N14/5/MATHL/HP3/ENG/TZ0/SG/M

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MARKSCHEME

November 2014

MATHEMATICS
SETS, RELATIONS AND GROUPS

Higher Level

Paper 3

11 pages

Instructions to Examiners

Abbreviations

M Marks awarded for attempting to use a correct **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 November 2014**". 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.

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 Mis-read

*If a candidate incorrectly copies information from the question, this is a mis-read (**MR**). A candidate should be penalized only once for a particular mis-read. 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 for paper 3, 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) $a = 1 \;\; b = 8 \;\; c = 4$
$d = 8 \;\; e = 4 \;\; f = 2$
$g = 4 \;\; h = 2 \;\; i = 1$ ***A3***

Note: Award ***A3*** for 9 correct answers, ***A2*** for 6 or more, and ***A1*** for 3 or more.

[3 marks]

(b)

Elements	**Order**
1	1
4, 11, 14	2
2, 7, 8, 13	4

A3

Note: Award ***A3*** for 8 correct answers, ***A2*** for 6 or more, and ***A1*** for 4 or more.

[3 marks]

(c) $\{1, 4\}, \{1, 11\}, \{1, 14\}$ ***A1A1***

Note: Award ***A1*** for 1 correct answer and ***A2*** for all 3 (and no extras).

[2 marks]

(d) $\{1, 2, 4, 8\}$, $\{1, 4, 7, 13\}$, ***A1A1***
$\{1, 4, 11, 14\}$ ***A2***

[4 marks]

Total [12 marks]

2. (a) **METHOD 1**

$f(x) = f(y) \Rightarrow \frac{4x+1}{2x-1} = \frac{4y+1}{2y-1}$ ***M1A1***

for attempting to cross multiply and simplify ***M1***

$(4x+1)(2y-1) = (2x-1)(4y+1)$

$\Rightarrow 8xy + 2y - 4x - 1 = 8xy + 2x - 4y - 1 \Rightarrow 6y = 6x$

$\Rightarrow x = y$ ***A1***

hence an injection ***AG***

[4 marks]

METHOD 2

$f'(x) = \frac{4(2x-1) - 2(4x+1)}{(2x-1)^2} = \frac{-6}{(2x-1)^2}$ ***M1A1***

< 0 (for all $x \neq 0.5$) ***R1***

therefore the function is decreasing on either side of the discontinuity

and $f(x) < 2$ for $x < 0.5$ and $x > 2$ for $f(x) > 0.5$ ***R1***

hence an injection ***AG***

Note: If a correct graph of the function is shown, and the candidate states this is decreasing in each part (or horizontal line test) and hence an injection, award ***M1A1R1***.

[4 marks]

(b) **METHOD 1**

attempt to solve $y = \frac{4x+1}{2x-1}$ ***M1***

$y(2x-1) = 4x+1 \Rightarrow 2xy - y = 4x+1$ ***A1***

$2xy - 4x = 1 + y \Rightarrow x = \frac{1+y}{2y-4}$ ***A1***

no value for $y = 2$ ***R1***

hence not a surjection ***AG***

[4 marks]

METHOD 2

consider $y = 2$ ***A1***

attempt to solve $2 = \frac{4x+1}{2x-1}$ ***M1***

$4x - 2 = 4x + 1$ ***A1***

which has no solution ***R1***

hence not a surjection ***AG***

Note: If a correct graph of the function is shown, and the candidate states that because there is a horizontal asymptote at $y = 2$ then the function is not a surjection, award ***M1R1***.

[4 marks]

Total [8 marks]

3. (a) $q \circ p = (1\,3)\,(2\,5)\,(1\,2\,5)$ ***(M1)***

$= (1\,5\,3)$ ***M1A1A1***

Note: ***M1*** for an answer consisting of disjoint cycles, ***A1*** for (1 5 3), ***A1*** for either (2) or (2) omitted.

Note: Allow $\begin{pmatrix} 1 & 2 & 3 & 4 & 5 \\ 5 & 2 & 1 & 4 & 3 \end{pmatrix}$

If done in the wrong order and obtained (1 3 2), award ***A2***.

