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A LEVEL

Examiners' report

FURTHER MATHEMATICS B (MEI)

H645

For first teaching in 2017

Y420/01 Summer 2022 series

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 are 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 Y420/01 series overview

Y420 is a relatively long paper and it was encouraging to see candidates providing good, clear structured solutions. A number of candidates did not attempt every question, notably more than in previous series, but the overall standard did not seem any lower than previous years.

More than half the candidates achieved over 100 marks and all candidates gained some credit for their work.

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 work clearly and logically • attempted the majority of questions and gained partial credit even if a full solution was not achieved • knew and understood key terms, definitions and formulae • checked solutions and reattempted if required • understood the requirements of the defined question command words.	• missed steps in working for detailed reasoning questions • made no attempt on a number of questions • appeared to have some gaps in knowledge of key terms, definitions and formulae Changed signs to match given answers rather than checking full solution for initial mistakes.

OCR support

Download our poster detailing the [different command words] and what they mean.

Section A overview

Section A proved to be accessible to most candidates. The questions that proved most challenging in this section were Question 1 and Question 4.

Question 1 (a)

1 (a) By considering $(r+1)^3 - r^3$, find $\sum_{r=1}^{n}(3r^2+3r+1)$. **[3]**

A good proportion of candidates recognised that this question involved using the method of differences to develop their solution. However, almost half of these candidates lost marks because although they wrote the consideration, they didn't use this to find the summation and instead attempted to use the standard result for $\sum_{r=1}^{n} r^3$ which wasn't credited by examiners.

Question 1 (b)

(b) Use this result to find $\sum_{r=1}^{n} r(r+1)$, expressing your answer in fully factorised form. **[4]**

Candidates who read the instruction "use this result" generally performed well here. A common misconception, in otherwise good solutions, was to not use $\sum_{r=1}^{n} 1 = n$. Some candidates did not factorise their solution fully.

Candidates that used standard summation formulae were only given partial marks.

Question 2

2 In this question you must show detailed reasoning.

Find the exact value of $\displaystyle\int_3^\infty \frac{1}{x^2-4x+5}\,\mathrm{d}x$. **[5]**

This question was answered well with the majority of candidates being credited with full marks. This question included the '**In this question you must show detailed reasoning**' requirement; some candidates lost a mark for not giving a clear limit argument. Some solutions did not show a clear initial factorisation leading to the arctan function with an argument which did not match their integral.

Exemplar 1

2

$$\int_3^\infty \frac{1}{x^2-4x+5} = \int_3^\infty \frac{1}{(x-2)^2+1}$$

$$= \Big[\arctan(x-2)\Big]_3^\infty$$ Let $\infty = a$

$\arctan(a-2) - \arctan(1)$

$\arctan(a-2) - \frac{\pi}{4}$

as $a \to \infty$ $\arctan \to \frac{\pi}{2}$

$\frac{\pi}{2} - \frac{\pi}{4} = \frac{\pi}{4}$

Here is an example of an incomplete limit argument which wasn't given credit. If the candidate had stated as $a \to \infty, \arctan(a-2) \to \frac{\pi}{4}$ this would have been sufficient.

Question 3

3 In this question you must show detailed reasoning.

Solve the equation $3\cosh x = 2\sinh^2 x$, giving your solutions in exact logarithmic form. **[6]**

Most candidates were able to secure at least 5 marks here. The second solution was omitted in just under half of the correct solutions which meant that the final mark couldn't be credited. Some candidates considered an exponential method from the outset of the question but this approach led to having a quartic equation which needed to be solved. This was typically not shown so no credit could be given since the question required detailed reasoning.

Assessment for learning

"**In this question you must show detailed reasoning"** is used to make clear that an answer obtained directly from the calculator, without any evidence of a clear mathematical argument, will not gain credit.

Question 4 (a)

4 (a) A transformation with associated matrix $\begin{pmatrix} m & 2 & 1 \\ 0 & 1 & -2 \\ 2 & 0 & 3 \end{pmatrix}$, where m is a constant, maps the vertices of a cube to points that all lie in a plane.

Find m. **[3]**

About half of the candidates answered this correctly. The majority of successful solutions involved the use of the determinant to find *m*. A few candidates considered the image of the unit cube, and although a valid approach, was rarely completed successfully.

