Qualification Accredited

Oxford Cambridge and RSA

AS LEVEL

Examiners' report

FURTHER MATHEMATICS A

H235

For first teaching in 2017

Y531/01 Summer 2024 series

Version 1

Contents

Contents 2

Introduction 3

Paper 1 series overview 4

- Question 1 5
- Question 2 (a) 5
- Question 2 (b) 5
- Question 3 (a) (i) 6
- Question 3 (a) (ii) 6
- Question 3 (a) (iii) 6
- Question 3 (b) 7
- Question 4 (a) 7
- Question 4 (b) 8
- Question 4 (c) 8
- Question 5 (a) 8
- Question 5 (b) 8
- Question 5 (c) 9
- Question 5 (d) 10
- Question 6 10
- Question 7 11
- Question 8 (a) 14
- Question 8 (b) 14
- Question 8 (c) 15
- Question 8 (d) (i) 15
- Question 8 (d) (ii) 15
- Question 8 (d) (iii) 16
- Question 9 16

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 1 series overview

Y531 is the mandatory paper for AS Further Mathematics. It is taken alongside two other papers which can be freely chosen from a choice of four. It tests knowledge of proof, complex numbers, matrices, vectors and further algebra as well as testing the understanding of the overarching themes of mathematical argument, problem solving and modelling. To do well on this paper candidates need a thorough understanding of the techniques covered and they need to support their answers with detailed working. They also need to have good algebraic and numerical manipulation skills.

Candidates found this paper quite difficult compared to previous papers, especially Question 9 which was an 'extended response' question. Some of the other question parts which were found to be difficult included the latter parts of Questions 5 and 8.

Candidates' layout and presentation has improved from last year. There are still some cases where it can be very hard to decipher what a candidate has written, and some cases where it appears that candidates cannot read what they had written. Question 7 was the question which suffered the most from poorly laid out solutions, as it required several lines of careful algebra to answer successfully.

Candidates must take careful note of any 'command word' given in the question. In particular, if a question asks for 'detailed reasoning', candidates must show all of their working. Calculators can be used to check, but the solutions must be fully detailed in order to gain full credit. This was a particular issue in Question 7, but also affected Question 3 in places.

Candidates who did well on this paper generally:	**Candidates who did less well on this paper generally:**
• used their calculator appropriately to help with manipulation • made sure that they supported their answers with sufficient working, especially when answering 'detailed reasoning' questions • had a good understanding of the OCR command words • set their working out in a clear and logical manner.	• did not follow instructions given in the questions • were over-reliant on their calculator in 'detailed reasoning' questions • did not always understand the meaning of the OCR command words.

Question 1

1 Use a matrix method to determine the solution of the following simultaneous equations. **[4]**

$$\begin{aligned} 2x-3y+\ \ z &= \ \ 1 \\ x-2y-4z &= 40 \\ 5x+6y-\ \ z &= 61 \end{aligned}$$

The majority of candidates knew what was required here, but a few ignored the instruction to use a matrix method and so gained no credit.

Other reasons for not gaining full credit were not showing the inverse matrix explicitly, or mistakes were made when finding the inverse.

Question 2 (a)

2 **In this question you must show detailed reasoning.**

(a) Express $\frac{8+\mathrm{i}}{2-\mathrm{i}}$ in the form $a+b\mathrm{i}$ where a and b are real. **[2]**

This question was answered correctly by almost all candidates. A small minority of candidates made a mistake in simplifying their answer. A few did not follow the instruction to show detailed reasoning and so gained no credit for their answer.

Question 2 (b)

(b) Solve the equation $4x^2-8x+5=0$. Give your answer(s) in the form $c+d\mathrm{i}$ where c and d are real. **[2]**

Most candidates did well on this question, many used the quadratic formula, but some used completing the square to efficiently find the solutions. The most common reasons for failing to gain full credit were not showing any justification for the solutions, or by leaving the solutions in the form $\frac{2\pm i}{2}$. The candidates who used completing the square were more likely to gain full credit as this gave the required form $1 \pm \frac{1}{2}i$ naturally.

Question 3 (a) (i)

3 **(a)** **(i)** Find $\begin{pmatrix} 1 \\ 2 \\ -1 \end{pmatrix} \times \begin{pmatrix} 3 \\ 5 \\ -2 \end{pmatrix}$. **[1]**

Almost all candidates gained the mark here. Many showed no working, perhaps as they used their calculators effectively to answer this. Some candidates who tried to evaluate the cross product manually made sign errors, and a few seemed to think that they needed to multiply the *x*, *y* and *z* coordinates together to find the resultant vector.

Question 3 (a) (ii)

(ii) State a geometrical relationship between the answer to part **(a)(i)** and the vectors $\begin{pmatrix} 1 \\ 2 \\ -1 \end{pmatrix}$ and $\begin{pmatrix} 3 \\ 5 \\ -2 \end{pmatrix}$. **[1]**

Candidates generally did well here, though a few stated that the vectors were parallel. Some misread the question and tried to show a relationship between the two vectors in the part (i). There were also a few candidates who stated that the vector in part (a) (i) was the 'perpendicular bisector' of the other two vectors.

Question 3 (a) (iii)

(iii) Verify the relationship stated in part **(a)(ii)**. **[2]**

Most candidates knew what was expected here, but some did not show the dot product calculation in enough detail to justify the verification. Some candidates did not know what was meant by the word 'verify', and there was a sizeable minority of candidates who made no attempt at this question.

OCR support

Candidates should be familiar with the OCR command words, as shown in our Command words poster.

