no notation at all, to denote equality; there is a universally recognised symbol to denote that one expression is equal to another ('=') and candidates should use this notation and no other.

Some candidates used example values for a, b and c, which was not acceptable for the requirements of a proof, or did not use three different elements.

Some candidates confused associativity with commutativity.

Assessment for learning

With questions like this, candidates should ask themselves whether they have demonstrated to a third party that they have understood the meaning of the property they are being asked to demonstrate. They should also include a conclusion that explicitly states how their algebra has proved their point as a matter of course.

Question 1 (b)

(b) Determine the value of e, the identity element for $\circ$. **[2]**

While most candidates correctly identified the value of e many candidates merely verified the value they had guessed. With the command word 'Determine' this was not considered to be worth full marks; what was required was the statement '$a \circ e = 3ae = a$' which again demonstrates a knowledge of the property being examined. The best candidates considered the definition of e in both directions and also noted that the required value of e is indeed in the set of real numbers. Some even considered the potentially rogue case where $a = 0$. This level of detail was not required since the question does make it clear that an identity element in the set exists, but it was pleasing to note that some candidates are aware of such subtleties.

Question 1 (c)

(c) Explain why $\mathbb{R}$ is closed under $\circ$. **[1]**

Once again, many candidates did not attain the mark here because they did not make it clear that they understood the meaning of the property in question. Answers along the lines of '$\circ$ is closed because multiplication is closed' while not incorrect were not considered sufficient. Candidates should view questions of this type as asking them to demonstrate that they understand the property in question and also how to demonstrate it in this case.

Some candidates chose to answer the question with a general statement along the lines of 'Because a real number multiplied by another real number is always a real number' (sometimes including the 3 explicitly). While this was considered acceptable in this case, candidates are strongly advised to use definitions and symbols and mathematical notation, which is far safer. Answers along the lines of 'Because real numbers will only produce real numbers' were not considered acceptable while answers along the lines of 'Because $a, b \in \mathbb{R} \Rightarrow a \circ b = 3ab \in \mathbb{R}$' are incontrovertibly correct.

A subtle point is that answers along the lines of 'Because a real number multiplied by another real number cannot be complex' were not considered acceptable (the statement is technically not true since the set $\mathbb{C}$ contains the set $\mathbb{R}$) since the issue here is whether the result of the binary operation $\circ$ acting on two elements of a certain set itself is a member of that set, not whether it is a member, or not, of a different set. After all, perhaps $a \circ b$ is another type of number, neither real nor complex.

Misconception

'Not complex' does not mean 'real' and the two are not interchangeable.

Exemplar 1

1(c)	No element, x, can be generated such that $x \notin \mathbb{R}$. if $a, b \in \mathbb{R}$ ~~[illegible]~~ $a \circ b = c \Rightarrow c \in \mathbb{R}$

This is an example where an over-emphasis on words causes a lack of rigour. Here the word 'generated' is being used without definition. The symbol x appears to change to the symbol c without any explanation. And it is simply stated that $a \circ b \in \mathbb{R}$ without any justification (for example, explicit or implicit mention of multiplication).

Question 1 (d)

(d) Explain why $\mathbb{R}$ under $\circ$ does **not** form a group. Justify your answer. **[2]**

Not many candidates attained both marks here. From the question, and the earlier parts, it is clear that the inverse axiom must be the axiom that is not met and so simply stating this was not sufficient for any credit. To obtain full credit, candidates firstly had to show (not just state) that the element 0 ($\in \mathbb{R}$) does not have an inverse in $\mathbb{R}$ and then had to explain why this means that $\mathbb{R}$ under $\circ$ does not form a group (i.e. because this means that not every element has an inverse in $\mathbb{R}$).

It was very clear that many candidates were confused between the meaning of a^{-1} in abstract algebra and in 'ordinary' algebra. Too many candidates either stated or implied that $aa^{-1} = 1$ (or, indeed, that $a \circ a^{-1} = 1$) neither of which is correct here.

