

# Markscheme

**May 2019**

**Sets, relations and groups**

**Higher level**

**Paper 3**

No part of this product may be reproduced in any form or by any electronic or mechanical means, including information storage and retrieval systems, without written permission from the IB.

Additionally, the license tied with this product prohibits commercial use of any selected files or extracts from this product. Use by third parties, including but not limited to publishers, private teachers, tutoring or study services, preparatory schools, vendors operating curriculum mapping services or teacher resource digital platforms and app developers, is not permitted and is subject to the IB's prior written consent via a license. More information on how to request a license can be obtained from <http://www.ibo.org/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

Aucune partie de ce produit ne peut être reproduite sous quelque forme ni par quelque moyen que ce soit, électronique ou mécanique, y compris des systèmes de stockage et de récupération d'informations, sans l'autorisation écrite de l'IB.

De plus, la licence associée à ce produit interdit toute utilisation commerciale de tout fichier ou extrait sélectionné dans ce produit. L'utilisation par des tiers, y compris, sans toutefois s'y limiter, des éditeurs, des professeurs particuliers, des services de tutorat ou d'aide aux études, des établissements de préparation à l'enseignement supérieur, des fournisseurs de services de planification des programmes d'études, des gestionnaires de plateformes pédagogiques en ligne, et des développeurs d'applications, n'est pas autorisée et est soumise au consentement écrit préalable de l'IB par l'intermédiaire d'une licence. Pour plus d'informations sur la procédure à suivre pour demander une licence, rendez-vous à l'adresse <http://www.ibo.org/fr/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

No se podrá reproducir ninguna parte de este producto de ninguna forma ni por ningún medio electrónico o mecánico, incluidos los sistemas de almacenamiento y recuperación de información, sin que medie la autorización escrita del IB.

Además, la licencia vinculada a este producto prohíbe el uso con fines comerciales de todo archivo o fragmento seleccionado de este producto. El uso por parte de terceros —lo que incluye, a título enunciativo, editoriales, profesores particulares, servicios de apoyo académico o ayuda para el estudio, colegios preparatorios, desarrolladores de aplicaciones y entidades que presten servicios de planificación curricular u ofrezcan recursos para docentes mediante plataformas digitales— no está permitido y estará sujeto al otorgamiento previo de una licencia escrita por parte del IB. En este enlace encontrará más información sobre cómo solicitar una licencia: <http://www.ibo.org/es/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

## 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. 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 correct 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 <b>A1</b> (ignore the further working)
2.	$\frac{1}{4}\sin 4x$	$\sin x$	Do not award the final <b>A1</b>
3.	$\log a - \log b$	$\log(a - b)$	Do not award the final <b>A1</b>

### 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 [**1 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:

$$f'(x) = (2 \cos(5x - 3))5 \quad (= 10 \cos(5x - 3)) \quad \mathbf{A1}$$

Award **A1** for  $(2 \cos(5x - 3))5$ , 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 for paper 3, but calculators with symbolic manipulation features (eg 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)  $xRx \Rightarrow x^2 + x^2 = 2x^2$  **M1**  
 since this is equal to  $0 \pmod{2}$  it is reflexive **R1**  
 $xRy \Leftrightarrow x^2 + y^2 \equiv 0 \pmod{2}$   
 $\Rightarrow y^2 + x^2 \equiv 0 \pmod{2}$  **M1**  
 $\Rightarrow yRx$ , hence symmetric **R1**  
 $xRy \Leftrightarrow x^2 + y^2 \equiv 0 \pmod{2} (= 2m)$  and  $yRz \Leftrightarrow y^2 + z^2 \equiv 0 \pmod{2} (= 2n)$  **M1**  
 adding and recognising  $2y^2 = 0 \pmod{2} \Rightarrow x^2 + y^2 + y^2 + z^2 = x^2 + 0 \pmod{2} + z^2$  **M1**  
 $\Rightarrow x^2 + z^2 = 2m + 2n = 2(m+n) \equiv 0 \pmod{2}$   
 $\Rightarrow xRz$  and hence transitive **R1**  
**[7 marks]**
- (b) one consists of even natural numbers and the other consists of odd natural numbers **A1A1**  
**[2 marks]**  
**Total [9 marks]**
2. (a)  $z_1 * e = Bz_1e (= z_1)$  **(M1)**  
 $\Rightarrow e = \frac{1}{B}$  **A1**  
**[2 marks]**
- (b)  $z_1 * z_1^{-1} = \frac{1}{B}$  **M1**  
 $\Rightarrow Bz_1z_1^{-1} = \frac{1}{B}$  **(A1)**  
 $\Rightarrow z_1^{-1} = \frac{1}{B^2z_1}$  **A1**  
 which is a member of  $\mathbb{C}$  (provided  $z_1 \neq 0$ )  
 hence inverse exists for all  $\mathbb{C}$  (except  $z_1 = 0$ ) **AG**  

**Note:** Candidates may use  $a + ib$  in place of  $z_1$ .

**[3 marks]**

continued...

