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Examiners' report

FURTHER MATHEMATICS B (MEI)

H645

For first teaching in 2017

Y435/01 Summer 2022 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.

Advance Information for Summer 2022 assessments

To support student revision, advance information was published about the focus of exams for Summer 2022 assessments. Advance information was available for most GCSE, AS and A Level subjects, Core Maths, FSMQ, and Cambridge Nationals Information Technologies. You can find more information on our website.

Paper Y435/01 series overview

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

The paper comprised 5 compulsory questions, covering almost every area of the specification, which nearly all candidates managed to attempt. 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 a majority of candidates:
Question 1, Question 2 (a), Question 2 (b), Question 2 (c), Question 3 (a), Question 4 (b), Question 5 (a) (i), Question 5 (a) (ii).

The following questions proved to be more challenging:
Question 3 (b) (i)-(iii), Question 4 (a), Question 4 (c), Question 4 (d), Question 4 (e) (i)-(iii), Question 5 (a) (iii), Question 5 (b), Question 5 (c), Question 5 (d), Question 5 (e), Question 5 (f).

Candidates who did well on this paper generally did the following:	Candidates who did less well on this paper generally did the following:
• set out their working neatly, clearly and logically • explained their reasoning • included every step, even seemingly trivial ones • used correct technical language • answered the question asked in the specified manner.	• left out their working or presented it in a poorly or illogically structured way • skipped steps or explanations in their reasoning • used technical language imprecisely • used incorrect or inappropriate methodology • did not answer the actual question asked.

Question 1

1 Three sequences, a_n, b_n and c_n, are defined for $n \geqslant 1$ by the following recurrence relations.

$$(a_{n+1} - 2)(2 - a_n) = 3 \text{ with } a_1 = 3$$

$$b_{n+1} = -\tfrac{1}{2}b_n + 3 \text{ with } b_1 = 1.5$$

$$c_{n+1} - \frac{c_n^2}{n} = 1 \text{ with } c_1 = 2.5$$

The output from a spreadsheet which presents the first 10 terms of a_n, b_n and c_n, is shown below.

	A	B	C	D
1	n	a_n	b_n	c_n
2	1	3	1.5	2.5
3	2	–1	2.25	7.25
4	3	3	1.875	27.28125
5	4	–1	2.0625	249.0889
6	5	3	1.96875	15512.32
7	6	–1	2.01563	48126390
8	7	3	1.99219	3.86E+14
9	8	–1	2.00391	2.13E+28
10	9	3	1.99805	5.66E+55
11	10	–1	2.00098	3.6E+110

Without attempting to solve any recurrence relations, describe the apparent behaviour, including as $n \to \infty$, of

- a_n
- b_n
- c_n **[7]**

While most candidates made a reasonable attempt at this question, very few candidates achieved full marks. In most cases, where marks were not awarded this was because candidates did not use the correct terminology. The advised approach would be for candidates to learn the technical descriptors in the relevant specs (found at Xs2 of H645 and Ms10 and Ms11 of H640) and to ask themselves whether each of them applies to the sequence in question, giving any additional details such as limit values or periods.

Candidates should be taught that technical language is important because it conveys a fixed meaning which is universally understood. Candidates should be strongly discouraged from using their own descriptors (such as "gets bigger" or "goes between" or "gets closer to") since these are, in general, open to misinterpretation.

Candidates should also be encouraged to read the questions carefully; in this question, for example, what is asked for is a description of the behaviour of the sequence and not, for example, a description of the behaviour of the first differences of the sequence.

Assessment for learning

Candidates should learn the technical words given in the spec and practise applying them correctly to sequences they encounter.

Question 2 (a)

2 The matrix $\mathbf{A}$ is given by $\mathbf{A} = \begin{pmatrix} 10 & 12 & -8 \\ -1 & 2 & 4 \\ 3 & 6 & 2 \end{pmatrix}$.

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

Show that the characteristic equation of $\mathbf{A}$ is $-\lambda^3 + 14\lambda^2 - 56\lambda + 64 = 0$. **[3]**

Almost all candidates appeared to know what was required to answer this question. However, not all candidates achieved full marks. The question explicitly required "detailed reasoning" and so a solution which simply showed an unsimplified, expanded determinant jumping straight to the given answer did not receive full credit. Candidates should be instructed that the onus is on them to make it clear *how* the answer is being derived.