Misconception

In abstract algebra aa^{-1} does not necessarily equal 1.

Question 2 (a)

2 **(a)** Determine the general solution of the recurrence relation $25u_{n+2} - 35u_{n+1} + 12u_n = c, n \geqslant 0$, where c is a constant. **[5]**

This question part was done well by most candidates. However there was a significant minority of candidates that struggled to deal with the trial function, with many of those candidates using $an + b$, or even a quadratic, rather than just a constant.

Quite a few candidates became notationally confused between the 'c' in the question and their 'C' or even 'c', the constant which they used in their trial function.

Assessment for learning

While practising, candidates should try to use different names for their constants (or other parameters) so that they are not confused if their 'first choice name' is already used in the question.

Question 2 (b) (i)

The manager of a company is using the recurrence relation in part **(a)** to model the number of containers held by the company using the sequence $u_0, u_1, u_2, \ldots$ which satisfies this recurrence relation.

The quantity u_0 represents the number of containers held by the company at the **start** of January 2000. The quantity u_n, for $n \geqslant 1$, represents the number of containers held by the company at the **end** of month n, where the first month is January 2000. If necessary, the quantity u_n is rounded to the nearest integer.

The company holds 20 containers at the start of January 2000 and 70 containers at the end of January 2000.

(b) In an initial model the manager uses $c = -10$.

(i) Determine the particular solution for u_n when $c = -10$. **[3]**

Again, this question part was well done by most candidates.

Question 2 (b) (ii)

(ii) The model predicts a single peak value for u_n.

Find, by direct calculation, the largest number of containers held by the company according to the model. **[2]**

Almost all candidates did manage to obtain full marks here. However, not all candidates were successful even though the question explicitly instructed candidates to use 'direct calculation'. In such cases, candidates should trust that the value being asked for will not be very far along the sequence.

Also, as in any modelling question, the answer must make sense in the context of the model; in this case a final answer of '89.2 containers' did not attain the final mark.

Candidates should also realise that attempted solution by differentiation is not appropriate in such questions since the sequence does not represent a continuous function; such an approach would only be accepted alongside a complete argument relating to discretisation.

Misconception

Generally speaking it is not appropriate to use calculus in recurrence relation questions since sequences are not continuous.

Exemplar 2

2(b)(ii)	$U_0 = 20$	$U_5 = 21.92$
	$u_1 = 70$	
	$u_2 = 88$	∴ largest number of containers
	$u_3 = 89.2$	$= \underline{\underline{89.2}}$
	$u_4 = 82.24$	

Candidate has not been awarded the **A1** mark since the final answer, 89.2, is not a sensible answer within the context of the model.

Question 2 (b) (iii)

(iii) Show that the model in part **(b)(i)** breaks down in the 19th month. **[3]**

While most candidates obtained at least 2 marks out of 3 here only about a third of candidate achieved full marks. Candidates were asked to show that the model breaks down 'in the 19th month', not 'by the 19th month' and so to obtain full marks it was necessary not only to show that $u_{19} < 0$ and to explain that this is not possible but also to show that $u_{18} > 0$ and hence that the breakdown occurred **in** the 19th month.

Key point call out – Read Questions Carefully

Candidates should always read questions very carefully.

Question 2 (c)

(c) In a second model the manager uses $c = 10$ instead of $c = -10$.

Show that the second model predicts that eventually the number of containers held by the company will be a constant k, where k is to be determined. **[2]**

This question was very straightforward and most candidates achieved both marks here. However, almost all candidates first found the new particular solution before considering the limit. However, given the form of the General Solution, this is entirely unnecessary in this situation.

Assessment for learning

It is hoped that candidates will be exposed to many different types of recurrence relation solutions and hence become familiar with the typically transient nature of the complementary function (which is often referred to as 'the transient solution').

