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Examiners' report

MATHEMATICS B (MEI)

H640

For first teaching in 2017

H640/03 Summer 2024 series

Version 1

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Contents

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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 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.

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Paper 3 series overview

This is the third paper of A Level Mathematics B (MEI) and only focuses on the pure section of the specification. As with previous years, the grade distribution shows a small proportion of the cohort scoring the maximum 75 marks, with almost a quarter scoring over 60 marks, and a couple of candidates scoring zero. While some candidates did leave one or two entire questions blank, there was no evidence overall that candidates did not have enough time to complete the paper.

Section B is a comprehension section: Candidates should be reminded that the paper is designed to take into account the time required to read the article in full before answering the questions. A small but significant proportion made little progress on this aspect of the assessment, but a slightly greater proportion scored full marks compared to previous years.

Candidates who did well on this paper generally:	Candidates who did less well on this paper generally:
• showed necessary and sufficient working with each question part • were confident manipulating fractions, surds and algebraic expressions • understood what was meant by exact form • could apply the appropriate method for each question • did not rely on their calculators in Detailed Reasoning (DR) questions • understood and familiar with aspects of proof • could produce or complete appropriate diagrams • were competent in all the different techniques in both integral and differential calculus.	• struggled to use exact forms often thinking that an answer correct to, e.g. 3 or greater decimal places was sufficiently accurate when a surd was expected • was less confident in choosing the right technique often going through three or four inappropriate techniques en route to a solution • was not familiar with types of functions such as one - to - one or many - to - one • was not confident using trigonometrical identities • lacked resilience approaching longer questions 6 marks or more • confused the different techniques of integral and differential calculus • could not maintain algebraic accuracy over a longer question, sometimes due to transposing errors in poorly presented lines of argument.

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Section A overview

Section A consisted, as usual, of a selection of pure maths questions covering the full range of content and difficulty. There is no restriction on which pure topics can feature on this paper: Some have regularly appeared on this paper, such as the surd question (4) but there were also topics we saw for the first time on this paper such Newton – Raphson (11) and integration by substitution (5). Many candidates had been prepared very well for this section and examiners were pleased to see a lot of well-presented solutions that were getting very close to scoring the maximum 60 out of 60.

Question 1

1 Solve the inequality $\frac{x}{5} > 6 - x$. **[2]**

This question was done well and the vast majority of candidates earned both marks. Almost all were able to make a successful first step in the rearrangement required but then poor algebra let some of the less successful responses down. Examples of errors in rearrangement were

$x > 30 - 5x$ becoming $-4x > 30$

$x/5 + x > 6$ becoming $2x/5 > 6$

$-6x > 30$ becoming $x < 5$

Question 2(a)

2 **(a)** The function f(x) is defined by

$$f(x) = \sqrt{1+2x} \text{ for } x \geqslant -\tfrac{1}{2}.$$

Find an expression for $f^{-1}(x)$ and state the domain of this inverse function. **[3]**

Almost all candidates were able to make a successful initial step towards finding an expression for the inverse function. About half started with $y = \sqrt{(1 + 2x)}$ and switched x and y immediately while the other half began by squaring both sides and switching the x and y at the end. This was a fairly routine Method mark, but algebraic mistakes often meant that the Accuracy mark could not be given.

A large number of candidates were unable to state the domain of the inverse function. Some were unclear about the difference between domain and range while others neglected to include zero in the domain.

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Question 2 (b)

(b) Explain why $g(x) = 1 + x^2$, with domain all real numbers, has no inverse function. **[1]**

The majority of candidates were able to gain the mark for this question, by realising that either g(*x*)was a many-to-one function and/or its inverse was one-to-many and so could not be a function.

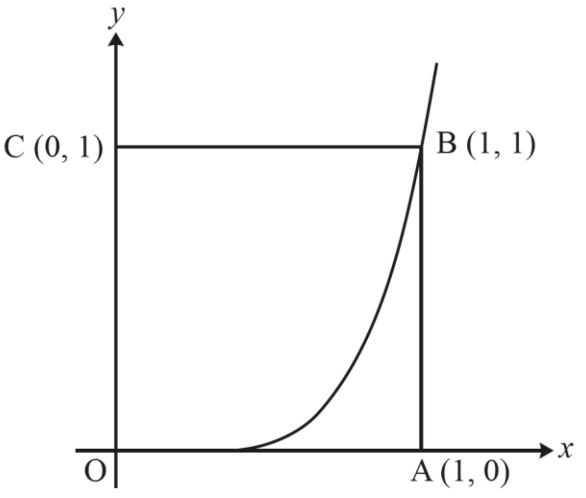
Almost a third of candidates did not understand the definition of a function and thought that it was impossible to find the inverse, because you would be square rooting a negative number. A few confused one-to-many and many-to-one.

