

Abstract Algebra Homework 1

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- 2) Which of the following multiplication tables defined on the set $G = \{a, b, c, d\}$ form a group? Support your answer in each case.

Theorem 1. Let $a, b, c \in G$. Given a is the Identity element of the set G , then $a \circ (b \circ c) = (a \circ b) \circ c, \forall b, c \in G$.

Proof. Let $d \in G$ with $b \circ c = d$. Then $a \circ (b \circ c) \implies a \circ d = d$.

We also have $(a \circ b) \circ c \implies b \circ c = d$.

$\therefore a \circ (b \circ c) = (a \circ b) \circ c$. ■

(a)

\circ	a	b	c	d
a	a	c	d	a
b	b	b	c	d
c	c	d	a	b
d	d	a	b	c

This Cayley Table does not form a group because it is not Associative:

$$\begin{aligned} a \circ (b \circ c) &= d \text{ and} \\ (a \circ b) \circ c &= a \\ \implies a \circ (b \circ c) &\neq (a \circ b) \circ c \end{aligned}$$

(b)

\circ	a	b	c	d
a	a	b	c	d
b	b	a	d	c
c	c	d	a	b
d	d	c	b	a

Closure: Every element in the Cayley Table is in the set G , so it is closed.

Identity: taking any element and multiplying it by a returns that element. So a is the identity element.

Inverse: A diagonal is formed in the table with the identity element a , so every element is its own inverse.

Associative: Because a is the identity element it is associative with every set of two elements by Theorem 1. Because every

element $p_{ij} = p_{ji}$ it is commutative as well, so only one permutation of the elements b, c, d needs to be tested for associativity. We have

$(b \circ c) \circ d = a$, and $b \circ (c \circ d) = a$, so $(b \circ c) \circ d = b \circ (c \circ d)$.

Therefore this Cayley Table is a group.

- (c) This Cayley Table is the same as the Cayley Table for the group $(\mathbb{Z}_4, +)$ where $a = 0, b = 1, c = 2, d = 3$, so This Cayley Table must be a group.

\circ	a	b	c	d
a	a	b	c	d
b	b	c	d	a
c	c	d	a	b
d	d	a	b	c

- (d) The identity element of this Cayley Table is a . There is no inverse for d where $d \circ p = a$ in this Cayley Table. Therefore this Cayley Table is not a Group.

\circ	a	b	c	d
a	a	b	c	d
b	b	a	c	d
c	c	b	a	d
d	d	d	b	c

- 13) Show that $\mathbb{R}^* = \mathbb{R} \setminus \{0\}$ is a group under the operation of multiplication.

Let $a, b, c \in \mathbb{R}^*$

Closure: Multiplying two real numbers will always return result in a real number.

Associativity: The Field Axioms of real numbers state $a * (b * c) = (a * b) * c$, so it is Associative as well.

Identity: The multiplicative identity for \mathbb{R}^* is 1 because $a \cdot 1 = a \forall a \in \mathbb{R}^*$.

Inverse: The multiplicative inverse for \mathbb{R}^* is $\frac{1}{a}$ because $a \cdot \frac{1}{a} = \frac{a \cdot 1}{a} = \frac{a}{a} = 1 \forall a \in \mathbb{R}^*$.

- 27) Prove that the inverse of $g_1 g_2 \dots g_n$ is $g_n^{-1} g_{n-1}^{-1} \dots g_1^{-1}$.

Proof by induction. Base Case ($n = 1$):

$$g_1 g_1^{-1} = e$$

Inductive Hypothesis ($n = k$):

$$(g_1 g_2 \dots g_k)(g_k^{-1} g_{k-1}^{-1} \dots g_1^{-1}) = e$$

Inductive Step ($n = k + 1$) (WTS: $(g_1 g_2 \dots g_{k+1})(g_{k+1}^{-1} g_k^{-1} \dots g_1^{-1}) = e$)

$$\begin{aligned}
& (g_1 g_2 \dots g_{k+1})(g_{k+1}^{-1} g_k^{-1} \dots g_1^{-1}) \\
&= (g_1 g_2 \dots g_k)(g_{k+1})(g_{k+1}^{-1})(g_k^{-1} g_{k-1}^{-1} \dots g_1^{-1}) && \text{(Associative Property)} \\
&= (g_1 g_2 \dots g_k)(e)(g_k^{-1} g_{k-1}^{-1} \dots g_1^{-1}) && \text{(Definition)} \\
&= (g_1 g_2 \dots g_k)(g_k^{-1} g_{k-1}^{-1} \dots g_1^{-1}) && \text{(Definition)} \\
&= e && \text{(Inductive Hypothesis)}
\end{aligned}$$

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31) Show that if $a^2 = e$ for all elements in a in a group G , then G must be abelian.

Proof. Let $a, b \in G$. Consider $a \cdot b \cdot b \cdot a$. Since $a^2 = a \cdot a = e \forall a \in G$, and G is a Group, we have

$$\begin{aligned} a \cdot b \cdot b \cdot a &= a \cdot (b \cdot b) \cdot a && \text{(Commutative Property)} \\ &= a \cdot e \cdot a && \text{(Hypothesis)} \\ &= a \cdot a && \text{(Identity Property)} \\ &= e && \text{(Hypothesis)} \end{aligned}$$

But $a \cdot b$ has an inverse element of $a \cdot b$, and we have proven that $(a \cdot b) \cdot (b \cdot a) = e$, so $a \cdot b = b \cdot a \forall a, b \in G$. Therefore G is commutative which makes it an Abelian Group. ■