There is a wide range of different approaches to the expansion of a determinant and all valid such approaches will be assessed inasmuch as this is possible. However, it is important that candidates make their methodology clear or else it is very difficult to make such an assessment.

A small number of candidates missed the right-hand side of the target equation (i.e. the "= 0"). In "Show that" questions it is generally good practice to check that the thing that they are being asked to show is, precisely, the last thing that they write in their solution.

Exemplar 1

2(a)

$(M-I\lambda) = \begin{pmatrix} 10-\lambda & 12 & -8 \\ -1 & 2-\lambda & 4 \\ 3 & 6 & 2-\lambda \end{pmatrix}$ $b = \begin{pmatrix}12\\2-\lambda\\6\end{pmatrix}$ $c = \begin{pmatrix}-8\\4\\2-\lambda\end{pmatrix}$

$b\times c =$

$\begin{pmatrix}12\\2-\lambda\\6\end{pmatrix} \times \begin{pmatrix}-8\\4\\2-\lambda\end{pmatrix} = \begin{pmatrix}(2-\lambda)^2-24\\-48-12(2-\lambda)\\48--8(2-\lambda)\end{pmatrix}$

$= \begin{pmatrix}\lambda^2-4\lambda-20\\12\lambda-72\\-8\lambda+64\end{pmatrix}$ $a = \begin{pmatrix}10-\lambda\\-1\\3\end{pmatrix}$

$\det(M-I\lambda) = \cancel{b\times a}\ (b\times c)\cdot a =$

$\begin{pmatrix}\lambda^2-4\lambda-20\\12\lambda-72\\-8\lambda+64\end{pmatrix}\cdot\begin{pmatrix}10-\lambda\\-1\\3\end{pmatrix} = 10\lambda^2-40\lambda-200$

$\cancel{+10}-\lambda^3+4\lambda^2+20\lambda$

$-12\lambda+72-24\lambda+192$

$= -\lambda^3+14\lambda^2-56\lambda+64$

This candidate has not completed the demand of the question. The characteristic equation has not been shown but, rather, the characteristic polynomial has been found and so the final mark has not been awarded.

Assessment for learning

In a "Show that" question candidates should check that the final line in their solution is precisely the thing that they have been asked to show.

Question 2 (b)

(b) Use the Cayley-Hamilton theorem to determine $\mathbf{A}^{-1}$. **[5]**

Again, most candidates seemed to know what was required to answer this question. However, it should be noted that candidates were asked to "determine" the inverse matrix and so working and justification were still expected. Candidates should familiarise themselves with the section entitled "The meanings of some instructions used in examination questions" in the specification. In order to attain full credit for this question candidates had to show that they understood the Cayley-Hamilton theorem and how to use it in order to obtain $\mathbf{A}^{-1}$. This involves various steps such as appreciating the difference between a scalar equation and a matrix equation, appreciating that matrix operations are different from scalar operations and substituting into the characteristic equation, including knowing how to deal with the appropriate identity matrix.

A small number of candidates used a different method to find $\mathbf{A}^{-1}$. This approach gained them no credit and simply wasted a lot of time; if candidates are specifically asked to use a certain methodology then they should realise that a different approach will almost certainly result in no credit. Of course, if no particular method is specified then all valid alternative methods will be assessed and will be entitled to full credit if correct and complete.

Some candidates attempted to divide by the matrix **A**. Candidates should be made aware that there is no such operation in matrix algebra/arithmetic and to indicate division by a matrix indicates an incomplete understanding of the method.

Some candidates did not show how the modified characteristic equation could be used to find $\mathbf{A}^{-1}$ and just jumped straight to the matrix. If candidates are in doubt about the level of detail required then they should ask themselves if someone else could follow their line of reasoning.

Misconception

? You cannot divide by a matrix.

Question 2 (c)

A matrix **E** and a diagonal matrix **D** are such that $\mathbf{A} = \mathbf{EDE}^{-1}$. The elements in the diagonal of **D** increase from top left to bottom right.

