Markscheme

May 2018

Further mathematics

Higher level

Paper 1

21 pages

Instructions to Examiners

Abbreviations

M Marks awarded for attempting to use a valid **Method**; working must be seen.

(M) Marks awarded for **Method**; may be implied by **correct** subsequent working.

A Marks awarded for an **Answer** or for **Accuracy**; often dependent on preceding ***M*** marks.

(A) Marks awarded for an **Answer** or for **Accuracy**; may be implied by **correct** subsequent working.

R Marks awarded for clear **Reasoning**.

N Marks awarded for **correct** answers if **no** working shown.

AG Answer given in the question and so no marks are awarded.

Using the markscheme

1 General

Mark according to RM™ Assessor instructions and the document "**Mathematics HL: Guidance for e-marking May 2018**". It is essential that you read this document before you start marking. In particular, please note the following:

- Marks must be recorded using the annotation stamps. Please check that you are entering marks for the right question.
- If a part is **completely correct**, (and gains all the "must be seen" marks), use the ticks with numbers to stamp full marks.
- If a part is completely wrong, stamp ***A0*** by the final answer.
- If a part gains anything else, it **must** be recorded using **all** the annotations.
- All the marks will be added and recorded by RM™ Assessor.

2 Method and Answer/Accuracy marks

- Do **not** automatically award full marks for a correct answer; all working **must** be checked, and marks awarded according to the markscheme.
- It is not possible to award ***M0*** followed by ***A1***, as ***A*** mark(s) depend on the preceding ***M*** mark(s), if any.
- Where ***M*** and ***A*** marks are noted on the same line, *eg* ***M1A1***, this usually means ***M1*** for an **attempt** to use an appropriate method (*eg* substitution into a formula) and ***A1*** for using the **correct** values.
- Where the markscheme specifies ***(M2)***, ***N3***, *etc.*, do **not** split the marks.
- Once a correct answer to a question or part-question is seen, ignore further working. However, if further working indicates a lack of mathematical understanding do not award the final ***A1***. An exception to this may be in numerical answers, where a correct exact value is followed by an incorrect decimal. However, if the incorrect decimal is carried through to a subsequent part, and correct ***FT*** working shown, award ***FT*** marks as appropriate but do not award the final ***A1*** in that part.

Examples

	Correct answer seen	Further working seen	Action
1.	$8\sqrt{2}$	$5.65685...$ *(incorrect decimal value)*	Award the final ***A1*** *(ignore the further working)*
2.	$\frac{1}{4}\sin 4x$	$\sin x$	Do not award the final ***A1***
3.	$\log a - \log b$	$\log(a-b)$	Do not award the final ***A1***

3 *N* marks

*Award **N** marks for **correct** answers where there is **no** working.*

- Do **not** award a mixture of ***N*** and other marks.
- There may be fewer ***N*** marks available than the total of ***M***, ***A*** and ***R*** marks; this is deliberate as it penalizes candidates for not following the instruction to show their working.

4 Implied marks

*Implied marks appear in **brackets eg (M1)**, and can only be awarded if **correct** work is seen or if implied in subsequent working.*

- Normally the correct work is seen or implied in the next line.
- Marks **without** brackets can only be awarded for work that is **seen**.

5 Follow through marks

*Follow through (**FT**) marks are awarded where an incorrect answer from one **part** of a question is used correctly in **subsequent** part(s). To award **FT** marks, **there must be working present** and not just a final answer based on an incorrect answer to a previous part.*

- If the question becomes much simpler because of an error then use discretion to award fewer ***FT*** marks.
- If the error leads to an inappropriate value (*eg* $\sin\theta = 1.5$), do not award the mark(s) for the final answer(s).
- Within a question part, once an error is made, no further **dependent *A*** marks can be awarded, but ***M*** marks may be awarded if appropriate.
- Exceptions to this rule will be explicitly noted on the markscheme.

6 Misread

*If a candidate incorrectly copies information from the question, this is a misread (**MR**).*
*A candidate should be penalized only once for a particular misread. Use the **MR** stamp to indicate that this has been a misread. Then deduct the first of the marks to be awarded, even if this is an **M** mark, but award all others so that the candidate only loses one mark.*

- If the question becomes much simpler because of the ***MR***, then use discretion to award fewer marks.
- If the ***MR*** leads to an inappropriate value (*eg* $\sin\theta = 1.5$), do not award the mark(s) for the final answer(s).

7 Discretionary marks *(d)*

An examiner uses discretion to award a mark on the rare occasions when the markscheme does not cover the work seen. In such cases the annotation DM should be used and a brief ***note*** *written next to the mark explaining this decision.*

8 Alternative methods

Candidates will sometimes use methods other than those in the markscheme. Unless the question specifies a method, other correct methods should be marked in line with the markscheme. If in doubt, contact your team leader for advice.