Question 4 (b)

(b) The transformations S and T of the plane have associated matrices **M** and **N** respectively, where $\mathbf{M} = \begin{pmatrix} k & 1 \\ -3 & 4 \end{pmatrix}$ and the determinant of **N** is $3k+1$. The transformation U is equivalent to the combined transformation consisting of S followed by T.

Given that U preserves orientation and has an area scale factor 2, find the possible values of k. **[4]**

Candidates were more successful with this part of the question and often used the first method shown in the mark scheme so any possible ordering errors in **NM** did not cause any issues.

Question 5 (a)

5 **(a)** Sketch the polar curve $r = a(1-\cos\theta)$, $0 \leqslant \theta < 2\pi$, where a is a positive constant. **[2]**

Almost all candidates sketched the correct shape for this question.

Question 5 (b)

(b) Determine the exact area of the region enclosed by the curve. **[5]**

The majority of candidates were given full marks for this question. Common mistakes were missing the *a* from their integral (or not squaring it) or substituting for $\cos^2\theta$ incorrectly.

Question 6

6 Prove by mathematical induction that $\begin{pmatrix} 2 & 0 \\ -1 & 1 \end{pmatrix}^n = \begin{pmatrix} 2^n & 0 \\ 1-2^n & 1 \end{pmatrix}$ for all positive integers n. **[5]**

Proof by induction is a well understood concept for the majority of candidates. About a fifth of candidates lost a mark for not having a clear conclusion, where a common error was omitting the conditional 'if'. Less successful responses were not rigorous when proving the case for $n = 1$ which resulted in marks not being credited.

Section B overview

Many candidates demonstrated a good understanding of the majority of the topics in Section B. It is worth noting that a number of candidates had found parts of the last question accessible and that this wasn't always considered the most difficult question.

Question 7

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

Show that $\int_2^3 \frac{x+1}{(x-1)(x^2+1)}\,dx = \frac{1}{2}\ln 2.$ **[9]**

The majority of candidates were given full marks for this question and demonstrated a good understanding of partial fractions and integrating them. A few candidates did not find the correct partial fractions which did not give them access to the majority of the marks for the question.

Question 8 (a)

8 Two sets of complex numbers are given by $\left\{z : \arg(z-10) = \frac{3}{4}\pi\right\}$ and $\{z : |z-3-6\mathrm{i}| = k\}$, where k is a positive constant. In an Argand diagram, one of the points of intersection of the two loci representing these sets lies on the imaginary axis.

(a) Sketch the loci on an Argand diagram. **[4]**

Most candidates knew they were dealing with a 'half-line' and a circle, and a good proportion had all the required features. However, sketches need to be annotated and examiners were not able to credit candidates with full marks if they omitted their angle or centre of the circle.

Assessment for learning

There are details of what is expected in a '**sketch'** question are given within section 2b of the specification covering 'The meanings of some instructions used in examination questions'.

Question 8 (b)

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

Find the complex numbers represented by the points of intersection. **[7]**

Less than half of the candidates were given full marks for this question. Some did not account for the circle and half-line meeting on the imaginary axis and therefore omitted a solution. It then made it unlikely for them to find the unknown k to access the remainder of the marks. Some candidates made good progress with the algebra and found the intersections but did not write these as complex numbers.

Question 9 (a)

9 The function $\mathrm{f}(x)$ is defined by $\mathrm{f}(x) = \ln(1 + \sinh x)$.

(a) Given that k lies in the domain of this function, explain why k must be greater than $\ln(\sqrt{2} - 1)$. **[2]**

Candidates found it very challenging to express their explanation with sufficient depth to gain both marks on this part of the question. Of those candidates who wrote a correct inequality for $\sinh k$, most attempted to solve it by using the exponential definitions. Unfortunately, the resulting quadratic inequality was almost always dealt with incompletely. Just under half of the candidates who were credited the method mark ignored the requirement for an explanation regarding the value of k, not x, and were not given the accuracy mark.

Misconception

? A number of candidates stated $-1 < x \leq 1$ for $\ln x$. Examiners were unsure if this is because candidates were considering that this was an expansion question or if it this was a genuine misconception.

Question 9 (b) (i)

(b) (i) Find $\mathrm{f}'(x)$. **[2]**

This question was well answered by the majority of candidates.