Question 3

3 In this question you must show detailed reasoning.

The diagram shows the curve with equation $y = x^5$ and the square OABC where the points A, B and C have coordinates (1, 0), (1, 1) and (0, 1) respectively.

The curve cuts the square into two parts.



Show that the relationship between the areas of the two parts of the square is

$$\frac{\text{Area to left of curve}}{\text{Area below curve}} = 5.$$ **[4]**

This was the first question on the paper which required detailed reasoning. There were many correct solutions to this question with full reasoning shown. Nearly all candidates realised that to find the area below the curve, they needed to integrate between appropriate limits. Most then went on to use the area of the square and the area below the curve, to correctly find the area to the left of the curve and complete the question. Some candidates integrated $y = x^5$ with respect to x to find the area below the curve and then went on to integrate $x = y^{1/5}$ with respect to y, to find the area to the left of the curve. This was of course acceptable but not the most efficient method. A few candidates misinterpreted the diagram and assumed that, because the curve was very close to the *x*-axis, the limits of integration for the area underneath the curve were 0.5 and 1. Others used the limits the wrong way round and ended up with -1/6 as the area, which then somehow became +1/6.

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Detailed Reasoning (DR questions)

On this paper there were seven '**In this question you must show Detailed Reasoning' (DR** questions). Generally candidates had been well prepared for these questions and in many cases gave accurate and well thought out responses. In **DR** questions candidates are expected to show sufficient working to demonstrate the principles involved.

One excellent piece of advice is 'you can use your calculator but make it look like you haven't'. This is especially true for questions such as this where a numerical answer can be found by typing the expression directly into the calculator.

Surds, and indices more generally, have been examined in similar questions seen in earlier series, so the idea of showing an understanding of the reasoning behind the maths for questions on these topics should be familiar.

Question 4

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

Determine the exact value of $\frac{1}{\sqrt{2}+1}+\frac{1}{\sqrt{3}+\sqrt{2}}+\frac{1}{2+\sqrt{3}}$. **[2]**

A significant number of candidates did not show sufficient working to gain marks on this DR question.

It was not unusual for candidates to start their solution by writing So, 1/(√2 + 1) = √2 - 1, etc. with no working shown.

There were also a significant number of candidates that did not realise that the most efficient method was to 'rationalising the denominator' of each term first. These candidates attempted to combine the three surd fractions into a single fraction with a common denominator. This resulted in a page full of working and was rarely completed successfully. Apart from anything else this approach wasted a lot of time when there were only 2 marks available.

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Exemplar 1

4

$$\frac{1}{\sqrt{2}+1} + \frac{1}{\sqrt{3}+\sqrt{2}} + \frac{1}{2+\sqrt{3}}$$

$$\times(-1+\sqrt{2}) \qquad \times(\sqrt{3}-\sqrt{2}) \qquad \times(2-\sqrt{3})$$

$$\frac{\sqrt{2}-1}{(\sqrt{2}+1)(-1+\sqrt{2})} + \frac{\sqrt{3}-\sqrt{2}}{(\sqrt{3}+\sqrt{2})(\sqrt{3}-\sqrt{2})} + \frac{2-\sqrt{3}}{(2+\sqrt{3})(2-\sqrt{3})}$$

$$\frac{\sqrt{2}-1}{2+\sqrt{2}-\sqrt{2}-1} + \frac{\sqrt{3}-\sqrt{2}}{3-\sqrt{6}+\sqrt{6}-2} + \frac{2-\sqrt{3}}{4-\sqrt{3}+\sqrt{3}-3}$$

$$=1 \qquad =1 \qquad =1$$

$$\sqrt{2}-1+\sqrt{3}-\sqrt{2}+2-\sqrt{3}$$

$$-1+2 = \boxed{1}$$

The candidate shows the rationalisation for each fraction and the calculation of the denominator. Even though the denominator simplifies to one (and many candidates will do it in their heads), the working must be shown in each case. This solution scores both marks.