(c) Determine the matrix **D**. **[4]**

Again, the majority of candidates knew what was required in this question. However, full marks were not nearly as common as they might have been. Once again, not all candidates have perhaps appreciated that the word "Determine" requires them to show working and provide justification.

Candidates who appreciated that the diagonal elements were the eigenvalues were given some credit but if they did not justify how these values were obtained then they did not receive full credit. Once again, candidates should be encouraged to ask themselves whether another person could follow their reasoning clearly and unambiguously.

A small number of candidates wasted what must have been a considerable amount of time by finding the matrix **E** which was neither requested by the demand nor required to find **D**.

Question 3 (a)

3 A sequence is defined by the recurrence relation $5t_{n+1} - 4t_n = 3n^2 + 28n + 6$, for $n \geqslant 0$, with $t_0 = 7$.

(a) Find an expression for t_n in terms of n. **[6]**

This was a very standard question and the vast majority of candidates scored either 5 or 6 marks here (with the loss of mark due to a small arithmetic slip).

A small number of candidates got the wrong complementary function (usually either $A\left(\frac{5}{4}\right)^n$ or $A(4)^n$).

Candidates are encouraged to derive the complementary function from scratch rather than to recall it from a formula which can easily be misremembered.

A small number of candidates used $5t_n - 4t_{n-1}$ rather than $5t_{n+1} - 4t_n$ but without adjusting the right-hand side, thus leading to an incorrect solution.

Similarly, a small number of candidates did not deal correctly with the initial condition, applying this to the complementary function rather than the general solution.

A small number of candidates used a different methodology to determine the values of the arbitrary constants and the constants in their trial solution. Candidates are strongly advised to stick to standard methodologies since these can always be applied.

It was common to see the fraction $\frac{4}{5}$ raised to a power but without brackets, so $\frac{4^n}{5}$. Candidates should be advised that such notation is, at best, ambiguous and this should be strongly discouraged.

Candidates should also be advised to set working out clearly; it was not uncommon to see errors in basic algebra, such as the opening of brackets, and the clearer the working the easier it is to avoid such basic errors.

Question 3 (b) (i)

Another sequence is defined by $v_n = \frac{t_n}{n^m}$, for $n \geqslant 1$, where m is a constant.

(b) In each of the following cases determine $\lim_{n\to\infty} v_n$, if it exists, or show that the sequence is divergent.

(i) $m = 3$ **[1]**

It was clear that many candidates did not know how to approach this question and its companions in parts (ii) and (iii) and so full marks here were less common.

Candidates should appreciate that some justification is required but, with only 1 mark on offer and a limited amount of space, only a brief justification is necessary.

Candidates should also appreciate that which their calculator might be superficially helpful to them in answering such questions, giving actual numbers for particular values of n will not suffice as justification.

Candidates should also be encouraged to be precise with their use of language and to answer the question precisely. So, for example, in this part, it would be insufficient simply to state that the limit exists, even with justification, since candidates are requested to determine its value (0).

Teachers should try to expose candidates to this kind of question; it is quite straightforward to append such questions to standard recurrence relation questions.

Question 3 (b) (ii)

(ii) $m = 2$ **[1]**

As for part (i) it is clear that many candidates did not really appreciate how to approach such a question.

Exemplar 2

3(b)(ii)	$v_n = 3 - 2n^{-1} + n^{-2} + 6(0.8^n)(n-2)$
	so $\lim\limits_{n\to\infty}$: $3 - 0 + 0 + 0$
	$= 3$

In this solution it is clear how the candidate has derived the correct answer. This is exactly the appropriate level of justification given the tariff of the question part and the amount of space available.

Question 3 (b) (iii)

(iii) $m = 1$ **[1]**

As for part (i) it is clear that many candidates did not really appreciate how to approach such a question.

Question 4 (a)

4 A binary operation, $\circ$, is defined on a set of numbers, A, in the following way.

$a \circ b = k_1 a - k_2 b + k_3$, for $a, b \in A$,

where k_1, k_2 and k_3 are constants (which are not necessarily in A) and the operations addition, subtraction and multiplication of numbers have their usual notation and meaning.

You are initially given the following information about $\circ$ and A.