- Alternative methods for complete questions are indicated by **METHOD 1**, **METHOD 2**, *etc*.
- Alternative solutions for part-questions are indicated by **EITHER** . . . **OR**.
- Where possible, alignment will also be used to assist examiners in identifying where these alternatives start and finish.

9 Alternative forms

Unless the question specifies otherwise, ***accept*** *equivalent forms.*

- As this is an international examination, accept all alternative forms of **notation**.
- In the markscheme, equivalent **numerical** and **algebraic** forms will generally be written in brackets immediately following the answer.
- In the markscheme, **simplified** answers, (which candidates often do not write in examinations), will generally appear in brackets. Marks should be awarded for either the form preceding the bracket or the form in brackets (if it is seen).

Example: for differentiating $f(x) = 2\sin(5x-3)$, the markscheme gives:

$f'(x) = \left(2\cos(5x-3)\right)5 \quad \left(=10\cos(5x-3)\right)$ ***A1***

Award ***A1*** for $\left(2\cos(5x-3)\right)5$, even if $10\cos(5x-3)$ is not seen.

10 Accuracy of Answers

Candidates should ***NO LONGER*** *be penalized for an accuracy error* ***(AP)***.

If the level of accuracy is specified in the question, a mark will be allocated for giving the answer to the required accuracy. When this is not specified in the question, all numerical answers should be given exactly or correct to three significant figures. Please check work carefully for ***FT***.

11 Crossed out work

If a candidate has drawn a line through work on their examination script, or in some other way crossed out their work, do not award any marks for that work.

12 Calculators

A GDC is required, but calculators with symbolic manipulation features (for example, TI-89) are not allowed.

Calculator notation
The Mathematics HL guide says:
Students must always use correct mathematical notation, not calculator notation.
Do **not** accept final answers written using calculator notation. However, do not penalize the use of calculator notation in the working.

13 More than one solution

Where a candidate offers two or more different answers to the same question, an examiner should only mark the first response unless the candidate indicates otherwise.

1. (a) $383 = 5 \times 74 + 13$ ***M1***

$74 = 5 \times 13 + 9$ ***A1***

$13 = 1 \times 9 + 4$ ***(A1)***

$9 = 2 \times 4 + 1$

$4 = 4 \times 1 + 0$

$\Rightarrow$ gcd $(74, 383) = 1$ ***A1***

[4 marks]

(b) **EITHER**

$1 = 9 - 2 \times 4$ ***(M1)***

$= 9 - 2(13 - 1 \times 9) = 3 \times 9 - 2 \times 13$ ***(A1)***

$= 3(74 - 5 \times 13) - 2 \times 13 = 3 \times 74 - 17 \times 13$ ***(A1)***

$= 3 \times 74 - 17(383 - 5 \times 74) = 88 \times 74 - 17 \times 383$

OR

$13 = 383 - 5 \times 74$ ***(M1)***

$9 = 74 - 5 \times 13$

$= 74 - 5(383 - 5 \times 74)$

$= 26 \times 74 - 5 \times 383$ ***(A1)***

$4 = 13 - 9$

$= (383 - 5 \times 74) - (26 \times 74 - 5 \times 383)$

$= 6 \times 383 - 31 \times 74$ ***(A1)***

$1 = 9 - 2 \times 4$

$= (26 \times 74 - 5 \times 383) - 2(6 \times 383 - 31 \times 74)$

$= 88 \times 74 - 17 \times 383$

THEN

$\Rightarrow s = 88$ and $t = -17$ ***A1A1***

[5 marks]

Total [9 marks]

2. (a) **METHOD 1**

$A^4 = 4A^2 + 4AI + I^2$ or equivalent ***M1A1***

$= 4(2A + I) + 4A + I$ ***A1***

$= 8A + 4I + 4A + I$

$= 12A + 5I$ ***AG***

[3 marks]

METHOD 2

$A^3 = A(2A + I) = 2A^2 + AI = 2(2A + I) + A (= 5A + 2I)$ ***M1A1***

$A^4 = A(5A + 2I)$ ***A1***

$= 5A^2 + 2A = 5(2A + I) + 2A$

$= 12A + 5I$ ***AG***

(b) $B^2 = \begin{bmatrix} 18 & 2 \\ 1 & 11 \end{bmatrix}$ ***(A1)***

$\begin{bmatrix} 18 & 2 \\ 1 & 11 \end{bmatrix} - \begin{bmatrix} 4 & 2 \\ 1 & -3 \end{bmatrix} - \begin{bmatrix} 4 & 0 \\ 0 & 4 \end{bmatrix} = \begin{bmatrix} 10 & 0 \\ 0 & 10 \end{bmatrix}$ ***(A1)***