Question 9 (b) (ii)

(ii) Show that $f''(x) = \dfrac{a\sinh x + b}{(1+\sinh x)^2}$, where a and b are integers to be determined. **[3]**

The majority of candidates answered this well. A common error was to write the terms on the numerator the wrong way round or to use an incorrect substitution.

Question 9 (c)

(c) Hence find a quadratic approximation to $f(x)$ for small values of x. **[3]**

Candidates showed a good understanding of approximations and correctly used the Maclaurin series to find this. A small number misquoted the formula for the Maclaurin series and should be encouraged to use this from the formula booklet.

Assessment for learning

Make sure that candidates know what formula are given in the formula booklet and which need to be memorised or derived. With the extra pressures of the exam, students are best advised to refer to the formulae booklet rather than memorising given formulae. For formulae not in the booklet, teachers are encouraged to regularly give low stakes quizzes to help students recall them correctly.

Question 9 (d)

(d) Find the percentage error in this approximation when $x = 0.1$. **[2]**

Most candidates performed well here, with work followed through from previous parts for the method marks. Marks were not given when incomplete methods were shown (i.e. not showing multiplying by 100) or for using truncated values in their formula.

Question 10 (a)

10 The equation

$$4x^4 + 16x^3 + ax^2 + bx + 6 = 0,$$

where a and b are real, has roots α, $\frac{2}{\alpha}$, β and 3β.

(a) Given that $\beta < 0$, determine all 4 roots. **[6]**

This was well answered by the majority of candidates with over half of them given full marks. This topic appeared to be both fully understood and methods applied well.

Misconception

A number of candidates took their positive value of beta which resulted in partial marks being given. Candidates should be reminded of the meaning of the inequalities (or be encouraged not to assume to always take the positive solution).

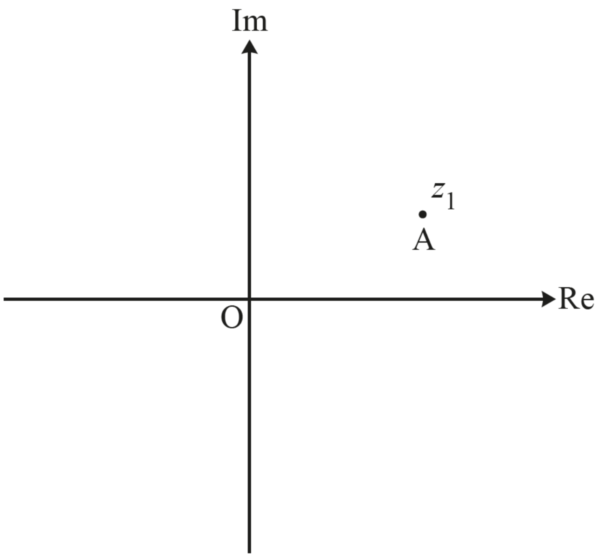
Question 10 (b)

(b) Determine the values of a and b. **[4]**

This was typically answered well. A common error was to be missing terms in the equations for $\frac{a}{4}$ and $-\frac{b}{4}$. Those candidates who considered the product of the factors of the whole expression or who used the factor theorem generally reached the answer more efficiently and with fewer errors.

Question 11 (a) (i)

11 An Argand diagram with the point A representing a complex number z_1 is shown below.



The complex numbers z_2 and z_3 are $z_1 e^{\frac{2}{3}i\pi}$ and $z_1 e^{\frac{4}{3}i\pi}$ respectively.

(a) **(i)** On the copy of the Argand diagram in the Printed Answer Booklet, mark the points B and C representing the complex numbers z_2 and z_3. **[2]**

This question was answered well by most candidates. Examiners would like to see a clear circle drawn to be confident that the modulus of each complex number is the same although this was rarely seen.

Question 11 (a) (ii)

(ii) Show that $z_1 + z_2 + z_3 = 0$. **[2]**

About half of candidates were given full marks for this question. A good proportion used the sum of a geometric progression. Lower scoring responses included errors such as missing z_1 in their solution or omitting steps from their method. As the answer is given examiners must be convinced that all terms had been evaluated for the accuracy mark to be credited.