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Exemplar 2

4

$$\frac{1}{\sqrt{2}+1} \times \frac{\sqrt{2}-1}{\sqrt{2}-1} = \frac{\sqrt{2}-1}{2-1} = \frac{\sqrt{2}-1}{1}$$

$$\frac{1}{\sqrt{3}+\sqrt{2}} \times \frac{\sqrt{3}-\sqrt{2}}{\sqrt{3}-\sqrt{2}} = \frac{\sqrt{3}-\sqrt{2}}{3-2} = \frac{\sqrt{3}-\sqrt{2}}{1}$$

$$\frac{1}{2+\sqrt{3}} \times \frac{2-\sqrt{3}}{2-\sqrt{3}} = \frac{2-\sqrt{3}}{2-3} = -\frac{2-\sqrt{3}}{1}$$

$$\frac{\sqrt{2}-1}{1} + \frac{\sqrt{3}-\sqrt{2}}{1} - \frac{2-\sqrt{3}}{1}$$

$$= \sqrt{2}-1+\sqrt{3}-\sqrt{2}-2+\sqrt{3}$$

$$= -3+2\sqrt{3}$$

The candidate rationalises and simplifying the first two terms but the third term has an error in the denominator (2-3) rather than (4-3). Therefore, the method is not accurate and only scores the M1 mark.

Exemplar 3

4

$$\frac{1}{\sqrt{2}+1} + \frac{1}{\sqrt{3}+\sqrt{2}} + \frac{1}{2+\sqrt{3}} \qquad \sqrt{2}-\sqrt{2}=0 \qquad \sqrt{3}-\sqrt{3}=0$$

$$= -1+\sqrt{2}+\sqrt{3}-\sqrt{2}+2-\sqrt{3}$$

$$= 1+\sqrt{2}+\sqrt{3}-\sqrt{2}-\sqrt{3}$$

$$= 1$$

The candidate has not shown any method to get from the three given terms. It is likely this has been done on the calculator. So, this response scores no marks.

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Question 5

5 In this question you must show detailed reasoning.

Using the substitution $u = x + 1$, find the value of the positive integer c such that

$$\int_c^{c+4} \frac{x}{(x+1)^2}\,dx = \ln 3 - \frac{1}{3}.$$ **[6]**

This **DR** question proved accessible for many, and plenty of candidates were able to demonstrate a good knowledge of integration by substitution. Almost all were given the first mark for finding $du = dx$, and there were frequent examples of complete and accurate integrations. A few decided to use integration by parts after the initial substitution, which was less successful than the intended method. The more successful candidates noticed that they could split the initial fraction into two fractions and therefore found the integral easier to solve.

In several cases, incorrect limits were used which caused the loss of the Accuracy marks. It is worth reminding candidates to use the correct limits for the variable that they are using.

The last Accuracy mark was not given in many cases – this was for either checking that their value for *c* was correct in the other equation, or for solving for *c* in both equations. The initial information came in two parts ($ln3$ and $\frac{-1}{3}$), and without the check, one of these pieces of information would not have been used. Candidates should make sure that their final answer satisfies all parts of a given question. Some candidates did not spot the method of comparing coefficients for the last part of the question, and attempted calculations that were much harder than they needed to be.

Question 6

6 In this question you must show detailed reasoning.

Solve the equation $\tan x - 3\cot x = 2$ for values of x in the interval $0° \leqslant x \leqslant 360°$. **[5]**

Candidates in general demonstrated a good knowledge of trigonometry in this question, and full marks were given frequently. Most candidates could spot the need to multiply through by $\tan x$, and were able to successfully form a quadratic and solution.

It was pleasing to see that almost all candidates considered the given interval carefully – only a very few left $-45°$ as a result.

This was another **DR** question, and candidates should remember that they need to show each step of their working, particularly any steps that can be solved by a calculator. It was not uncommon for candidates to leave workings out for the third Method mark, and to instead presumably solve the quadratic on their calculator. This unfortunately lost them 2 marks. As with any **DR** question, it is worth trying to complete as much of the question as possible without a calculator.