$\Rightarrow k = 10$ ***A1***

[3 marks]

Total [6 marks]

3. (a) $4303_5 = 4\times5^3 + 3\times5^2 + 0\times5^1 + 3\times5^0$ ***(M1)***

$= 500 + 75 + 3$

$= 578$ ***A1***

[2 marks]

(b) **METHOD 1**

$1000 = a_0 + 7a_1 + 49a_2 + 343a_3$ ***(M1)***

(Since $343a_3 < 1000$) $\Rightarrow a_3 = 2$ ***(A1)***

$1000 = a_0 + 7a_1 + 49a_2 + 686$

$a_0 + 7a_1 + 49a_2 = 314 \Rightarrow a_2 = 6$ ***(A1)***

$a_0 + 7a_1 = 20 \Rightarrow a_1 = 2,\ a_0 = 6$ ***(A1)***

$\Rightarrow 1000_{10} = 2626_7$ ***A1***

METHOD 2

$1000 = 7 \times 142 + 6$ ***(M1)***

$142 = 7 \times 20 + 2$ ***(A1)***

$20 = 7 \times 2 + 6$ ***(A1)***

$2 = 7 \times 0 + 2$ ***(A1)***

$\Rightarrow (1000)_{10} = 2626_7$ ***A1***

[5 marks]

Total [7 marks]

4. (a)

	T_1	T_2	T_3	T_4
T_1	T_1	T_2	T_3	T_4
T_2	T_2	$\boldsymbol{T_3}$	$\boldsymbol{T_4}$	$\boldsymbol{T_1}$
T_3	T_3	$\boldsymbol{T_4}$	$\boldsymbol{T_1}$	$\boldsymbol{T_2}$
T_4	T_4	$\boldsymbol{T_1}$	$\boldsymbol{T_2}$	$\boldsymbol{T_3}$

A2

[2 marks]

Note: Award ***A1*** for 6, 7 or 8 correct.

(b) (i) the table is closed – no new elements ***A1***

T_1 is the identity ***A1***

T_3 (and T_1) are self-inverse; T_2 and T_4 are an inverse pair. Hence every element has an inverse ***A1***

hence it is a group ***AG***

(ii) all elements in the group can be generated by T_2 (or T_4) ***R1***

hence the group is cyclic ***AG***

[4 marks]

continued…

Question 4 continued

(c) T_3 is represented by $\begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$ ***A1***

T_4 is represented by $\begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$ ***A1***

T_5 is represented by $\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$ ***A1***

[3 marks]

(d) (i) $\begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix} = \begin{pmatrix} 0 & -1 \\ -1 & 0 \end{pmatrix}$ ***(M1)A1***

Note: Award ***M1A0*** for multiplying the matrices in the wrong order.

(ii) a reflection in the line $y = -x$ ***A1***

[3 marks]

Total [12 marks]

5. let $u = \ln x$ ***(M1)***

$\Rightarrow \frac{\mathrm{d}u}{\mathrm{d}x} = \frac{1}{x}$

$\int \frac{1}{x(\ln x)^2}\,\mathrm{d}x = \int \frac{1}{u^2}\,\mathrm{d}u$ ***(A1)***

$= -\frac{1}{u} = -\frac{1}{\ln x}$ ***(A1)***

$\int_2^m \frac{1}{x(\ln x)^2}\,\mathrm{d}x = \left[-\frac{1}{\ln x}\right]_2^m$ ***M1***

$= \left[-\frac{1}{\ln m} + \frac{1}{\ln 2}\right]$ ***A1***

as $m \to \infty$, $-\frac{1}{\ln m} \to 0$ ***(A1)***

$\int_2^\infty \frac{1}{x(\ln x)^2}\,\mathrm{d}x = \frac{1}{\ln 2}$ and hence the series converges ***R1***

[7 marks]

6. (a) (i) $B \cup C = \{3\ 4\ 6\ 8\ 9\ 12\ 15\ 16\ 18\ 20\}$ ***(M1)***

$\Rightarrow A \cap (B \cup C) = \{4\ 6\ 8\ 12\ 16\ 18\ 20\}$ ***A1***

(ii) $B \setminus C = B \cap C' = \{3\ 6\ 9\ 15\ 18\}$ ***(M1)(A1)***

$A \setminus (B \setminus C) = \left(A \cap (B \cap C')'\right) = \{2\ 4\ 8\ 10\ 12\ 14\ 16\ 20\}$ ***A1***