Question 2 continued

- (c) attempt to show that  $(z_1 \circ z_2) \circ z_3 = z_1 \circ (z_2 \circ z_3)$  **(M1)**  
 $LHS = (z_1 \circ z_2) \circ z_3 = A(z_1 + z_2) \circ z_3$   
 $\Rightarrow A(Az_1 + Az_2 + z_3)$  **A1**  
 $RHS = z_1 \circ (z_2 \circ z_3) = z_1 \circ A(z_2 + z_3)$   
 $\Rightarrow A(z_1 + Az_2 + Az_3)$  **A1**  
 $LHS = RHS$  when  $A = 1$  **A1**

**Note:** If a candidate “guesses”  $A = 1$  and then verifies the result works award **M1A0A0A1**.

[4 marks]

- (d) attempt to show that  $z_1 * (z_2 \circ z_3) = (z_1 * z_2) \circ (z_1 * z_3)$  **M1**  
 $LHS = z_1 * (z_2 \circ z_3) = z_1 * A(z_2 + z_3)$  **(A1)**  
 $= ABz_1(z_2 + z_3) (= ABz_1z_2 + ABz_1z_3)$  or equivalent **A1**  
 $RHS = (z_1 * z_2) \circ (z_1 * z_3) = (Bz_1z_2) \circ (Bz_1z_3)$  **A1**  
 $= AB(z_1z_2 + z_1z_3)$   
 $= ABz_1(z_2 + z_3) (= ABz_1z_2 + ABz_1z_3)$  or equivalent **A1**  
 hence  $*$  is distributive over  $\circ$  for all values of  $A$  and  $B$  **AG**

**Note:** Any reasonable attempt at recognising the distributive property should be given **M1**.  
 This could include only one side being correct.

[5 marks]

**Total [14 marks]**

3. (a) (i)  $ba^2 = baa = a^3ba$  **M1**  
 $a^3ba = a^3a^3b = a^4a^2b = ea^2b$  **M1**  
 $= a^2b$  **AG**
- (ii)  $ba^3 = baa^2 = a^3ba^2$  **M1**  
 $= a^3baa = a^3a^3ba = a^3a^3a^3b = (a^4)^2 ab = (e)^2 ab$  **M1**  
 $= ab$  **AG**

[4 marks]

continued...



Question 3 continued

- (b)  $P = a^3b$
- $Q = b$
- $R = a^3$
- $S = e$
- $T = a$
- $U = a^2$
- $V = a^3$
- $W = e$

**A4**

**Note:** Award **A3** for 6 or 7 correct, **A2** for 4 or 5 correct, **A1** for 2 or 3 correct and **A0** otherwise.

[4 marks]

- (c) since one group is Abelian and the other is not then they are not isomorphic **R1**

**Note:** Award **R1** for any valid reason – for example “one group commutative”.

[1 mark]

**Total [9 marks]**

- 4. closure: Consider  $(m + n\sqrt{5})(p + q\sqrt{5})$  **M1**

$$= mp + 5nq + \sqrt{5}(np + mq) \quad \mathbf{A1}$$

this is of the form  $a + b\sqrt{5}$  and since neither  $m + n\sqrt{5}$  nor  $p + q\sqrt{5} = 0 + 0\sqrt{5}$ , the product cannot be zero

$$\text{(also noting } p^2 \neq 5q^2 : (mp + 5nq)^2 = 5(np + mq)^2 \Rightarrow (m^2 - 5n^2)(p^2 - 5q^2) = 0$$

$$\text{therefore } (mp + 5nq)^2 = 5(np + mq)^2 \text{ iff } (m^2 - 5n^2) = 0 \text{ or } (p^2 - 5q^2) = 0$$

hence closed) **R1**

identity:  $1 + 0\sqrt{5}$  **A1**

inverse: Consider  $\frac{1}{a + b\sqrt{5}}$  **M1**

$$= \frac{a - b\sqrt{5}}{(a + b\sqrt{5})(a - b\sqrt{5})} \quad \mathbf{(M1)}$$

$$= \frac{a}{a^2 - 5b^2} - \sqrt{5} \left( \frac{b}{a^2 - 5b^2} \right) \quad \mathbf{A1}$$

(since  $a, b$  cannot simultaneously be zero and  $a^2$  cannot equal  $5b^2$ , all elements have an inverse)

(associativity can be assumed)

hence  $S$  is a group under the operation of multiplication **AG**

**Total [7 marks]**

5. (a) for bijection required to show injective and surjective **(M1)**  
 suppose  $f(x, y) = f(u, v)$  **(M1)**  
 $\Rightarrow x + y = u + v$  (i),  $x - y = u - v$  (ii) **A1**  
 (i) + (ii)  $2x = 2u \Rightarrow x = u$ , (i) - (ii)  $2y = 2v \Rightarrow y = v$  **(M1)A1**  
 $(x, y) = (u, v)$   
 since  $f(x, y) = f(u, v) \Rightarrow (x, y) = (u, v)$  ( $\Rightarrow f$  is injective) **R1**  
 let  $f(x, y) = (s, t)$  **(M1)**  
 $\Rightarrow x + y = s, x - y = t$   
 $\Rightarrow x = \frac{s+t}{2}, y = \frac{s-t}{2}$  **A1**  
 $\frac{s+t}{2}$  and  $\frac{s-t}{2}$  are both real ( $\Rightarrow f$  is surjective) **R1**  
 hence  $f$  is a bijection **AG**  
**[9 marks]**
- (b) consider surjectivity **(M1)**  
 since  $x = \frac{s+t}{2}, y = \frac{s-t}{2}$ , do not necessarily belong to  $\mathbb{Z}$  (if  $s, t$  are both odd  
 or  $s, t$  are both even the expressions belong to  $\mathbb{Z}$  but if  $s$  is even and  $t$  is  
 odd or vice versa this is no longer true) **R1**  
 hence the function  $g$  is not surjective and hence not a bijection **AG**  

**Note:** Accept using a counter example.

**[2 marks]**  
**Total [11 marks]**
-