Abstract Algebra MAT02B3 / MAT3B20

Solutions to the Exam - November 2021

Marks: 39 ..... total time 3 hours

Question 1 [0.5+2+ 1.5+2=6]

(a) Define what is meant by a group.

A: A group is a non-empty set G with a binary operation on G that satisfies:
(1) for all $a, b, c \in G$: $a(bc) = (ab)c$ (associativity).
(2) there exists an element $e \in G$ such that for all $a \in G$: $ae = ea = a$,
(3) for all $a \in G$ there exists an element b with $ab = ba = e$ (inverse element).

(b) Let G be the set of all 2×2-matrices of the form

$$\begin{pmatrix} 0 & a \\ b & 0 \end{pmatrix}.$$

where a and b are real numbers. Is G a group under matrix addition? Prove your answer.

A: G is a group. Clearly $G \neq \emptyset$. If $A = \begin{pmatrix} 0 & a_1 \\ a_2 & 0 \end{pmatrix}$ and $B = \begin{pmatrix} 0 & b_1 \\ b_2 & 0 \end{pmatrix}$ are matrices in G, then clearly

$$A + B = \begin{pmatrix} 0 & a_1 + b_1 \\ a_2 + b_2 & 0 \end{pmatrix}$$

is an element of G. Hence G is closed under matrix addition.
(1) Since matrix addition is associative for all 2×2 matrices, it is also associative for all matrices in G.
(2) The matrix $\begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$ is an identity element for matrix addition since

$$\begin{pmatrix} 0 & a_1 \\ a_2 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} = \begin{pmatrix} 0 & a_1 \\ a_2 & 0 \end{pmatrix}, \quad \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & a_1 \\ a_2 & 0 \end{pmatrix} = \begin{pmatrix} 0 & a_1 \\ a_2 & 0 \end{pmatrix}.$$

Moreover, $\begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} \in G$.
(3) For a given $A \in G$, $A = \begin{pmatrix} 0 & a_1 \\ a_2 & 0 \end{pmatrix}$, define $-A = \begin{pmatrix} 0 & -a_1 \\ -a_2 & 0 \end{pmatrix}$. Then

$$A + -A = \begin{pmatrix} 0 & a_1 \\ a_2 & 0 \end{pmatrix} + \begin{pmatrix} 0 & -a_1 \\ -a_2 & 0 \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix},$$

$$-A + A = \begin{pmatrix} 0 & -a_1 \\ -a_2 & 0 \end{pmatrix} + \begin{pmatrix} 0 & a_1 \\ a_2 & 0 \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix},$$

hence $-A$ is the inverse of A. Moreover, $-A$ is clearly in G.
Since G satisfies all group axioms, G is a group.

(c) Let the set G be defined by

$$G = \{2^k \mid k \in \mathbb{Z}\} \cup \{0\}.$$

Prove that G is not a group under the usual addition.
A: The set G is not closed under addition. For example $2^1 + 2^0 = 3 \notin G$. Hence G is not a group.

(d) State what is meant by the "socks-shoes property", and prove that every group has this property.

A: The socks-shoes property states that for elements a, b of a group G, the inverse of ab is $b^{-1}a^{-1}$.

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