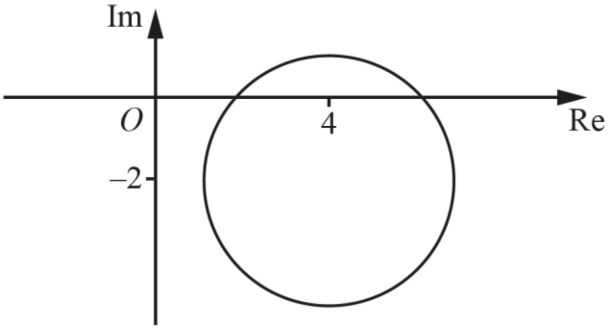
Question 3 (b)

(b) Find the angle between the vectors $2\mathbf{i}-2\mathbf{j}+\mathbf{k}$ and $4\mathbf{i}-\mathbf{j}+8\mathbf{k}$. **[3]**

Most candidates answered this well, with a few making mistakes when calculating the dot product such as using sin rather than cos or making mistakes when calculating the magnitudes of the two vectors.

Question 4 (a)

4 The Argand diagram shows a circle of radius 3. The centre of the circle is the point which represents the complex number $4-2\text{i}$.



(a) Use set notation to define the locus of complex numbers, z, represented by points which lie on the circle. **[2]**

The majority of candidates could write down an equation for the circle using $|z-(4-2\text{i})|$ but only a minority could use set notation accurately to describe the locus, despite there being an example of how to set this out in the next part of the question. A few candidates thought that the locus was all the points inside the circle rather than just the points on the circle.

Question 4 (b)

The locus L is defined by $L = \{z : z \in \mathbb{C}, |z - \mathrm{i}| = |z + 2|\}$.

(b) On the Argand diagram in the Printed Answer Booklet, sketch and label the locus L. **[2]**

The majority of candidates knew what was required here, but some did not clearly show that the required line was perpendicular to the line joining (-2,0) and (0,1). Those candidates who did show that the line was perpendicular used a variety of methods to show this, including simply showing a 'right angle' symbol, showing construction arcs used to draw the line, or finding the equation of the line. A few candidates did not indicate which of the two lines they had drawn was the requested one.

Question 4 (c)

You are given that the locus $\left\{z : z \in \mathbb{C}, \arg(z-1) = \frac{1}{4}\pi, \mathrm{Re}(z) = 3\right\}$ contains only one number.

(c) Find this number. **[2]**

This question had a relatively high omit rate. The most successful candidates drew a diagram representing the information in the question which they could use efficiently to find the solution. A small number of candidates did not write their final answer as a number leaving it as $x = 3$, $y = 2$.

Question 5 (a)

5 The line through points $A(8, -7, -2)$ and $B(11, -9, 0)$ is denoted by L_1.

(a) Find a vector equation for L_1. **[2]**

The majority of candidates could answer this question, but a sizeable proportion did not write their answer as an equation and so were not given the second mark. A small number of candidates added together the vectors $\overrightarrow{OA}$ and $\overrightarrow{OB}$ rather than finding the difference between them.

Question 5 (b)

(b) Determine whether the point $(26, -19, -14)$ lies on L_1. **[2]**

The majority of candidates earned full credit for this part. A few made sign errors when finding their values of λ or did not fully explain where there was no consistent value of λ possible.

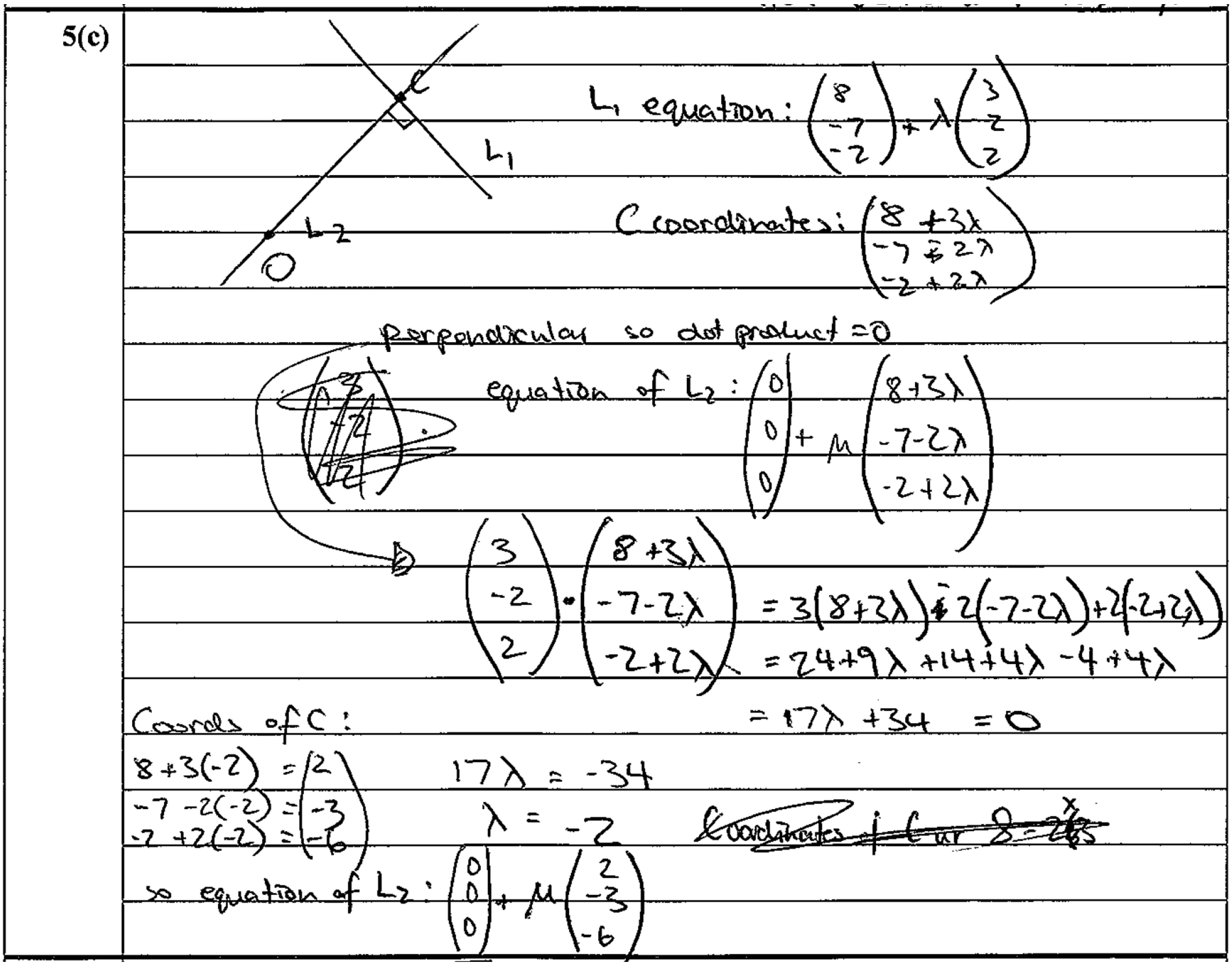
Question 5 (c)