Those who changed $\tan x$ to $\frac{\sin x}{\cos x}$, and the equivalent for $\cot x$ did not generally do so well, Overall, only a small proportion of candidates that attempted this alternative method were able to complete this successfully to obtain the correct answers.

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Question 7

7 Prove that $\sin 8\theta \tan 4\theta + \cos 8\theta = 1$. **[3]**

Students often find trigonometry proof questions difficult. The question requires the use of two or three double angle formulas. Most students recognised that they needed to use the sin double angle formula, combined with tan=sin/cos, led them to a $\sin^2$ expression. which then led quite easily to 1 with the cos double angle formula. Those with a good grasp of the formulas arrived at the proof elegantly and quickly. A good number of students took different routes, coming unstuck by using the tan double angle formula. This led them nowhere helpful and they generally stopped there. There were more than a few that intent on taking factors (like 4) out of the sin8θ to give 4sin2θ. This uncovered a lack of understanding of the sin function. When practising identities like these it is worth going on to practise sin, cos and tan of 4θ, 6θ, 8θ, 74θ, etc. There were a few that treated this identity as an equation, which lost them the final A mark and betrayed a lack of understanding of what was required.

Question 8 (a) and (b)

8 In this question you must show detailed reasoning.

(a) Express $\cos x + \sqrt{3}\sin x$ in the form $R\sin(x+\alpha)$, where $R > 0$ and $0 < \alpha < \frac{1}{2}\pi$. Give the values of R and α in exact form. **[4]**

(b) Hence solve the equation $\cos x = \sqrt{3}(1-\sin x)$ for values of x in the interval $-\pi \leqslant x \leqslant \pi$. Give the roots of this equation in exact form. **[4]**

This question was answered reasonably well. If Rcosα and Rsinα were stated correctly, they generally went on to complete the question completely. However, when R was overlooked, they lost 2 marks, despite getting the correct angle for α.

Some students were confused about whether tanα was 1/√3 or √3/1. Part b was done generally well, although the biggest error was in finding the second angle, where they made the mistake of calculating π-π/6 instead of 2π/3-π/6.

Too many students were prone to write $\sin^{-1}(\sqrt{3}/2)$ without naming the angle. A few did not seem to recognise the connection with the previous part and tried to solve the trig equation by squaring both sides. This was acceptable as long as all solutions were checked to see if they worked in the original equation.

Avoiding the 'hence' naturally amounted to more time spent on the question.

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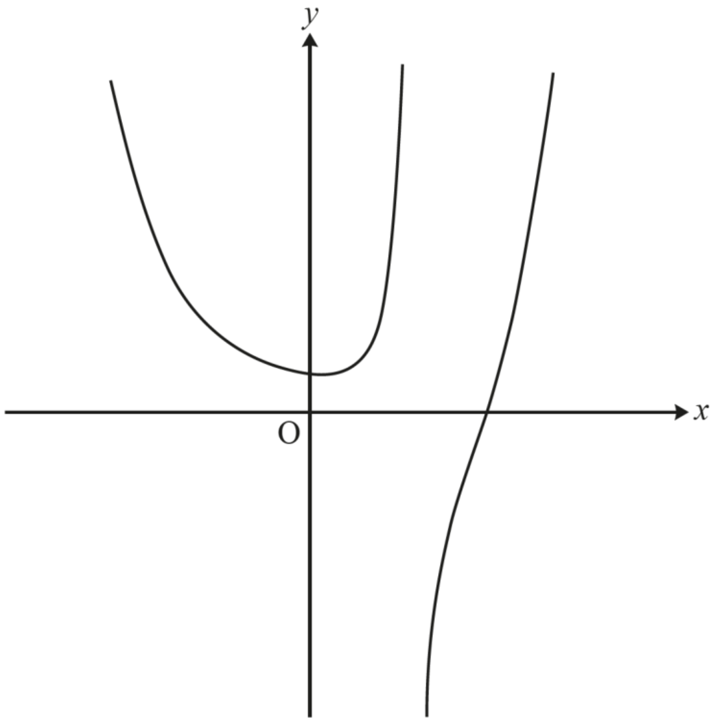
Question 9 (a), (b), (c), (d) (i) and (d) (ii)

9 This question is about the equation $f(x)=0$, where $f(x)=x^4-x-\frac{1}{3x-2}$.

Fig. 9.1 shows the curve $y=f(x)$.