Question 3 (a)

3 M is the group $(\{0, 1, 2, 3, 4, 5, 6, 7, 8\}, +_9)$ where $+_9$ denotes the binary operation of addition modulo 9.

(a) Write down the identity element of M. Justify your answer. **[1]**

Unfortunately, fewer than half of candidates were able to obtain this mark. When providing justification, candidates must display knowledge of the property in question and then show how it relates to this context. In this regard, stating something like '$a + e = a$' alone is not relevant since the binary operation under question here is not '+' but '$+_9$'.

The successful candidates used symbols rather than words; it is so hard to convey the meaning precisely and unambiguously using words, while symbols can do so precisely and concisely. So, for example, answers along the lines of 'Adding 0 modulo 9 to a number leaves the number alone' were not considered rigorous enough since the issue is not whether the number chosen somehow gets changed but rather whether the result of applying the binary operation with the number and 0 results in the same number or a different number.

Key point call out – Symbols versus Words

Symbols are better at conveying meaning rigorously than words.

Question 3 (b)

(b) By considering the order of M, explain why there can be **no** subgroup of M of order 5. **[2]**

A question of this nature is regularly asked and candidates appeared well prepared and most obtained both marks.

Having said this, candidates would be well-advised to state explicitly the order of *M* in their answers. Candidates are also advised either to quote correctly, or appeal to, Lagrange's theorem in their answers.

Question 3 (c)

You are given that M is a cyclic group.

(c) Find **all** possible generators of M. **[2]**

Again, most candidates obtained both marks available here. However, a substantial minority only obtained 1, with many omitting one or more generator while some included either 3 or 6 or both.

A small number of candidates did not gain a mark due to poor notation, stating a generator, for example, as '<1>' (which is the group generated by '1') rather than just '1'.

Key point call out - Notation

Notation should be learnt precisely and used correctly.

Question 3 (d) (i)

You are given that there is only one proper, non-trivial subgroup of M, denoted by $(H, +_9)$.

(d) **(i)** Write down H. **[1]**

While most candidates did identify *H* correctly a substantial minority did not. Again, many candidates did not demonstrate a clear knowledge of the requirement of the question which was for the subset *H* and not for the subgroup $(H, +_9)$.

Question 3 (d) (ii)

(ii) Show that there can be **no** other proper, non-trivial subgroups of M. **[2]**

Candidates seem to find it difficult to produce correct, complete and rigorous arguments and so not many candidates were given both marks here. There are many ways of showing what is required but the successful responses addressed the issue of 'proper' and 'non-trivial' explicitly before showing that, for example, the only possible candidates to be elements of such a subgroup are already in *H*.

Many candidates were not clear about the meaning of the words 'proper' and 'non-trivial'. While there are differences in the mathematical world, depending largely on the context of the usage, in this unit their meanings are clearly set out in the specification.

Key point call out – Technical Vocabulary

Learn definitions of technical vocabulary from the specification.

Question 4 (a)

4 A surface, S, is defined in 3-D by $z = \mathrm{f}(x, y)$ where $\mathrm{f}(x, y) = x^3 - 12xy^2 + 96y^2 + 30$.

You are given that the point (0, 0, 30) on S is a stationary point.

(a) Determine the coordinates of any other stationary points on S. **[6]**

This question part was very well answered by most candidates.

Question 4 (b)

(b) By sketching the section $z = \mathrm{f}(x, 0)$ on the coordinate axes provided in the Printed Answer Booklet, determine the nature of the stationary point $(0, 0, 30)$ on S. **[2]**

While almost all candidates correctly identified the equation of the section correctly, very few candidates could correctly sketch the graph $z = x^3 + 30$ with a huge number of candidates not showing the graph as horizontal as it crosses the z-axis.

Many candidates also identified the stationary point on S as a point of inflection (which, rather, is the nature of the stationary point of the section). Also, many candidates did not justify their answer, as required by the use of the command word 'determine'.

In consequence, while most scored at least 1 mark, very few candidates managed to score both marks on this question.

OCR support

More information about the meaning of command words can be found in Section 2b of the specification.