The line L_2 passes through the origin, O, and intersects L_1 at the point C. The lines L_1 and L_2 are perpendicular.

(c) By using the fact that C lies on L_1, find a vector equation for L_2. **[4]**

There were some very good solutions to this part, but it was found to be one of the more difficult questions on the paper. A lot of candidates gained a mark from realising that they could write the position of *C* using their equation from part (a), and a sizeable number could use the fact that *OC* is perpendicular to L_1 to write down another equation, but only a minority went on to solve these two equations and find λ.

Exemplar 1



5(c)

L_1 equation: $\begin{pmatrix}8\\-7\\-2\end{pmatrix}+\lambda\begin{pmatrix}3\\-2\\2\end{pmatrix}$

C coordinates: $\begin{pmatrix}8+3\lambda\\-7\mp2\lambda\\-2+2\lambda\end{pmatrix}$

perpendicular so dot product = 0

equation of L_2: $\begin{pmatrix}0\\0\\0\end{pmatrix}+\mu\begin{pmatrix}8+3\lambda\\-7-2\lambda\\-2+2\lambda\end{pmatrix}$

$\begin{pmatrix}3\\-2\\2\end{pmatrix}\cdot\begin{pmatrix}8+3\lambda\\-7-2\lambda\\-2+2\lambda\end{pmatrix}=3(8+3\lambda)\mp2(-7-2\lambda)+2(-2+2\lambda)$

$=24+9\lambda+14+4\lambda-4+4\lambda$

$=17\lambda+34=0$

$17\lambda=-34$

$\lambda=-2$

~~Coordinates of C are 8 - 2x3~~

Coords of C:

$8+3(-2)=$ $\begin{pmatrix}2\\-3\\-6\end{pmatrix}$
$-7-2(-2)=$
$-2+2(-2)=$

so equation of L_2: $\begin{pmatrix}0\\0\\0\end{pmatrix}+\mu\begin{pmatrix}2\\-3\\-6\end{pmatrix}$

This response is typical of a good candidate solution to this question, where they used the geometry of the situation and their knowledge of what it means for two lines to be perpendicular to locate C and hence find a vector equation for L_2. The lack of an '**r =** ' was ignored in this part as it had already been penalised in part 5 (a).

Question 5 (d)

(d) Hence find the shortest distance from O to L_1. **[2]**

This question had a very high omit rate, due to the fact that the preceding part was found to be very difficult. A mark was available to candidates who recognised that the required length was $|\overrightarrow{OC}|$ so could be earned by candidates even if they could not answer the previous part.

Question 6

6 You are given that $\mathbf{A} = \begin{pmatrix} 1 & a \\ 0 & 1 \end{pmatrix}$ where a is a constant.

Prove by induction that $\mathbf{A}^n = \begin{pmatrix} 1 & an \\ 0 & 1 \end{pmatrix}$ for all integers $n \geqslant 1$. **[5]**

There were some very clear proofs for this question, but some candidates did not set out their argument logically.

Some candidates did not show the basis case with sufficient detail to be fully convincing, but in these cases the other four marks were still available.

More candidates gained the final mark for the conclusion of the proof than in previous years, perhaps helped partially by the fact that the basis case here was n = 1. However, there are still some candidates who did not provide a clear conclusion to their argument, usually by stating something along the lines of 'since it is true for $n = 1$, $n = k$ and $n = k + 1$ it is true for all n'.

A handful of candidates assumed that the proposition was true for $n = k+1$ and then used the inverse of **A** to show that it must then be true for $n = k$.

Question 7

7 **In this question you must show detailed reasoning.**

The roots of the equation $2x^3 - 3x^2 - 3x + 5 = 0$ are α, β and γ.

By considering $(\alpha+\beta+\gamma)^2$ and $(\alpha\beta+\beta\gamma+\gamma\alpha)^2$, determine a cubic equation with integer coefficients whose roots are $\frac{\alpha\beta}{\gamma}$, $\frac{\beta\gamma}{\alpha}$ and $\frac{\gamma\alpha}{\beta}$. **[6]**