- $A = \mathbb{R}$
- $0 \circ 0 = 2$
- An identity element, e, exists for $\circ$ in A

(a) Show that $a \circ b = a + b + 2$. **[5]**

This question was not approached well by the majority of candidates and it was rare that full marks were awarded. It was clear that many candidates did not really know how to tackle a question where the operation was unfamiliar and the methodology not obvious.

Candidates should be encouraged to use the given information fully. In this case, almost all candidates did manage to use the fact that $0 \circ 0 = 2$ to derive $k_3 = 2$. However, most candidates found it hard to use the existence of an identity element properly. For example, while many candidates were able to use the identity property one way round they did not then use it the other way round. Many candidates also tried to examine the operation for values other than the identity, which approach proved fruitless.

Some candidates assumed properties (such as commutativity or associativity) which are not in general true for this class of operation. Candidates should be discouraged from making assumptions; generally speaking, all of the information required to solve the question will be explicitly given in the question.

Assessment for learning

Use the given information fully. Do not assume things unless these are covered by an actual rule, in which case state the rule.

Question 4 (b)

(b) State the value of e. **[1]**

Most candidates gave the correct value of e (-2). A small number came up with 0 or 1 or 2 although with the operation explicitly given it would have been easy to see with a simple example, in a matter of seconds, that the incorrect value does not work; this would also have led candidates to the correct value.

Key point call out (check your answer)

Candidates should be encouraged to check their answers, especially where this is simple to do.

Question 4 (c)

(c) Explain whether $\circ$ is commutative over A. **[1]**

Although the tariff for this question was only 1 mark candidates should have realised that rigour was required because it is so straightforward. Simply giving a vague statement such as "It is because addition is commutative" is insufficient since it does not convey any explanation of what is meant by commutativity. Candidates were expected to show, explicitly, that $a \circ b = b \circ a$ and hence deduce that $\circ$ is commutative, all of which is easily possible in a single line of working.

Question 4 (d)

(d) Determine whether or not $(A, \circ)$ is a group. **[6]**

This is a very standard question for this paper and candidates should approach it in a systematic fashion, going through each of the 4 axioms explicitly and as rigorously as possible. Note that even where one or more of the properties is given (in this case, identity) this should be mentioned explicitly, although the justification for it being satisfied can simply be "given in the question" or just "given".

It is strongly advised that candidates follow and complete this procedure even in the case where they find that a property is not satisfied and so they conclude that (A, ∘) is not a group. In this way they may still attain some credit even after an axiom conclusion is incorrect.

Candidates are also advised to stick to the rigorous definitions and explanations. So, in this case to justify closure they should say if $a, b \in \mathbb{R}$ then $a \circ b = a + b + 2 \in \mathbb{R}$ rather than something like "it is closed because real numbers add to real numbers".

A common error with the analysis of the inverse axiom was to omit to specify that the inverse was also in the set.

A small number of candidates confused associativity with commutativity. Similarly, a small number of candidates, even having successfully tested the four axioms, did not reach a conclusion. Once again, candidates should be encouraged to check the exact demand of the question.

Assessment for learning

Be rigorous and systematic.

Question 4 (e) (i)

(e) Explain whether your answer to part **(d)** would change in each of the following cases, giving details of any change.

(i) $A = \mathbb{Z}$ **[1]**

Candidates should realise that, with only 1 mark on offer and a limited amount of space, they do not need to go through the entire analysis again. In this question all that was expected was the correct conclusion justified by the statement that the analysis in (d) still applied.

Question 4 (e) (ii)

(ii) $A = \{2m : m \in \mathbb{Z}\}$ **[1]**

Candidates should realise that, with only 1 mark on offer and a limited amount of space, they do not need to go through the entire analysis again. In this question all that was expected was the correct conclusion justified by the statement that the analysis in (d) still applied.

Question 4 (e) (iii)

(iii) $A = \{n : n \in \mathbb{Z}, n \geqslant -2\}$ **[1]**

In this question all that was required was that candidates realised that it was the inverse property which was no longer satisfied. Candidates should know from Mathematics A Level that a single counter-example suffices as demonstration although they should take care to make sure that their counter-example is correct.

A small number of candidates incorrectly concluded that because the inverse was not always in the set under question then the set was not closed, which is not the case.