Fig. 9.1



(a) Show, by calculation, that the equation $f(x)=0$ has a root between $x=1$ and $x=2$. **[2]**

(b) **Fig. 9.2** shows part of a spreadsheet being used to find a root of the equation.

Fig. 9.2

	A	B
1	x	f(x)
2	1.5	3.1625
3	1.25	0.619977679
4	1.125	-0.250466087
5		

Write down a suitable number to use as the next value of x in the spreadsheet. **[1]**

(c) Determine a root of the equation $f(x)=0$. Give your answer correct to **1** decimal place. **[1]**

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(d) **Fig. 9.3** shows a similar spreadsheet being used to search for another root of $f(x) = 0$.

Fig. 9.3

	A	B
1	x	f(x)
2	0	0.5
3	1	-1
4	0.5	1.5625
5	0.75	-4.4336
6	0.6	4.5296
7	0.7	-10.4599
8	0.65	19.5285
9	0.675	-40.4674
10	0.6625	79.5301
11	0.66875	-160.4687

(i) Explain why it looks from rows 2 and 3 of the spreadsheet as if there is a root between 0 and 1. **[1]**

(ii) Explain why this process will **not** find a root between 0 and 1. **[1]**

Q9(a): Well done by almost all.

Q9(b). Mainly well done, however 1.0625 was a common incorrect response.

Q9(c): Most gave the answer 1.2, however many did not give a justifying calculation.

Q9(di) Well answered by most.

Q9(dii) Reasonably well answered with observation of discontinuity and/or asymptote.

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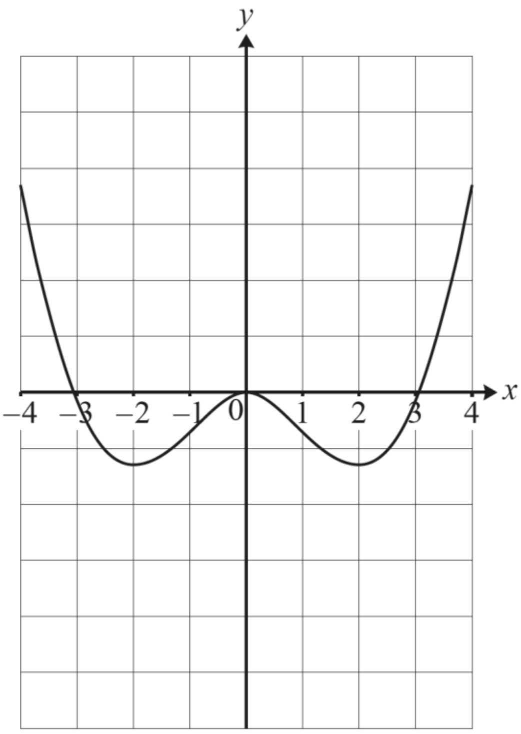
Question 10

10 The diagram below shows the curve $y = \mathrm{f}(x)$.



Sketch the graph of the gradient function, $y = \mathrm{f}'(x)$, on the copy of the diagram in the **Printed Answer Booklet**. **[3]**

Successful candidates started by identifying points with zero gradient and marking these on the *x*-axis.

They then worked out that the initial gradient is negative and that the gradient function would be cubic and completed the graph from there, scoring full marks.

Some candidates picked up 1 or 2 marks, either by drawing a positive cubic graph or by drawing a graph with rotational symmetry. Even the graph $y = x$ scored 1 mark for rotational symmetry.

Common incorrect responses included trying to reflect the graph in the line $y = x$. These candidates appeared to be muddled between a gradient function and an inverse function. Others reflected the graph in the *x*-axis.