Question 11 (b)

(b) Given now that z_1, z_2 and z_3 are roots of the equation $z^3 = 8\mathrm{i}$, find these three roots, giving your answers in the form $a + \mathrm{i}b$, where a and b are real and exact. **[4]**

This question was well answered by over half of the candidates. Few candidates wrote out the exponential or modulus argument form of z^3 explicitly. The most commonly given incorrect answer assumed that two of the solutions had to be complex conjugates. Candidates are expected to know that if the equation being solved does not have real coefficients, as here, then this is not the case.

Question 12

12 Solve the differential equation $(4 - x^2)\dfrac{\mathrm{d}y}{\mathrm{d}x} - xy = 1$, given that $y = 1$ when $x = 0$, giving your answer in the form $y = \mathrm{f}(x)$. **[9]**

Most candidates were able to obtain partial credit here. Most knew to divide through by $\dfrac{1}{4 - x^2}$ and to consider an integrating factor, though sign errors in the integral for the integrating factor or when integrating it, or both, were common. Some candidates did not divide the righthand side of the equation by $\left(4 - x^2\right)$.Many, having correctly identified $\dfrac{\mathrm{d}y}{\mathrm{d}x} - \dfrac{x}{4 - x^2}y$ as the lefthand side then went on to integrate $\dfrac{x}{4 - x^2}$ instead of $-\dfrac{x}{4 - x^2}$. Both those who had the correct integral, and those who did not, often made further errors in the integration. The written working must be checked carefully to make sure that accuracy marks are not given where subsequent errors 'cancel out' earlier mistakes.

Exemplar 2

12

$$(4-x^2)\frac{dy}{dx} - xy = 1$$

$$\frac{dy}{dx} - \frac{x}{4-x^2}y = \frac{1}{4-x^2}$$

$$e^{\int \frac{x}{4-x^2}dx} = e^{-\frac{1}{2}\ln 4-x^2}$$
$$= e^{\ln(4-x^2)^{-\frac{1}{2}}}$$
$$= (4-x^2)^{-1/2}$$

$$(4-x^2)^{-1/2}\frac{dy}{dx} - x(4-x^2)^{-1/2}y = (4-x^2)^{-1/2}$$

$$\frac{d}{dx}\left((4-x^2)^{-1/2}y\right) = (4-x^2)^{-1/2}$$

$$(4-x^2)^{-1/2}y = \int (4-x^2)^{-1/2}dx$$

$$(4-x^2)^{-1/2}y = \int \frac{1}{\sqrt{4-x^2}}dx$$

$$(4-x^2)^{-1/2}y = \arcsin\left(\frac{x}{2}\right) + c$$

$$y = \frac{\arcsin(x/2)}{\sqrt{4-x^2}} + \frac{c}{\sqrt{4-x^2}}$$

$y = 1, x = 0$ $$1 = 0 + \frac{c}{2}$$

$$2 = c$$

$$y = \frac{\arcsin(x/2)}{\sqrt{4-x^2}} + \frac{2}{\sqrt{4-x^2}}$$

This candidate has got to the correct answer through fortuitous working. They started correctly but then omitted the negative from their first integral. They then integrated this correctly to lead to an incorrect integrating factor. The candidate then multiplied through by this but has an incorrect righthand side which simplifies to the correct integral (fortuitously) This was seen a number of times by examiners and being credited with B1M0M1A0M0A0. The candidate can still be awarded subsequent M marks, but A Marks cannot be awarded if the solution has been obtained from wrong working (see note e in the Subject-specific Marking Instructions for A Level Mathematics B (MEI) on the mark scheme).

Question 13 (a)

13 The points A and B have coordinates $(4, 0, -1)$ and $(10, 4, -3)$ respectively. The planes Π_1 and Π_2 have equations $x-2y=5$ and $2x+3y-z=-4$ respectively.

(a) Find the acute angle between the line AB and the plane Π_1. **[4]**

Candidates were generally able to get 3 marks here. Many incorrectly deduced an acute angle of $83.1°$. It was common to see inefficient or informal methods here (and throughout the other parts of 13); in this case considering a formula in terms of $\sin\theta$ or using the modulus of the scalar product. It is worth noting that if a candidate gets an incorrect final solution without a clear formal method seen then they may only be given a maximum of 1 mark.