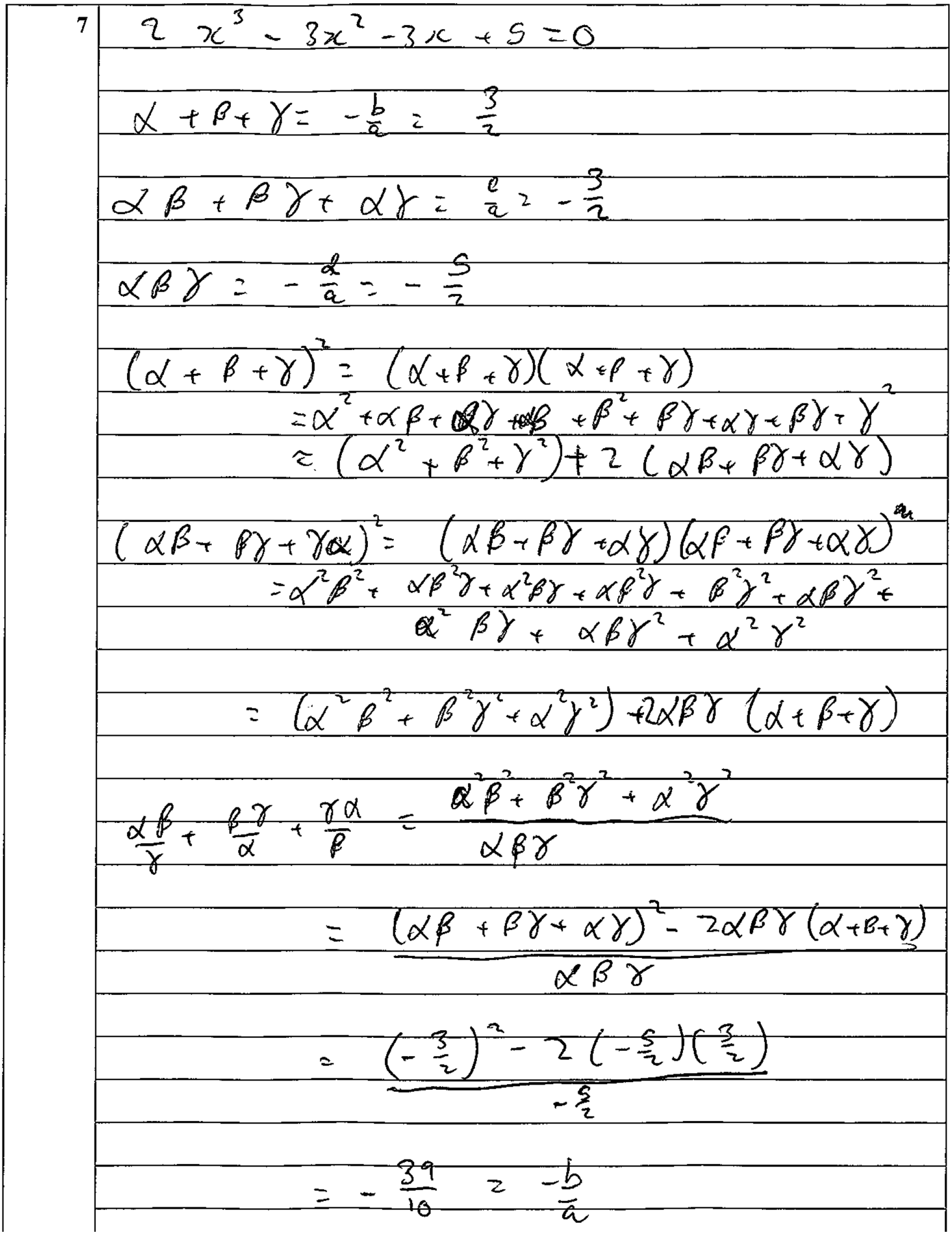
There were some very good solutions to this question with clearly laid out working, but also some where the working was hard to follow (and it seemed that the candidates were also finding it difficult to follow their own working).

The best solutions followed the advice in the question and considered the expansions of $(\alpha + \beta + \gamma)^2$ and $(\alpha\beta + \beta\gamma + \gamma\alpha)^2$ before finding the expressions for the sum and products of the new roots.

The most common marks gained were the first few M marks for listing the values of Vieta’s formulae for the old roots, and for showing that the product of the new roots was the same as the product of the old roots.

Apart from the final accuracy mark, the most common mark lost was the one for finding the sum of the new roots, usually because the denominator $\alpha\beta\gamma$ went missing.

Exemplar 2



7 $2x^3 - 3x^2 - 3x + 5 = 0$

$\alpha + \beta + \gamma = -\frac{b}{a} = \frac{3}{2}$

$\alpha\beta + \beta\gamma + \alpha\gamma = \frac{c}{a} = -\frac{3}{2}$

$\alpha\beta\gamma = -\frac{d}{a} = -\frac{5}{2}$

$(\alpha+\beta+\gamma)^2 = (\alpha+\beta+\gamma)(\alpha+\beta+\gamma)$

$= \alpha^2 + \alpha\beta + \alpha\gamma + \alpha\beta + \beta^2 + \beta\gamma + \alpha\gamma + \beta\gamma + \gamma^2$

$= (\alpha^2 + \beta^2 + \gamma^2) + 2(\alpha\beta + \beta\gamma + \alpha\gamma)$

$(\alpha\beta + \beta\gamma + \gamma\alpha)^2 = (\alpha\beta + \beta\gamma + \alpha\gamma)(\alpha\beta + \beta\gamma + \alpha\gamma)$

$= \alpha^2\beta^2 + \alpha\beta^2\gamma + \alpha^2\beta\gamma + \alpha\beta^2\gamma + \beta^2\gamma^2 + \alpha\beta\gamma^2 +$