[4 marks]

(b) (i) any cycle with length 4 *eg* (1 2 3 4) ***A1***

(ii) any permutation with 2 disjoint cycles one of length 2 and one of length 3 *eg* (1 2) (3 4 5) ***M1A1***

Note: Award ***M1A0*** for any permutation with 2 non-disjoint cycles one of length 2 and one of length 3.
Accept non cycle notation.

[3 marks]

(c) (i) (1, 2), (1, 3), (1, 4), (1, 5) ***M1A1***

(ii) (2 3), (2 4), (2 5), (3 4), (3 5), (4 5) ***(M1)***

6 ***A1***

Note: Award ***M1*** for at least one correct cycle.

[4 marks]

Total [11 marks]

4. (a) $f(e_G) = e_H \Rightarrow f\left(a * a^{-1}\right) = e_H$ ***M1***

f is a homomorphism so $f\left(a * a^{-1}\right) = f(a) \circ f\left(a^{-1}\right) = e_H$ ***M1A1***

by definition $f(a) \circ \left(f(a)\right)^{-1} = e_H$ so $f\left(a^{-1}\right) = \left(f(a)\right)^{-1}$ (by the left-cancellation law) ***R1***

[4 marks]

(b) from (a) $f(x^{-1}) = \left(f(x)\right)^{-1}$

hence $f(x^{-1}) = (p^2)^{-1} = p^5$ ***M1A1***

[2 marks]

(c) $f(x * y) = f(x) \circ f(y)$ (homomorphism) ***(M1)***

$p^2 \circ f(y) = p$ ***A1***

$f(y) = p^5 \circ p$ ***(M1)***

$= p^6$ ***A1***

[4 marks]

Total [10 marks]

5. (a) in a **finite** group the order of any subgroup (exactly) divides the order of the group ***A1A1***

[2 marks]

(b) **METHOD 1**

$\left(a*b^{-1}\right)*\left(b*a^{-1}\right)=a*b^{-1}*b*a^{-1}=a*e*a^{-1}=a*a^{-1}=e$ ***M1A1A1***

Note: ***M1*** for multiplying, ***A1*** for at least one of the next 3 expressions, ***A1*** for *e*.
Allow $\left(b*a^{-1}\right)*\left(a*b^{-1}\right)=b*a^{-1}*a*b^{-1}=b*e*b^{-1}=b*b^{-1}=e$.

METHOD 2

$\left(a*b^{-1}\right)^{-1}=\left(b^{-1}\right)^{-1}*a^{-1}$ ***M1A1***

$=b*a^{-1}$ ***A1***

[3 marks]

(c) $a*a^{-1}=e\in H$ (as H is a subgroup) ***M1***
so aRa and hence R is reflexive
$aRb\Leftrightarrow a*b^{-1}\in H$. H is a subgroup so every element has an inverse in H so
$\left(a*b^{-1}\right)^{-1}\in H$ ***R1***

$\Leftrightarrow b*a^{-1}\in H\Leftrightarrow bRa$ ***M1***
so R is symmetric
$aRb, bRc \Leftrightarrow a*b^{-1}\in H,\ b*c^{-1}\in H$ ***M1***
as H is closed $(a*b^{-1})*(b*c^{-1})\in H$ ***R1***
and using associativity ***R1***
$(a*b^{-1})*(b*c^{-1})=a*(b^{-1}*b)*c^{-1}=a*c^{-1}\in H\Leftrightarrow aRc$ ***A1***
therefore R is transitive

R is reflexive, symmetric and transitive ***A1***

Note: Can be said separately at the end of each part.

hence it is an equivalence relation ***AG*** ***[8 marks]***

(d) $aRb\Leftrightarrow a*b^{-1}\in H\Leftrightarrow a*b^{-1}=h\in H$ ***A1***
$\Leftrightarrow a=h*b\Leftrightarrow a\in Hb$ ***M1R1***

[3 marks]

continued ...

Question 5 continued

(e) (d) implies that the right cosets of H are equal to the equivalence classes of the relation in (c) ***R1***
hence the cosets partition G ***R1***
all the cosets are of the same size as the subgroup H so the order of G must be a multiple of $|H|$ ***R1***

[3 marks]

Total [19 marks]