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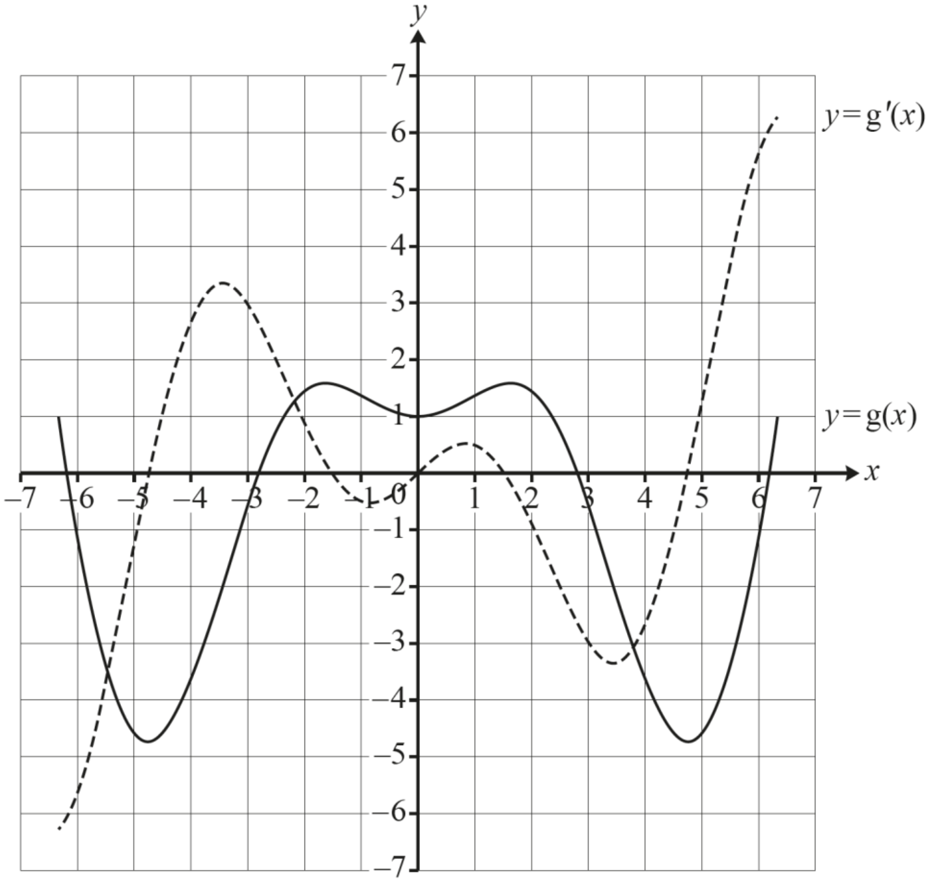
Question 11 (a), (b) and (c)

11 **Fig. 11.1** shows the curve with equation $y = g(x)$ where $g(x) = x\sin x + \cos x$ and the curve of the gradient function $y = g'(x)$ for $-2\pi \leqslant x \leqslant 2\pi$.

Fig. 11.1



(a) Show that the x-coordinates of the points on the curve $y = g(x)$ where the gradient is 1 satisfy the equation $\frac{1}{x} - \cos x = 0$. **[3]**

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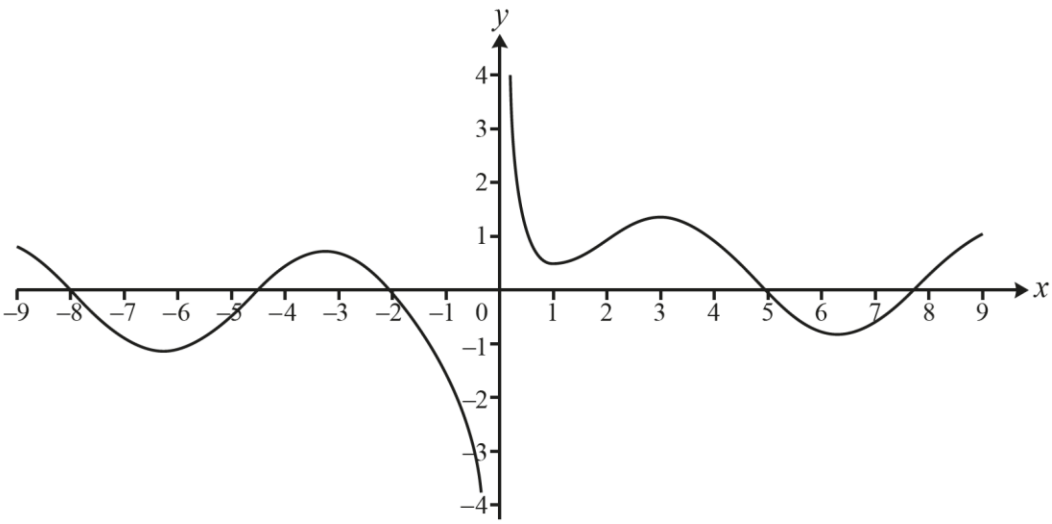
Fig. 11.2 shows part of the curve with equation $y = \frac{1}{x} - \cos x$.