$\alpha^2\beta\gamma + \alpha\beta\gamma^2 + \alpha^2\gamma^2$

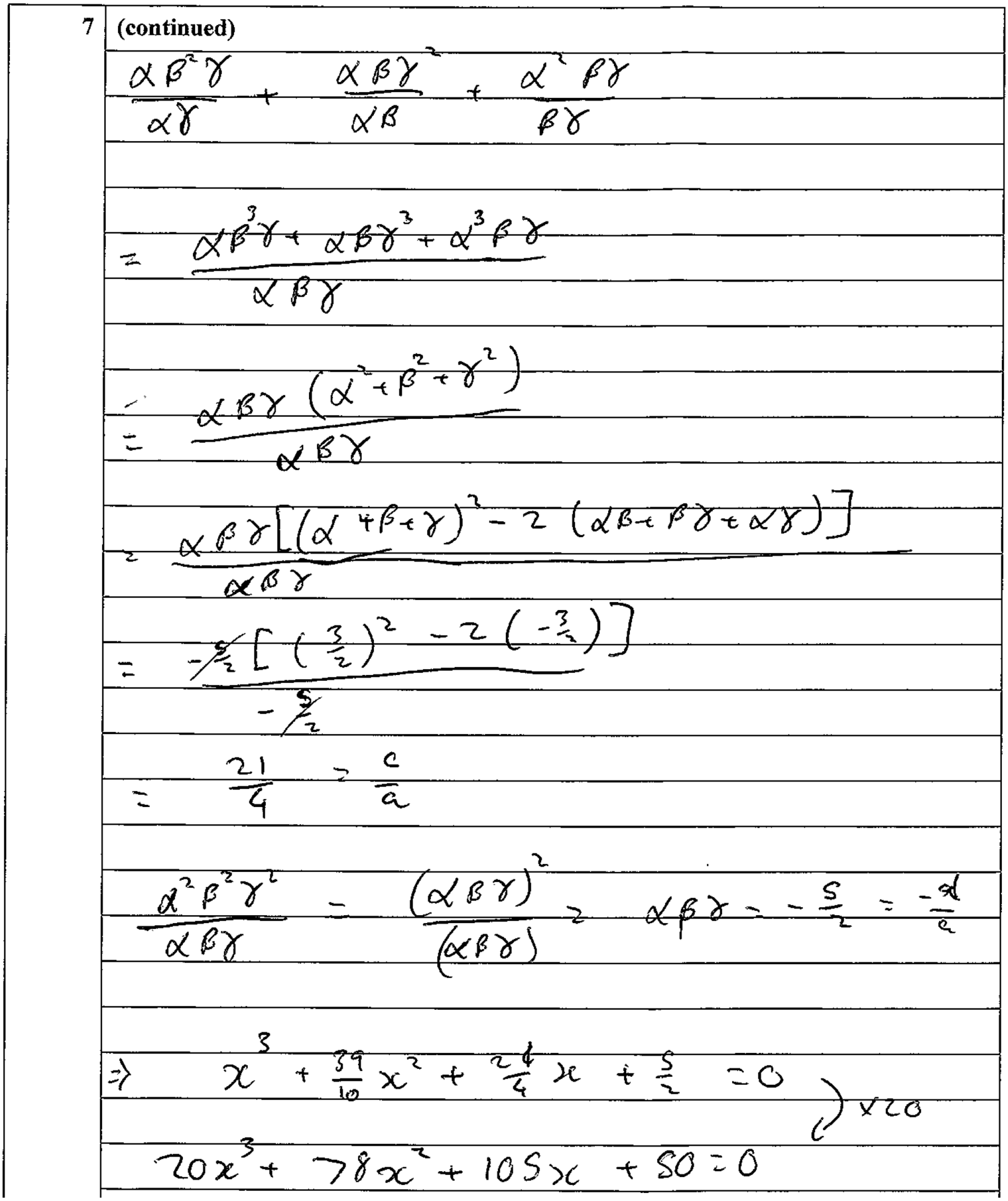
$= (\alpha^2\beta^2 + \beta^2\gamma^2 + \alpha^2\gamma^2) + 2\alpha\beta\gamma(\alpha+\beta+\gamma)$

$\frac{\alpha\beta}{\gamma} + \frac{\beta\gamma}{\alpha} + \frac{\gamma\alpha}{\beta} = \frac{\alpha^2\beta^2 + \beta^2\gamma^2 + \alpha^2\gamma^2}{\alpha\beta\gamma}$

$= \frac{(\alpha\beta + \beta\gamma + \alpha\gamma)^2 - 2\alpha\beta\gamma(\alpha+\beta+\gamma)}{\alpha\beta\gamma}$

$= \frac{(-\frac{3}{2})^2 - 2(-\frac{5}{2})(\frac{3}{2})}{-\frac{5}{2}}$

$= -\frac{39}{10} = \frac{-b}{a}$



7 (continued)

$$\frac{\alpha\beta^2\gamma}{\alpha\gamma} + \frac{\alpha\beta\gamma^2}{\alpha\beta} + \frac{\alpha^2\beta\gamma}{\beta\gamma}$$

$$= \frac{\alpha\beta^3\gamma + \alpha\beta\gamma^3 + \alpha^3\beta\gamma}{\alpha\beta\gamma}$$

$$= \frac{\alpha\beta\gamma(\alpha^2+\beta^2+\gamma^2)}{\alpha\beta\gamma}$$

$$= \frac{\alpha\beta\gamma[(\alpha+\beta+\gamma)^2 - 2(\alpha\beta+\beta\gamma+\alpha\gamma)]}{\alpha\beta\gamma}$$

$$= \frac{\cancel{-\frac{5}{2}}[(\frac{3}{2})^2 - 2(-\frac{3}{2})]}{\cancel{-\frac{5}{2}}}$$

$$= \frac{21}{4} = \frac{c}{a}$$

$$\frac{\alpha^2\beta^2\gamma^2}{\alpha\beta\gamma} = \frac{(\alpha\beta\gamma)^2}{(\alpha\beta\gamma)} = \alpha\beta\gamma = -\frac{5}{2} = -\frac{d}{a}$$

$$\Rightarrow x^3 + \frac{39}{10}x^2 + \frac{21}{4}x + \frac{5}{2} = 0 \quad \times 20$$

$$20x^3 + 78x^2 + 105x + 50 = 0$$

This response was one of the few that considered the expansions of $(\alpha+\beta+\gamma)^2$ and $(\alpha\beta+\beta\gamma+\gamma\alpha)^2$ before they started considering the sum and products of the roots. The candidate has spaced out their working well and used the 'one equal sign per line' mantra to make their working easy to follow, and to help make sure that algebraic mistakes are minimised. Overall, this is a good example of how candidates could present their solutions.

Question 8 (a)

8 Three transformations, T_A, T_B and T_C, are represented by the matrices **A**, **B** and **C** respectively.

You are given that $\mathbf{A} = \begin{pmatrix} 1 & 0 \\ 2 & 3 \end{pmatrix}$ and $\mathbf{B} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$.