[5 marks]

(b) let x be any element of M

then $x = 10q$ for $q \in \mathbb{Z}$ ***M1***

hence $x = 5(2 \times q)$ ***A1***

since $2 \times q$ is an integer, x is an element of N ***R1***

since M is smaller than N, ***R1***

it is a proper subset ***AG***

[4 marks]

Total [9 marks]

7. (a) $\bar{X} \sim \mathrm{N}\left(\mu, \frac{\sigma^2}{n}\right)$

$\bar{X} \sim \mathrm{N}\left(65, \frac{36}{100}\right)$ ***(A1)***

$\mathrm{P}(\text{Type I Error}) = \mathrm{P}(\bar{X} > 66.5)$ ***(M1)***

$= 0.00621$ ***A1***

[3 marks]

(b) (i) $\mathrm{P}(\text{Type II Error}) = \mathrm{P}(\text{accept } H_0 \mid H_1 \text{ is true})$

$= \mathrm{P}(\bar{X} \le 66.5 \mid \mu = 67.9)$ ***(M1)***

$= \mathrm{P}(\bar{X} \le 66.5)$ when $\bar{X} \sim \mathrm{N}\left(67.9, \frac{36}{100}\right)$ ***(M1)***

$= 0.00982$ ***A1***

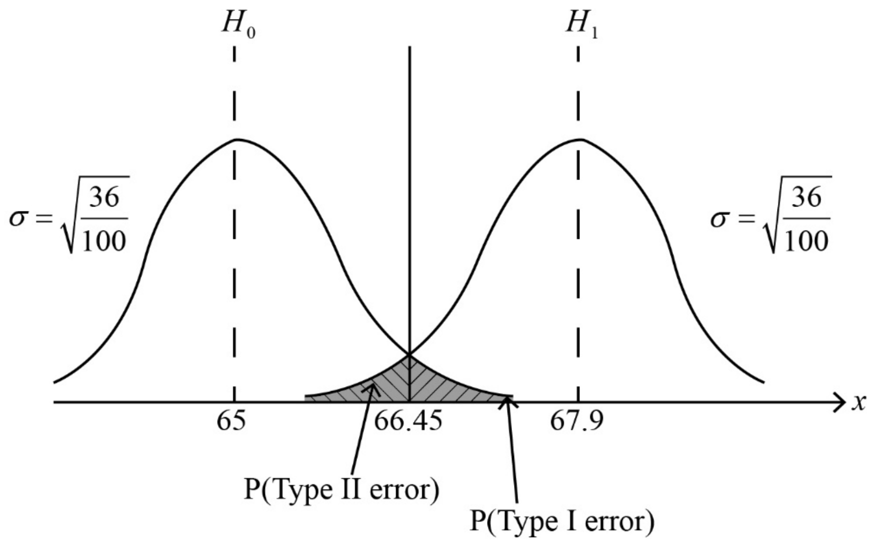
continued…

Question 7 continued

(ii) the variances of the distributions given by H_0 and H_1 are equal, ***(R1)***

by symmetry the value of $\bar{x}$ lies midway between 65 and 67.9 ***(M1)***

$\Rightarrow \bar{x} = \frac{1}{2}(65 + 67.9) = 66.45$ ***A1***



[6 marks]

Total [9 marks]

8. (a) $\begin{pmatrix} 1 & 0 & 1 & -1 \\ 3 & 1 & 2 & 1 \\ 2 & a & -1 & b \end{pmatrix} \Rightarrow \begin{pmatrix} 1 & 0 & 1 & -1 \\ 3a-2 & 0 & 2a+1 & a-b \\ 2 & a & -1 & b \end{pmatrix}$ or equivalent ***M1A1***

$$\begin{pmatrix} 0 & 0 & a-3 & -4a+2+b \\ 3a-2 & 0 & 2a+1 & a-b \\ 2 & a & -1 & b \end{pmatrix}$$

$z = \dfrac{-4a+b+2}{a-3}$ ***M1A1***

$x = -1 - z$ ***M1***

$$x = -1 - \left(\frac{-4a+b+2}{a-3}\right)$$

$$x = \frac{-a+3+4a-b-2}{a-3}$$

$x = \dfrac{3a-b+1}{a-3}$ ***A1***

$y = 1 - 3x - 2z$ ***M1***

$$y = 1 - 3\left(\frac{3a-b+1}{a-3}\right) - 2\left(\frac{-4a+b+2}{a-3}\right)$$

$$= \frac{a-3-9a+3b-3+8a-2b-4}{a-3}$$

$= \dfrac{b-10}{a-3}$ ***A1***

[8 marks]