Question 5 (a) (i)

5 A surface S is defined by $z = \mathrm{f}(x, y)$, where $\mathrm{f}(x, y) = y\mathrm{e}^{-(x^2+2x+2)y}$.

(a) **(i)** Find $\dfrac{\partial \mathrm{f}}{\partial x}$. **[1]**

Although this question was generally well answered, a surprising number of candidates did not attain this mark, often through carelessness. However, it did seem clear that some candidates were not entirely comfortable with finding partial derivatives in a case which is not straightforward and such candidates should be encouraged to practise partial derivatives on a range of function types from A Level Mathematics and Further Mathematics.

Question 5 (a) (ii)

(ii) Show that $\dfrac{\partial \mathrm{f}}{\partial y} = -(x^2y + 2xy + 2y - 1)\mathrm{e}^{-(x^2+2x+2)y}$. **[1]**

This question was generally well answered. However, again candidates should appreciate that the onus is on them to show how a given result is obtained. They should also, as previously advised, make sure that the last line in their solution is the result that they are being asked to derive or, at least, that the left-hand side of their equation is stated, in an unbroken chain of equality, as being equal to the right-hand side.

Question 5 (a) (iii)

(iii) Determine the coordinates of any stationary points on S. **[4]**

Most candidates seemed to know how to approach this question although fewer than half managed to attain 3 or 4 out of 4.

Of candidates who attained 3 out of 4 the two most common errors were either to omit the z co-ordinate or not to deal correctly with the case $y = 0$ (i.e. including an extra 'rogue' stationary point or simply ignoring it without justification).

Many candidates seemed to be uncertain about how to go about solving two equations simultaneously. Many candidates, given two equations, one easy and one hard, seemed to think it advantageous to tackle the hard equation first.

Some candidates, given the two equations $\dfrac{\partial \mathrm{f}}{\partial x} = 0$ and $\dfrac{\partial \mathrm{f}}{\partial y} = 0$ seemed to think that the sensible thing to do was to eliminate 0.

Some candidates thought that there were stationary points when either $\dfrac{\partial \mathrm{f}}{\partial x} = 0$ or $\dfrac{\partial \mathrm{f}}{\partial y} = 0$.

Misconception

There is a stationary point on a surface where **both** $\frac{\partial f}{\partial x} = 0$ **and** $\frac{\partial f}{\partial y} = 0$ are satisfied. Solve the simpler one and then substitute solution(s) into the harder one and solve. Don't forget the z co-ordinate.

Question 5 (b)

Fig. 5.1 shows the graph of $z = e^{-x^2}$ and **Fig. 5.2** shows the contour of S defined by $z = 0.25$.

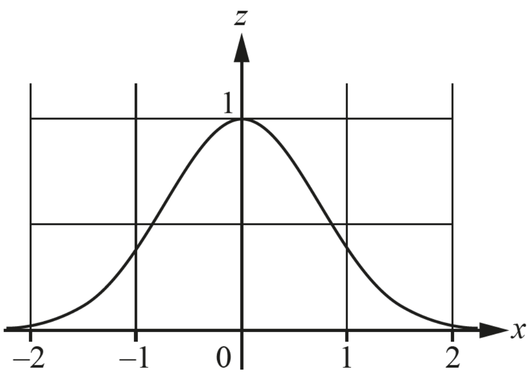


Fig. 5.1

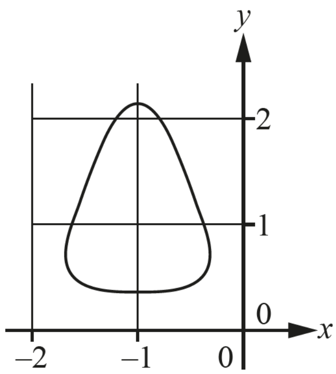


Fig. 5.2

(b) Specify a sequence of transformations which transforms the graph of $z = e^{-x^2}$ onto the graph of the section defined by $z = f(x, 1)$. **[2]**

Very few candidates attained full marks here even though what was required was little more than A Level Mathematics skills. Candidates should expect to have to use methodologies from assumed knowledge (i.e. GCSE and A Level Mathematics) in these harder contexts and should also be encouraged to use the correct terminology where appropriate, so "translation" rather than "shift" and "stretch" rather than "enlarge".