Fig. 11.2



(b) Use the Newton-Raphson method with a suitable starting value to find the smallest positive x-coordinate of a point on the curve $y = x\sin x + \cos x$ where the gradient is 1.

You should write down at least the following.

- The iteration you use
- The starting value
- The solution correct to **4** decimal places **[4]**

(c) Explain why $x_1 = 3$ is **not** a suitable starting value for the Newton-Raphson method in part **(b)**. **[1]**

11 (a) Many candidates successfully gained full marks on this part. The first step was to differentiate the function. Those who did make mistakes here usually did not use the product rule for the $x \sin x$ term. The next step was to set the derivative equal to 1 before rearranging to the given answer.

11 (b) Part (b) was far less successful. Many candidates did not read the question carefully and tried to use $y = x \sin x + \cos x$ in the Newton Raphson formula instead of the equation of the given curve. Those who did use the correct formula were mostly successful in differentiating it. Some then lost the second mark by not using the subscripts in the formula when stating it. Starting values from 3.6 to 6.1 were given M1 but other values which also give the required root were also given M1. We did not expect to see intermediate iterations.

11 (c) Few candidates gave convincing reasons for this question. Candidates often commented that it was a turning point but then did not say why this was a problem. We were looking for an explanation that referred to the gradient of the curve or convergence to a different root. The easiest explanation was that you cannot divide by zero in the Newton Raphson formula.

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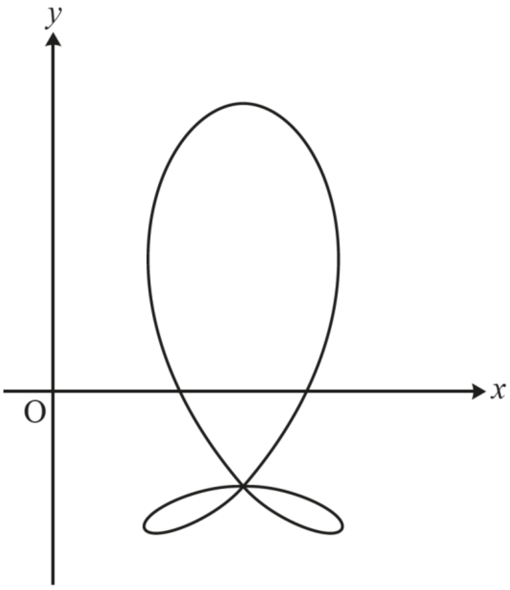
Question 12 (a) and (b)

12 The diagram shows the curve with parametric equations

$$x = \sin 2\theta + 2,\ y = 2\cos\theta + \cos 2\theta, \text{ for } 0 \leqslant \theta < 2\pi.$$



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

Determine the exact coordinates of all the stationary points on the curve. **[8]**

(b) Write down the equation of the line of symmetry of the curve. **[1]**

This was probably the question that candidates generally found to be the most challenging on the paper.

The most successful responses showed quick realisation that the solution centred on solving d*y*/d*θ* = 0 by using the sin double angle formula and factorisation. Many candidates missed out the factorisation step, choosing instead to divide through by sin *θ*, hence losing two of the solutions. This was penalised in the mark scheme so that all 4 Accuracy marks were then lost. Once correct factorisation was obtained, candidates generally went on to obtain most, if not all, of the Accuracy marks. (It should be noted that, although not penalised in the mark scheme, there was little evidence of checking that d*x*/d*θ* ≠ 0, when d*y*/d*θ* = 0.)

Successful responses for the Accuracy marks paid close attention to the constraints on given in the question, so as not to be penalised later in their working by including solutions outside the range, notably the inclusion of *θ* = 2π. Good solutions (as ever) were characterised by clear presentation, especially with a few words, such as 'at a stationary point d*y*/d*x* = 0'. Clear presentation was most essential around the factorisation stage, where unclear and/or ambiguous working jeopardised the awarding of Method marks.

Less successful responses were often characterised by rewriting of the equation for *y* using the cos double angle formula, making the differentiation more difficult and prone to sign errors. Quite often, unnecessary rearrangement of equations back and forth also led to sign errors, which meant all 4 Accuracy marks were then lost. In several cases, some candidates did not explicitly state that they had set d*y*/d*θ* equal to zero so that subsequent steps (e.g. a solution for sin *θ* or cos *θ*) were not sufficiently justified.