(b) when $a = 3$ the denominator of x, y and $z = 0$ ***R1***

Note: Accept any valid reason.

hence no unique solutions ***AG***

[1 mark]

(c) For example let $z = \lambda$ ***(M1)***

$x = -1 - \lambda$ ***(A1)***

$y = 1 - 3(-1-\lambda) - 2\lambda$

$y = 4 + \lambda$ ***(A1)***

$r = \begin{pmatrix} -1 \\ 4 \\ 0 \end{pmatrix} + \lambda \begin{pmatrix} -1 \\ 1 \\ 1 \end{pmatrix}$ ***A1***

[4 marks]

Note: Accept answers which let $x = \lambda$ or $y = \lambda$.

Total [13 marks]

9. (a) $A \times B$ is a rectangle *A1*
vertices at $(0,0)$, $(3,0)$, $(0,4)$ and $(3,4)$ or equivalent description *A1*
and its interior *A1*

Note: Accept diagrammatic answers.

[3 marks]

(b) (i) need to prove it is injective and surjective *R1*
need to show if $f(x,y) = f(u,v)$ then $(x,y) = (u,v)$ *M1*
$\Rightarrow x + 3y = u + 3v$
$2x - y = 2u - v$ *A1*
Equation 2 – 2 Equation 1 $\Rightarrow y = v$
Equation 1 + 3 Equation 2 $\Rightarrow x = u$ *A1*
thus $(x,y) = (u,v) \Rightarrow f$ is injective

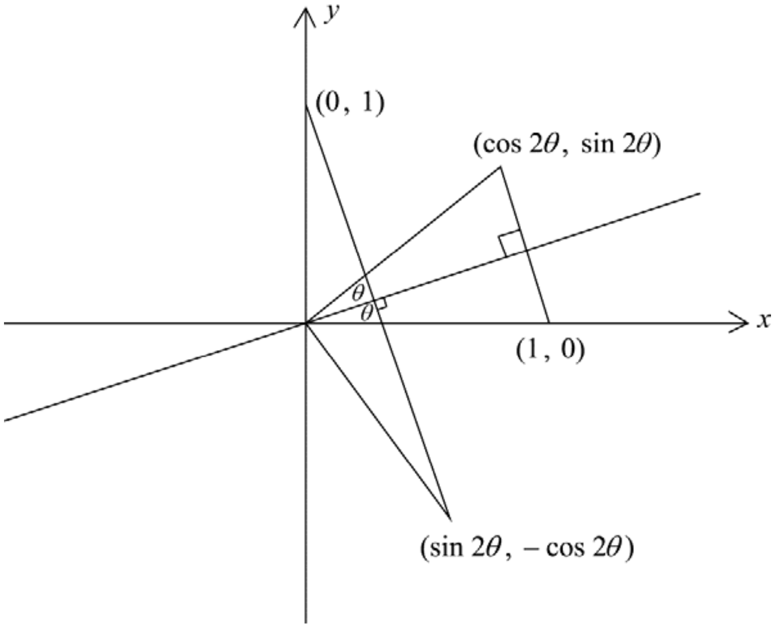
let (s,t) be any value in the co-domain $\mathbb{R} \times \mathbb{R}$
we must find (x,y) such that $f(x,y) = (s,t)$ *M1*
$s = x + 3y$ and $t = 2x - y$ *M1*
$\Rightarrow y = \dfrac{2s - t}{7}$ *A1*
and $x = \dfrac{s + 3t}{7}$ *A1*
hence $f(x,y) = (s,t)$ and is therefore surjective

(ii) $f^{-1}(x,y) = \left(\dfrac{x + 3y}{7}, \dfrac{2x - y}{7}\right)$ *A1A1*

[10 marks]

Total [13 marks]

10. (a) (i)



(M1)

using the transformation of the unit square:

$\begin{pmatrix}1\\0\end{pmatrix}\to\begin{pmatrix}\cos 2\theta\\ \sin 2\theta\end{pmatrix}$ and $\begin{pmatrix}0\\1\end{pmatrix}\to\begin{pmatrix}\sin 2\theta\\ -\cos 2\theta\end{pmatrix}$ ***(M1)***

hence the matrix $\boldsymbol{P}$ is $\begin{pmatrix}\cos 2\theta & \sin 2\theta\\ \sin 2\theta & -\cos 2\theta\end{pmatrix}$ ***A1***

(ii) using the transformation of the unit square:

$\begin{pmatrix}1\\0\end{pmatrix}\to\begin{pmatrix}\cos \theta\\ \sin \theta\end{pmatrix}$ and $\begin{pmatrix}0\\1\end{pmatrix}\to\begin{pmatrix}-\sin \theta\\ \cos \theta\end{pmatrix}$ ***(M1)***

hence the matrix $\boldsymbol{Q}$ is $\begin{pmatrix}\cos \theta & -\sin \theta\\ \sin \theta & \cos \theta\end{pmatrix}$ ***A1***

[5 marks]

continued…

Question 10 continued

(b) $\boldsymbol{PQ} = \begin{pmatrix} \cos\theta\cos 2\theta + \sin\theta\sin 2\theta & \cos\theta\sin 2\theta - \sin\theta\cos 2\theta \\ -\cos 2\theta\sin\theta + \sin 2\theta\cos\theta & -\sin\theta\sin 2\theta - \cos\theta\cos 2\theta \end{pmatrix}$ ***M1A1***

$= \begin{pmatrix} \cos(2\theta-\theta) & \sin(2\theta-\theta) \\ \sin(2\theta-\theta) & -\cos(2\theta-\theta) \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ \sin\theta & -\cos\theta \end{pmatrix}$ ***M1A1***

this is a reflection in the line $y = \left(\tan\frac{1}{2}\theta\right)x$ ***A1***

[5 marks]

(c) $\boldsymbol{Q}^{\mathrm{T}}\boldsymbol{Q} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}\begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}$

$= \begin{pmatrix} \cos^2\theta + \sin^2\theta & -\cos\theta\sin\theta + \cos\theta\sin\theta \\ -\sin\theta\cos\theta + \cos\theta\sin\theta & \sin^2\theta + \cos^2\theta \end{pmatrix}$ ***M1A1***

$= \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$ ***AG***

[2 marks]

Total [12 marks]

11. (a) $z = \dfrac{y-x}{y+x}$

$\Rightarrow \dfrac{\mathrm{d}z}{\mathrm{d}x} = \dfrac{(y+x)\left(\dfrac{\mathrm{d}y}{\mathrm{d}x}-1\right)-(y-x)\left(\dfrac{\mathrm{d}y}{\mathrm{d}x}+1\right)}{(y+x)^2}$ ***M1A1***

$\Rightarrow \dfrac{\mathrm{d}z}{\mathrm{d}x} = \dfrac{y\dfrac{\mathrm{d}y}{\mathrm{d}x}+x\dfrac{\mathrm{d}y}{\mathrm{d}x}-y-x-y\dfrac{\mathrm{d}y}{\mathrm{d}x}+x\dfrac{\mathrm{d}y}{\mathrm{d}x}-y+x}{(y+x)^2}$ ***A1***

$\Rightarrow \dfrac{\mathrm{d}z}{\mathrm{d}x} = \dfrac{2}{(y+x)^2}\left(x\dfrac{\mathrm{d}y}{\mathrm{d}x}-y\right)$ ***AG***

[3 marks]

(b) $f(x)\left(\dfrac{(y+x)^2}{2}\right)\dfrac{\mathrm{d}z}{\mathrm{d}x} = y^2 - x^2$ ***(M1)***

$f(x)\dfrac{\mathrm{d}z}{\mathrm{d}x} = 2\dfrac{(y-x)(y+x)}{(y+x)^2}$ ***A1***

$f(x)\dfrac{\mathrm{d}z}{\mathrm{d}x} = 2\dfrac{(y-x)}{(y+x)} = 2z$ ***AG***

[2 marks]