A useful classroom poster summarising the meaning of command words.

Question 4 (c)

(c) Determine the value of a. **[5]**

Most candidates coped with this problem-solving question well with the majority scoring full marks. As in previous years, a small number of candidates thought that the normal to a surface at a point was a plane and (usually) formed the equation of the tangent plane at the point.

Question 4 (d)

The contour given by $z = 542$ comprises a straight line and a curve. The curved portion of the contour is denoted by C. You are given that there are **two** points on C where the x coordinate is 8.

(d) Determine the values of the y coordinates at these **two** points on C. **[3]**

This question proved to be far more challenging and very few fully correct solutions were seen. The intended mode of solution was to substitute the z value in and rearrange the equation to find y^2 in terms of x. Then, substitution of the x value, 8, led to a value of 0 for both numerator and denominator. At this level, it was expected that candidates would therefore realise that there must be a common factor of x – 8 which could be cancelled, leading to the correct answer. Other modes of solution were also seen.

Candidates who simply used the y-values from part (a) were not given full credit since there was no justification that the points found actually lie on the curved part of the given contour as required by the question.

Question 5 (a) (i)

5 In this question you must show detailed reasoning.

The matrix **A** is given by $\begin{pmatrix} a & b & 0 \\ -b & a & 0 \\ 0 & 0 & 1 \end{pmatrix}$ where a and b are constants with $a^2 + b^2 = 1$ and $a \neq \pm 1$.

(a) (i) By finding the characteristic equation of **A** in terms of a, show that, for any value of a, 1 is always one of the eigenvalues of **A**. **[3]**

While most candidates did reasonably well on this question, scoring at least 2 out of 3, less than half secured full marks. There are a few reasons for this.

Firstly, as usually happens, many candidates did not actually find the characteristic equation, omitting the '= 0' that is required.

Secondly, many candidates left the parameter b in their answer, in spite of the explicit demand to find in 'terms of a'.

Thirdly, many candidates made algebraic errors when expanding their determinant to form the characteristic polynomial. While the level of algebra required was not challenging, candidates should check their working for careless slips in signs and brackets which occur more often under exam conditions than in the normal classroom environment.

Fourthly, most candidates did not seem to realise that in fact expanding the determinant was not actually necessary and that if the 3rd row (or column) was used to find the determinant then this would come out already factorised. As it is, even if using the 1st row (or column), careful inspection would reveal that 1 - λ is a common factor. Unfortunately, too many candidates seem to be too quick to expand brackets rather than pause to consider the best form of the expression they are working with.

Assessment for learning

Don't expand expressions if it is not necessary to do so. In general, the factorised form is more useful than the expanded form.

Question 5 (a) (ii)

(ii) By showing that the other eigenvalues of **A** are $a \pm \sqrt{a^2 - 1}$, prove that the other eigenvalues of **A** are **not** 1. **[3]**

Once again, most candidates scored at least 2 out of 3, albeit a smaller majority than for Question 5 (a).

Candidates who did not get the characteristic equation correct in part (a) did not generally make too much progress in this part. However, many candidates who did obtain the correct characteristic equation then wasted precious time factorising it (using the knowledge that $1 - \lambda$ must be a factor) when in fact the factorised form was invariably easily obtainable from their earlier working.

The last mark proved hardest to obtain. Many candidates simply stated that the only value of *a* which leads to $\lambda = 1$ is 1, which is not rigorous enough for the command word 'prove'. Many other candidates incorrectly argued that since $a = 1 \Rightarrow \lambda = 1$ then $a \neq 1 \Rightarrow \lambda \neq 1$.