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A minority of candidates tried to find a Cartesian equation, but no successful attempts were seen. Some, realising they could not continue, either stopped or restarted. Some, however, tried to differentiate (with respect to x) their expression for y (which was now given in terms of x) and mistakenly differentiated some of the terms with respect to θ instead.

The vast majority of candidates obtained the correct equation for the mirror line in part (b).

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Section B overview

It seemed that candidates found this comprehension harder that the ones in recent years. This could be that despite the topics assessed being very familiar and generally quite accessible, the points on the lines being algebraic (t, t^2) rather than (5, -2) made the reasoning demands much higher. Many candidates left much of Section B blank.

On the other hand, there were plenty of candidates who got well into the task and scored very well on some or all of the questions in this section.

Question 13 and 14

13 Substitute appropriate values of t_1 and t_2 to verify that $t_1 t_2$ gives the correct value for the y-coordinate of the point of intersection of the tangents at the points A and B in **Fig. C1**. **[1]**

14 Substitute appropriate values of t_1 and t_2 to verify that the expression $t_1^2 + t_2^2 + t_1 t_2 + \frac{1}{2}$ gives the correct value for the y-coordinate of the point of intersection of the normals at the points A and B in **Fig. C2**. **[1]**

Questions 13 and 14 provided a relatively straightforward start to the comprehension section and many candidates gained these 2 marks for clearly showing what numbers were substituted for the different *t* values.

Question 15 (a) and (b)

15 (a) Show that, for the curve $y = ax^2 + bx + c$, the equation of the tangent at the point with x-coordinate t is $y = (2at + b)x - at^2 + c$. **[3]**

(b) Hence show that for the curve with equation $y = ax^2 + bx + c$, the tangents at two points, P and Q, on the curve cross at a point which has x-coordinate equal to the mean of the x-coordinates of points P and Q, as given in lines 11 to 14. **[3]**

Question 15 tested some relatively basic co-ordinate geometry. Part (a) required the equation of a tangent at a point but as is often the case, the context here made it difficult for many candidates to demonstrate the standard skills that they were probably very familiar with. Examiners were looking to see d*y*/d*x* for the curve followed by $y - y_1 = m(x - x_1)$ and the correct completion to the given answer. However again the context and the algebraic nature of the points made it hard for many to show these familiar skills.

Part (b) was about solving simultaneous equations where both were linear. Candidates would find it useful to practise some standard textbook questions on this topic before trying this question with the more challenging non-numeric equations.

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Question 16

16 Show that the expression $a\left(\frac{x_P + x_Q}{2}\right)^2 + b\left(\frac{x_P + x_Q}{2}\right) + c - a\left(\frac{x_P - x_Q}{2}\right)^2$ is equivalent to $ax_P x_Q + b\left(\frac{x_P + x_Q}{2}\right) + c$, as given in lines 15 and 16. **[2]**

Many candidates gave good solutions to this question. They knew how to combine the two terms containing *a*. In most cases they expanded the two terms, cancelled the squared terms and simplified the x_P and x_Q terms. This led to the correct result. A few candidates used 'difference of two squares' but it was not common.

Question 17

17 Show that, for the curve $y = x^2$, the equation of the normal at the point (t, t^2) is $y = -\frac{x}{2t} + t^2 + \frac{1}{2}$, as given in line 27. **[3]**

Although a significant proportion of candidates made no attempt at this question, those that did generally scored well. Most could correctly differentiate this quadratic and many could then substitute the *x* value (*t*) and apply the idea of negative reciprocal to get the gradient of the normal. Those with the gradient for the normal could then finish the question successfully.

Question 18

18 A student is investigating the intersection points of tangents to the curve $y = 6x^2 - 7x + 1$. She uses software to draw tangents at pairs of points with x-coordinates differing by 5.

Find the equation of the curve that all the intersection points lie on. **[2]**

There were a some correct solutions to this final question.

Some candidates did not appreciate that this was a question on tangents and used information on normals, or used the points A and B given on lines 22 and 23 (giving *h* = 4). Others unfortunately used the curve *y* = *x2* given on line 22, rather than the stated curve from the question.

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