(a) Find the matrix which represents the inverse transformation of T_A. **[1]**

This part was answered well.

Question 8 (b)

(b) By considering matrix multiplication, determine whether T_A followed by T_B is the same transformation as T_B followed by T_A. **[2]**

Transformations R and S are each defined as being the result of successive transformations, as specified in the table.

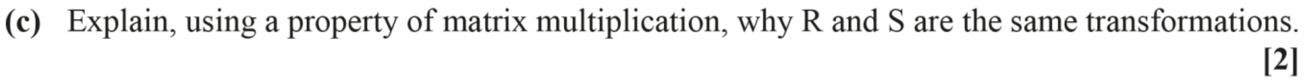
Transformation	First transformation	followed by
R	T_A followed by T_B	T_C
S	T_A	T_B followed by T_C

Almost all candidates gained full credit for showing that **AB** ≠ **BA**, and subsequent incorrect statements about matrix multiplication were ignored. A few candidates made sign errors, and some did not make a correct comparison between **AB** and **BA.**

Misconception

From the comments that candidates wrote it seems that a lot of them think that matrices can never commute. The most common comment along these lines was '**AB** ≠ **BA** as matrix multiplication is not commutative'.

Question 8 (c)

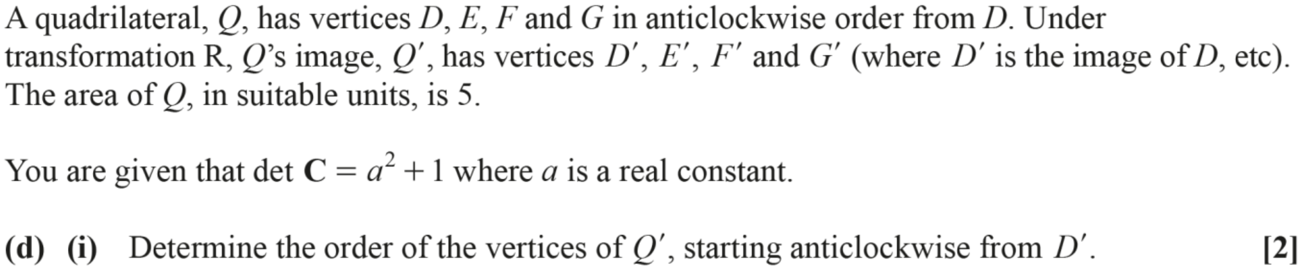


(c) Explain, using a property of matrix multiplication, why R and S are the same transformations. **[2]**

This part was found difficult by a lot of candidates. Some realised that the relative property was 'associativity' but did not identify R as being **C**(**BA**) and S as being (**CB**)**A**. Some candidates claimed that both R and S were equal to **CBA** with no brackets present.

A considerable minority of candidates thought that the property required was 'commutativity'.

Question 8 (d) (i)



A quadrilateral, Q, has vertices D, E, F and G in anticlockwise order from D. Under transformation R, Q's image, Q', has vertices D', E', F' and G' (where D' is the image of D, etc). The area of Q, in suitable units, is 5.

You are given that det $\mathbf{C} = a^2 + 1$ where a is a real constant.

(d) (i) Determine the order of the vertices of Q', starting anticlockwise from D'. **[2]**

Most candidates realised that they needed to consider the determinant of the matrix representing the transformation R, but a significant minority of candidates gave no working to support their answer, despite the question saying 'Determine'.

A lot of candidates assumed in this part that transformation R was represented by matrix **C** only, neglecting to consider the determinants of **A** and **B**. These candidates could gain a special case mark.

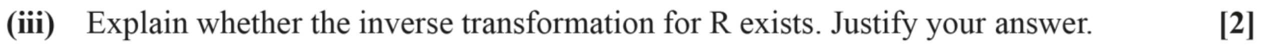
A few candidates tried to consider the effect of the transformation on the unit square, but without being given matrix **C** explicitly this was not a viable method.

Question 8 (d) (ii)

(ii) Find, in terms of a, the area of Q'. **[1]**

The majority of candidates knew that they had to multiply the determinant by the area of *Q*, however only a few candidates could do this accurately. The most common mistakes were either to think that matrix **C** represented transformation R, or to not take the modulus of their answer and so ending up with a negative area.

Question 8 (d) (iii)

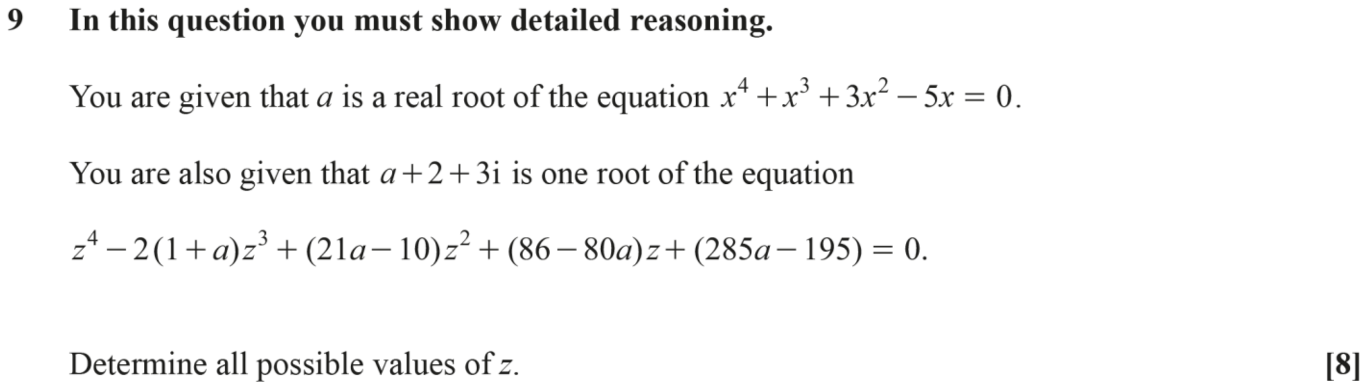


(iii) Explain whether the inverse transformation for R exists. Justify your answer. **[2]**

Candidates who thought that transformation R was represented by matrix **C** could gain full credit here, and the majority of candidates did earn both marks. Some candidates thought that they had to show that the determinant was positive rather than showing that it was not equal to 0.