Question 13 (b)

(b) Show that the line AB meets Π_1 and Π_2 at the same point, whose coordinates should be specified. **[5]**

Candidates demonstrated a better understanding on this question than the previous part. The most common successful method was to substitute the equation of the line into both planes to find the same value of lambda for each and then find the coordinates.

Question 13 (c) (i)

(c) **(i)** Find $(\mathbf{i}-2\mathbf{j})\times(2\mathbf{i}+3\mathbf{j}-\mathbf{k})$. **[1]**

The majority of candidates calculated this correctly.

Question 13 (c) (ii)

(ii) Hence find the acute angle between the planes Π_1 and Π_2. **[3]**

Out of the candidates who attempted this question, less than half achieved full marks. Many candidates didn't take note of the instruction 'hence' and used $\mathbf{a.b} = |\mathbf{a}||\mathbf{b}|\cos\theta$ to solve which gained no credit.

Assessment for learning

If the '**hence**' command is shown then the candidate must use their solution from the previous part to gain credit.

Question 13 (c) (iii)

(iii) Find the shortest distance between the point A and the line of intersection of the planes Π_1 and Π_2. **[4]**

This question proved to be very challenging, with a number of candidates providing no response. The formula required isn't in the formula booklet so candidates need to memorise this or work it out from first principles. Some candidates attempted to use the incorrect formula for the distance between two skew lines which is given in the formula booklet.

Question 14 (a)

14 (a) Find $(3-\mathrm{e}^{2\mathrm{i}\theta})(3-\mathrm{e}^{-2\mathrm{i}\theta})$ in terms of $\cos 2\theta$. **[2]**

The vast majority were able to get M1 here though errors with signs or missing $\mathrm{i}S$ often resulted in the accuracy mark being withheld. The most common incorrect final answer was $10-3\cos\theta$.

Question 14 (b)

(b) Hence show that the sum of the infinite series

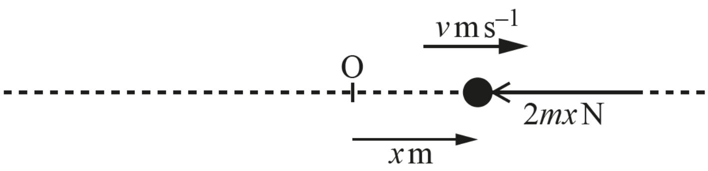
$$\sin\theta + \frac{1}{3}\sin 3\theta + \frac{1}{9}\sin 5\theta + \frac{1}{27}\sin 7\theta + \dots$$

can be expressed as $\dfrac{6\sin\theta}{5-3\cos 2\theta}$. **[6]**

Those candidates who knew to consider $C + \mathrm{i}S$ generally performed well here. Marks were most commonly lost for missing $\mathrm{i}S$ or from slips resulting from attempting to make too many reasoning steps in a single line of mathematical argument. A large number of candidates did not initially use their previous result efficiently, instead multiplying their numerator and denominator by $1-\frac{1}{3}e^{2i\theta}$. This is not incorrect but sometimes led to incorrect simplification.

Question 15 (a) (i)

15 In an oscillating system, a particle of mass m kg moves in a horizontal line. Its displacement from its equilibrium position O at time t seconds is x metres, its velocity is $v\,\mathrm{m\,s^{-1}}$, and it is acted on by a force $2mx$ newtons acting towards O as shown in the diagram.



Initially, the particle is projected away from O with speed $1\,\mathrm{m\,s^{-1}}$ from a point 2 m from O in the positive direction.

(a) **(i)** Show that the motion is modelled by the differential equation $\dfrac{d^2x}{dt^2} + 2x = 0$. **[1]**

This question was answered well with most candidates understanding that they needed to start with $F = ma$. Common mistakes seen involved sign errors or issues with rearranging the equation.

Question 15 (a) (ii)

(ii) State the type of motion. **[1]**

The vast majority of candidates knew that this was simple harmonic motion.

Question 15 (a) (iii)

(iii) Write down the period of the motion. **[1]**

More than half of the candidates were able to find the period of the motion without difficulty.

Question 15 (a) (iv)

(iv) Find x in terms of t. **[4]**

The majority of candidates were able to access this question well, although a significant minority did not show sufficient working to gain any partial credit.