continued…

Question 11 continued

(c) **METHOD 1**

$$f(x)\frac{\mathrm{d}z}{\mathrm{d}x}=2z$$

$$\frac{1}{z}\frac{\mathrm{d}z}{\mathrm{d}x}=\frac{2}{f(x)}$$

$$\frac{1}{z}\frac{\mathrm{d}z}{\mathrm{d}x}=\frac{2}{x-3}$$ ***M1A1***

EITHER

$\Rightarrow \ln z=2\ln(x-3)+c$ ***A1***

when $y=5, x=4 \Rightarrow z=\frac{1}{9}$ ***M1***

$\Rightarrow c=\ln\frac{1}{9}$ ***A1***

$\Rightarrow \ln z=2\ln(x-3)+\ln\frac{1}{9}$

$\Rightarrow \ln z=\ln(x-3)^2-\ln 9$ ***A1***

$\Rightarrow \ln z=\ln\left(\frac{x-3}{3}\right)^2$ ***A1***

$\Rightarrow z=\left(\frac{x-3}{3}\right)^2$

OR

$\Rightarrow \ln z=2\ln(x-3)+\ln c$ ***A1***

$z=c(x-3)^2$ ***M1A1***

when $y=5, x=4 \Rightarrow z=\frac{1}{9}$ ***M1***

$\Rightarrow c=\frac{1}{9}$ ***A1***

THEN

$\Rightarrow \frac{y-x}{y+x}=\left(\frac{x-3}{3}\right)^2$ ***AG***

continued…

Question 11 continued

METHOD 2

$f(x)\frac{\mathrm{d}z}{\mathrm{d}x} = 2z$

$f(x)\frac{\mathrm{d}z}{\mathrm{d}x} - 2z = 0$

$\frac{\mathrm{d}z}{\mathrm{d}x} - \frac{2z}{x-3} = 0$ ***M1***

integrating factor is $e^{\int \frac{-2}{x-3}\mathrm{d}x}$ ***A1***

$e^{\int \frac{-2}{x-3}\mathrm{d}x} = e^{-2\ln(x-3)}$

$= \frac{1}{(x-3)^2}$ ***A1***

hence $\frac{d}{\mathrm{d}x}\left[\frac{z}{(x-3)^2}\right] = 0$ ***M1***

$z = A(x-3)^2$ ***A1***

when $y = 5, x = 4 \Rightarrow z = \frac{1}{9}$ ***M1***

$\Rightarrow A = \frac{1}{9}$ ***A1***

$\Rightarrow \frac{y-x}{y+x} = \left(\frac{x-3}{3}\right)^2$ ***AG***

[7 marks]

Total [12 marks]

12. (a) auxiliary equation is $m^2 - 4m + 4 = 0$ ***M1A1***

hence m has a repeated root of 2 ***(A1)***

solution is of the form $u_n = a(2)^n + bn(2)^n$ ***M1***

using the initial conditions ***M1***

$\Rightarrow a = 1$ and $b = -\frac{1}{2}$

$\Rightarrow u_n = 2^n - \frac{n}{2}(2)^n$ ***A1***

[6 marks]

continued…

Question 12 continued

(b) $v_n = \frac{4}{5}\left(\frac{1}{2}\right)^n + \frac{1}{5}(3)^n$

let $n=0$ $v_0 = \frac{4}{5}\left(\frac{1}{2}\right)^0 + \frac{1}{5}(3)^0 = \frac{4}{5} + \frac{1}{5} = 1$

let $n=1$ $v_1 = \frac{4}{5}\left(\frac{1}{2}\right)^1 + \frac{1}{5}(3)^1 = \frac{2}{5} + \frac{3}{5} = 1$

hence true for $n=0$ and $n=1$ ***M1A1***

assume that $v_j = \frac{4}{5}\left(\frac{1}{2}\right)^j + \frac{1}{5}(3)^j$ is true for all $j < k+1$ ***M1***

hence $v_k = \frac{4}{5}\left(\frac{1}{2}\right)^k + \frac{1}{5}(3)^k$ and $v_{k-1} = \frac{4}{5}\left(\frac{1}{2}\right)^{k-1} + \frac{1}{5}(3)^{k-1}$

$$v_{k+1} = \frac{7v_k - 3v_{k-1}}{2}$$

$$v_{k+1} = \frac{7\left[\frac{4}{5}\left(\frac{1}{2}\right)^k + \frac{1}{5}(3)^k\right] - 3\left[\frac{4}{5}\left(\frac{1}{2}\right)^{k-1} + \frac{1}{5}(3)^{k-1}\right]}{2}$$ ***M1A1***

$$v_{k+1} = \frac{7\left[\frac{8}{5}\left(\frac{1}{2}\right)^{k+1} + \frac{1}{15}(3)^{k+1}\right] - 3\left[\frac{16}{5}\left(\frac{1}{2}\right)^{k+1} + \frac{1}{45}(3)^{k+1}\right]}{2}$$ ***(A1)***

$$v_{k+1} = \frac{\frac{56}{5}\left(\frac{1}{2}\right)^{k+1} + \frac{7}{15}(3)^{k+1} - \frac{48}{5}\left(\frac{1}{2}\right)^{k+1} - \frac{1}{15}(3)^{k+1}}{2}$$ ***(A1)***

$$v_{k+1} = \frac{\frac{8}{5}\left(\frac{1}{2}\right)^{k+1} + \frac{6}{15}(3)^{k+1}}{2}$$ ***(A1)***

Note: Only one of the above ***(A1)*** can be implied.

$$v_{k+1} = \frac{4}{5}\left(\frac{1}{2}\right)^{k+1} + \frac{1}{5}(3)^{k+1}$$

since the basis step and the inductive step have been verified, the Principle of Mathematical Induction tells us that $v_n = \frac{4}{5}\left(\frac{1}{2}\right)^n + \frac{1}{5}(3)^n$ is the general solution ***R1***

[9 marks]

Note: Only award final ***R1*** if at least 5 previous marks have been awarded.