A significant proportion of candidates did not answer this question, perhaps not understanding what was required to answer it.

Question 9



9 In this question you must show detailed reasoning.

You are given that a is a real root of the equation $x^4+x^3+3x^2-5x=0$.

You are also given that $a+2+3\mathrm{i}$ is one root of the equation

$$z^4-2(1+a)z^3+(21a-10)z^2+(86-80a)z+(285a-195)=0.$$

Determine all possible values of z. **[8]**

There were some excellent and clear solutions to this question, but it was found to be difficult by many candidates.

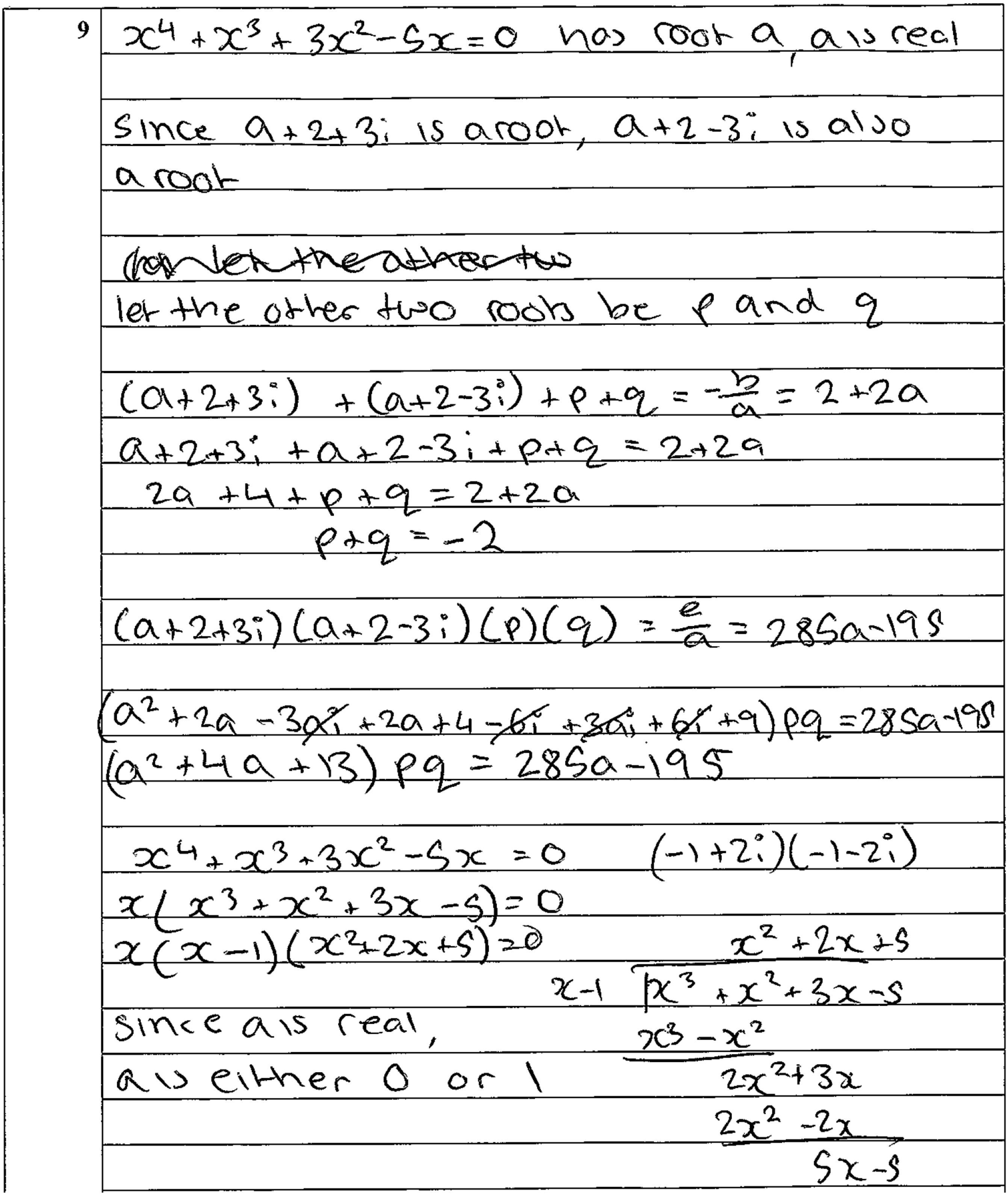
Some got confused between the two quartics and thought that a + 2 +3i was a root of the quartic in x, which meant they made very little progress through the question. Often, they substituted x = a + 2 + 3i into the quartic in x.

When finding the values of a, many candidates did not justify when a = 1 was a root, or did not show there were no further roots after finding a = 0 and 1.

Some candidates considered the quartic in z correctly when a = 1 but did not repeat the process when a = 0, possibly because they did not consider 0 to be a 'real' number.

A significant number of candidates did not support their answer with enough working to be convincing, despite the question being a 'detailed reasoning' question. Candidates should be cautious about overreliance on their calculators for these sorts of questions.