Question 15 (a) (v)

(v) Find the amplitude of the motion. **[2]**

A significant number of candidates omitted this question completely. Of those that attempted it candidates often lost marks by writing their solution to the previous part in full harmonic form rather than just considering the amplitude. This often led to errors in their working.

Question 15 (b) (i)

(b) The motion is now damped by a force $2mv$ newtons.

(i) Show that $\frac{d^2x}{dt^2}+2\frac{dx}{dt}+2x=0$. **[1]**

Many candidates were able to show this correctly.

Question 15 (b) (ii)

(ii) State, giving a reason, whether the system is under-damped, critically damped or over-damped. **[1]**

About half the candidates were able to answer this correctly. The mark could only be awarded with a stated reason using either the calculation of the discriminant or referring to the auxiliary equation.

Question 15 (b) (iii)

(iii) Determine the general solution of this differential equation. **[3]**

This question was well answered by the majority of candidates. A number of candidates continued to find the particular solution which wasn't penalised but did show a misunderstanding of the terms required for differential equations.

Misconception

Candidates not understanding the difference between a particular and general solution.

Question 15 (c) (i)

(c) Finally, a variable force $2m\cos 2t$ newtons is added, so that the motion is now modelled by the differential equation

$$\frac{d^2x}{dt^2} + 2\frac{dx}{dt} + 2x = 2\cos 2t.$$

(i) Find x in terms of t. **[7]**

About a quarter of candidates were credited full marks on this question. Most candidates got the correct particular integral. Arithmetic slips were quite common leading to the accuracy mark being lost. Many used an incorrect complementary function, which they had often found in Question 15 (b) (iii). This resulted from a lack of awareness that the introduction of the variable force in this part would change any particular solution found previously. Many stopped once they had found the particular integral and did not find values for *A* or *B*.

Exemplar 3

15(c)(i)

Particular integral $x_p = C\cos 2t + B\sin 2t$

$\frac{dx}{dt} = -2C\sin 2t + 2B\cos 2t$

$\frac{d^2x}{dt^2} = -4C\cos 2t - 4B\sin 2t$

$-4C\cos 2t - 4B\sin 2t - 4C\sin 2t + 4B\cos 2t + 2C\cos 2t + 2B\sin 2t = 2\cos 2t$

Compare coefficients of $\cos 2t$

$-4C + 4B + 2C = 2$

$4B - 2C = 2$

c.c. of $\sin 2t$

$-4B - 4C + 2B = 0$

$-4C - 2B = 0$

$3B = 2 \therefore B = \frac{2}{3}$

$\therefore C = -\frac{1}{3}$

$x = e^{-t}(A\cos t + B\sin t) - \frac{1}{3}\cos 2t + \frac{2}{3}\sin 2t$

sub $x = 2$ $t = 0$

$2 = A - \frac{1}{3} \therefore A = \frac{7}{3}$

$\frac{dx}{dt} = -e^{-t}(A\cos t + B\sin t) + e^{-t}(-A\sin t + B\cos t) + \frac{2}{3}\sin 2t + \frac{4}{3}\cos 2t$

sub $\frac{dx}{dt} = 1$ $t = 0$

$1 = A + B + \frac{4}{3}$

$B = -\frac{8}{3}$

(answer space continued on next page)

15(c)(i)	**(continued)**
	$x = e^{-t}\left(\frac{7}{3}\cos t - \frac{8}{3}\sin t\right) - \frac{1}{3}\cos 2t + \frac{2}{3}\sin 2t$

This candidate has given a good attempt at this question. They have made a mistake when finding the coefficients of $\cos 2t$ and $\sin 2t$ but have the correct method throughout. They were credited with 4 out of the 7 marks available.

Assessment for learning

There can be a large amount of algebraic manipulation and calculus required as part of the method in many pure techniques. Students should be encouraged to regularly practice these skills and told explicitly to check their workings carefully for sign slips and numeracy errors as these regularly occur.

Question 15 (c) (ii)

In the long term, the particle is seen to perform simple harmonic motion with a period of just over 3 seconds.

(ii) Verify that this behaviour is consistent with the answer to part **(c)(i)**. **[2]**

A number of candidates gave no response to this question but most of the candidates who attempted it were credited for their solution.

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