Total [15 marks]

13. (a) $\begin{pmatrix} 2 & -4 \\ -1 & -1 \end{pmatrix}\begin{pmatrix} k \\ k \end{pmatrix} = \begin{pmatrix} -2k \\ -2k \end{pmatrix} \left(= -2\begin{pmatrix} k \\ k \end{pmatrix} \right)$ ***M1A1***

hence still on the line $y = x$ ***AG***

[2 marks]

(b) consider $\begin{pmatrix} 2 & -4 \\ -1 & -1 \end{pmatrix}\begin{pmatrix} 4k \\ -k \end{pmatrix}$ ***M1***

$= \begin{pmatrix} 12k \\ -3k \end{pmatrix} \left(= 3\begin{pmatrix} 4k \\ -k \end{pmatrix} \right)$ ***A1***

hence the line is invariant ***A1***

[3 marks]

(c) hence the eigenvalues are -2 and 3 ***A1A1***

[2 marks]

(d) $\begin{pmatrix} 1 \\ 1 \end{pmatrix}$ and $\begin{pmatrix} 4 \\ -1 \end{pmatrix}$ or equivalent ***A1A1***

[2 marks]

Total [9 marks]

14. (a) $\bar{x} = 43.94$ ***(A1)***

unbiased variance estimate $= 466.0847$ ***(A1)***

Note: Accept sample variance $= 464.2204$.

$\Rightarrow$ 90% confidence interval is $(41.7, 46.2)$ ***A1A1***

[4 marks]

(b) Z-value is -1.87489 or -1.87866 ***(A1)***

probability is 0.0304 or 0.0301 ***(A1)***

$\Rightarrow \lambda \geq 3.01$ ***(M1)A1***

[4 marks]

Total [8 marks]

15. EITHER

attempt to differentiate ***(M1)***

let $y = 2at \Rightarrow \frac{\mathrm{d}y}{\mathrm{d}t} = 2a$ and $x = at^2 \Rightarrow \frac{\mathrm{d}x}{\mathrm{d}t} = 2at$ ***A1***

hence $\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{\mathrm{d}y}{\mathrm{d}t} \times \frac{\mathrm{d}t}{\mathrm{d}x} = \frac{2a}{2at} = \frac{1}{t}$ ***A1***

let P have coordinates $\left(at_1^2, 2at_1\right)$ and Q have coordinates $\left(at_2^2, 2at_2\right)$ ***(M1)***

therefore gradient of tangent at P is $\frac{1}{t_1}$ and gradient of tangent at Q is $\frac{1}{t_2}$ ***A1***

since these tangents are perpendicular $\frac{1}{t_1} \times \frac{1}{t_2} = -1 \Rightarrow t_1 t_2 = -1$ ***A1***

mid-point of PQ is $\left(\frac{a\left(t_1^2 + t_2^2\right)}{2}, a\left(t_1 + t_2\right)\right)$ ***A1***

$y^2 = a^2\left(t_1^2 + 2t_1t_2 + t_2^2\right)$ ***M1***

$y^2 = a^2\left(\frac{2x}{a} - 2\right)$ $\left(\Rightarrow y^2 = 2ax - 2a^2\right)$ ***A1***

OR

attempt to differentiate ***(M1)***

$2y\frac{\mathrm{d}y}{\mathrm{d}x} = 4a$ ***A1***

$\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{2a}{y}$

let coordinates of P be $\left(x_1, y_1\right)$ and the coordinates of Q be $\left(x_2, y_2\right)$ ***(M1)***

coordinates of midpoint of PQ are $\left(\frac{x_1 + x_2}{2}, \frac{y_1 + y_2}{2}\right)$ ***M1***

if the tangents are perpendicular $\frac{2a}{y_1} \times \frac{2a}{y_2} = -1$ ***A1***

$\Rightarrow y_1 y_2 = -4a^2$

$y_1^2 + y_2^2 = 4a\left(x_1 + x_2\right)$ ***A1***

$\frac{y_1^2 + 2y_1y_2 + y_2^2}{4} = \frac{4a\left(x_1 + x_2\right) + 2y_1y_2}{4}$ ***M1***

$\left(\frac{y_1 + y_2}{2}\right)^2 = 2a\left(\frac{x_1 + x_2}{2}\right) - \frac{8a^2}{4}$ ***A1***

hence equation of locus is $y^2 = 2ax - 2a^2$ ***A1***

[9 marks]