Exemplar 3

5(a)(ii)	$(1-\lambda)\left[(a-\lambda)(a-\lambda)+b^2\right]=0$
	$(a-\lambda)(a-\lambda)+b^2=0$
	$a^2-2a\lambda+\lambda^2+b^2=0$
	$\cancel{a^2}-2a\lambda+\lambda^2+1-\cancel{a^2}=0$
	$\lambda^2-2a\lambda+1=0$
	$(\lambda-a)^2-a^2+1=0$
	$(\lambda-a)^2=a^2-1$
	$\lambda-a=\pm\sqrt{a^2-1}$
	$\lambda=a\pm\sqrt{a^2-1}$
	$\therefore$
	$\cancel{a\pm\sqrt{a^2-1}=1}$
	$a\,\cancel{\mp=\sqrt{a^2-1}}$
	$\cancel{a^2=a^2-1\Rightarrow\text{not }1}$
	$\lambda=1$ only when $a=1$ since a is not 1,
	λ cannot be 1

Candidate has derived and solved the correct equation for **M1A1**. However, the final **B1** is not awarded since candidate has simply stated, rather than proved as per demand, that ‘λ = 1 only when a = 1’.

Question 5 (b)

(b) Hence show that **either** some of the eigenvalues of **A** must be non-real **or** some of the elements of **A** must be non-real. **[3]**

This question proved to be the challenging on the paper for this cohort of candidates and very few candidates were given full marks. There are many approaches to the solution but the intended one was to consider all possibilities for the value of the parameter *a* (as suggested by elimination of *b* in part 5 (a) (i)). But candidates seemed to find it very difficult to consider all possible values systematically. It was not uncommon for candidates to assume that *a* is real but then happily consider the possibility of the non-realness of *b*. Or to consider firstly that *a* is real and > 1 but then instead of considering a being real and –1 < *a* < 1, instead to consider non-real eigenvectors or real *b*.

A lot of candidates made statements which are not true, such as 'if (*a* is real and) *a* < 1 then $\sqrt{1-a^2}$ is real.'

Some candidates seemed to be a little confused by the demand; candidates should realise that in Mathematics, if either A or B is true then it is entirely possible that they are both true.

Assessment for learning

When carrying out a proof by exhaustion it is important to consider all possibilities systematically.

Misconception

If asked to prove that either A or B is true then this does not mean that if A is true then B is not (or vice-versa). A∩B ⊆ A∪B.

Question 5 (c) (i)

You are now given the following information.

- a and b are both real.
- **A** represents a rotation by an acute angle in 3-D space.
- **e** is a real eigenvector of **A** associated with the eigenvalue 1.

(c) (i) Explain the significance of **e**, and the fact that its associated eigenvalue is 1, in relation to the transformation that **A** represents. **[2]**

This question was simply asking candidates to state standard facts about eigenvectors and eigenvalues as they relate to a specific transformation, in accordance with spec point Xm6. It was disappointing, therefore, that most candidates could not simply quote that the eigenvector, **e**, is in the direction of the axis of rotation and that because its eigenvalue is unity then this axis is a line of invariant points.

Question 5 (c) (ii)

(ii) Explain **geometrically** why the other eigenvectors of **A** can **not** be real. **[1]**

As mentioned on previous questions, candidates appear to struggle to 'explain' and this question proved more challenging than part 5 (c) (i). Even so a large minority of candidates did earn this mark with a convincing explanation.

Question 5 (c) (iii)

(iii) Find a vector equation for the axis of rotation of the transformation that **A** represents. **[2]**

Candidates found this last question part very difficult. Most candidates did not appear to recognise the given matrix as a rotation about the z-axis; candidates were expected to recognise that the vector $\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$ is an eigenvector of **A** whose eigenvalue is 1 and this, coupled with the answers to the rest of part 5 (c), is sufficient. Candidates who instead attempted to find this eigenvector formally generally did not succeed but instead deduced from the z equation (which gives $z = z$) not that z can take on any value (eg 1) but instead that $z = 0$. They often then 'solved' the x and y equations incorrectly (the correct solution being $x = y = 0$) and came up with a completely incorrect (and usually non-numerical) eigenvector.

Misconception

? Algebraically, the equation $z = z$ does not imply that $z = 0$ but rather that there is no restriction on the value that z can take.

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