Key point call out (use appropriate terminology)

Use the appropriate and recognised terminology.

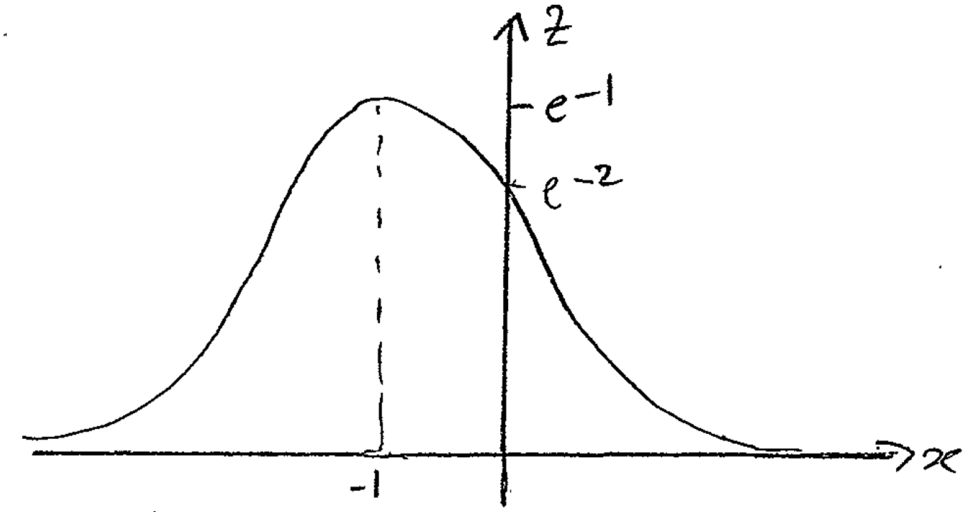
Question 5 (c)

(c) Hence, or otherwise, sketch the section defined by $z = \mathrm{f}(x, 1)$. **[1]**

Once again, the skills required here were little more than A Level Mathematics skills. Candidates should be encouraged to give basic information on sketches, such as axes intercepts and locations of turning points where these are easily identifiable, as in this case. Candidates should also practise sketching of basic graph shapes so that features such as symmetry and asymptotic behaviour look correct, at least approximately.

Exemplar 3

5(c)



This candidate has drawn a good sketch indicating the features of interest and showing the correct symmetry and asymptotic behaviour.

Question 5 (d)

(d) Using **Fig. 5.2** and your answer to part **(c)**, classify any stationary points on S, justifying your answer. **[2]**

While most candidates correctly classified the stationary point as a maximum, most seemed to struggle to provide an appropriate justification and found it difficult to bring together the pieces of information provided by Fig 5.2 and the sketch in part (c). Candidates may well find it hard to picture the situation in 3-D and may also find it difficult to, in effect, unlearn what they have learnt about stationary points from A Level Mathematics. Very few candidates came up with a convincing explanation.

Question 5 (e)

You are given that P is a point on S where $z = 0$.

(e) Find, in vector form, the equation of the tangent plane to S at P. **[4]**

Many candidates appeared to find this question difficult. At first glance it does appear that there is insufficient information given in the question and this might have inhibited some candidates. However, candidates should be encouraged to follow the relevant basic methodologies. In this case, if candidates had formed the grad, most of which had already been given or found earlier, and then used $y = 0$ they would have been well on their way to solving the problem even if they did not know, from the start, precisely which direction to head in.

Many candidates did not attain the final mark because they did not express their answer in vector form, as required by the question.

Assessment for learning

Candidates should always check that they have satisfied the actual demand in the question. In this case they need to present their answer in vector, rather than Cartesian, form.

Question 5 (f)

The tangent plane found in part **(e)** intersects S in a straight line, L.

(f) Write down, in vector form, the equation of L. **[1]**

To any candidates who correctly pictured the situation in part (e) this question is actually very straightforward. From the small number of candidates who got this part correct, even out of those with 3 or 4 marks in (e), it is therefore evident that candidates are often not thinking about the actual configuration of the objects in question. Candidates should be encouraged to think about lines, planes and surfaces as actual entities; this will often make it easier to solve problems, even abstract ones.

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