Exemplar 3



9 $x^4 + x^3 + 3x^2 - 5x = 0$ has root a, a is real

Since a + 2 + 3i is a root, a + 2 − 3i is also a root

~~(can) let the other two~~

let the other two roots be p and q

$(a+2+3i) + (a+2-3i) + p + q = -\frac{b}{a} = 2 + 2a$

$a+2+3i + a+2-3i + p+q = 2+2a$

$2a + 4 + p + q = 2 + 2a$

$p+q = -2$

$(a+2+3i)(a+2-3i)(p)(q) = \frac{e}{a} = 285a - 195$

$(a^2 + 2a - 3\cancel{ai} + 2a + 4 - \cancel{6i} + \cancel{3ai} + \cancel{6i} + 9)pq = 285a - 195$

$(a^2 + 4a + 13)pq = 285a - 195$

$x^4 + x^3 + 3x^2 - 5x = 0$ $(-1+2i)(-1-2i)$

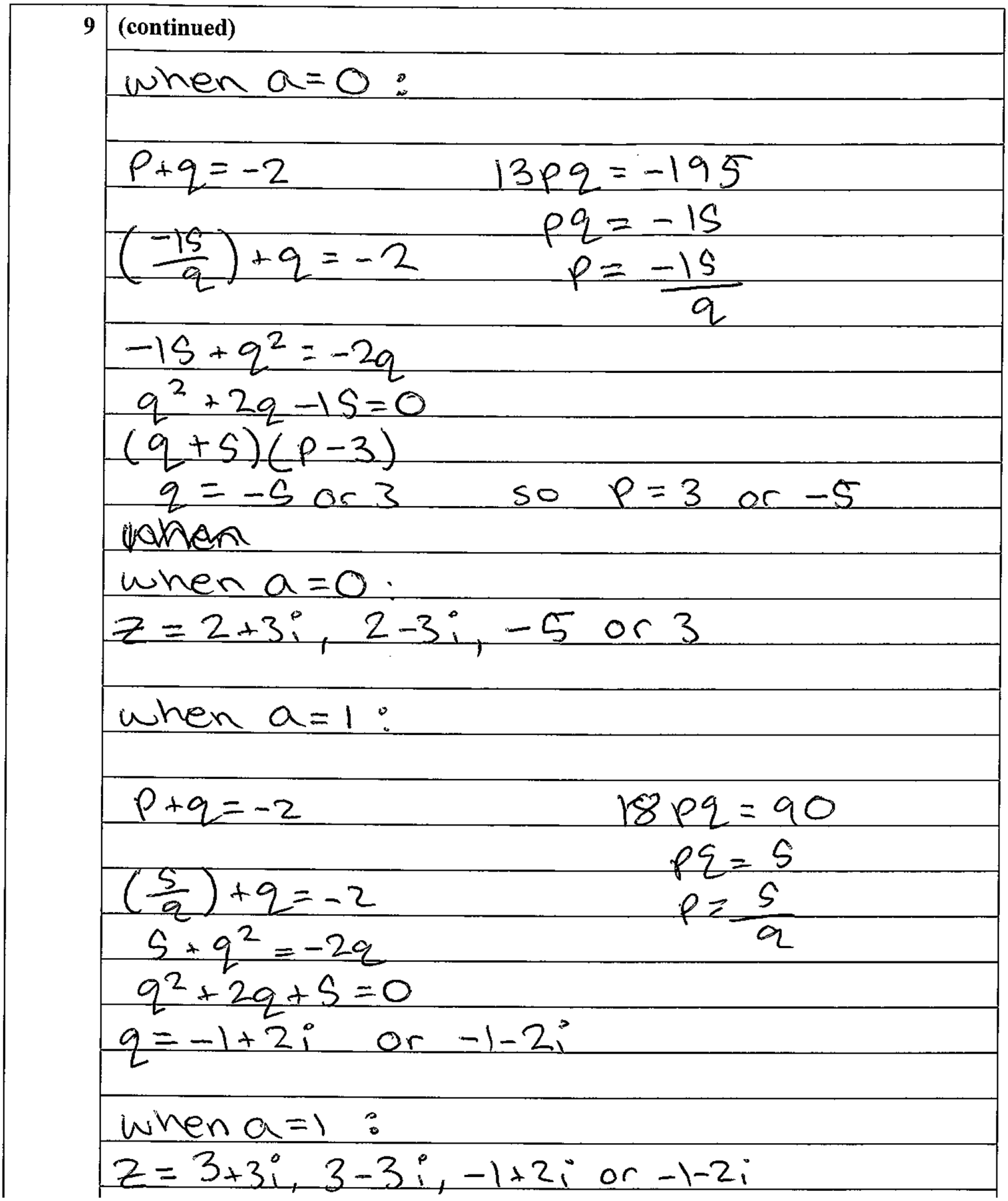
$x(x^3 + x^2 + 3x - 5) = 0$

$x(x-1)(x^2+2x+5) = 0$

Since a is real,

a is either 0 or 1

$$\begin{array}{r|l} & x^2 + 2x + 5 \\ \hline x-1 & x^3 + x^2 + 3x - 5 \\ & x^3 - x^2 \\ \hline & 2x^2 + 3x \\ & 2x^2 - 2x \\ \hline & 5x - 5 \end{array}$$



9 **(continued)**

when $a=0$:

$p+q=-2$ $\qquad$ $13pq=-195$

$pq=-15$

$p=\frac{-15}{q}$

$\left(\frac{-15}{q}\right)+q=-2$

$-15+q^2=-2q$

$q^2+2q-15=0$

$(q+5)(p-3)$

$q=-5$ or 3 $\qquad$ so $p=3$ or -5

~~when~~

when $a=0$:

$z=2+3i,\ 2-3i,\ -5$ or 3

when $a=1$:

$p+q=-2$ $\qquad$ $18pq=90$

$pq=5$

$p=\frac{5}{q}$

$\left(\frac{5}{q}\right)+q=-2$

$5+q^2=-2q$

$q^2+2q+5=0$

$q=-1+2i$ or $-1-2i$

when $a=1$:

$z=3+3i,\ 3-3i,\ -1+2i$ or $-1-2i$

This is an example of an alternate method used and applied efficiently to solve the problem. It is another example of good layout which helps the candidate keep track of their working and minimises the chance of making arithmetical/algebraic errors.

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