

Exercises from Charles Pinter's 'A Book of Abstract Algebra'

Unathi Skosana

June 16, 2021

Exercises accompanying the notes from Charles Pinter's 'A Book of Abstract Algebra'

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Operations 1

Operations

Exercise 1. For each rule, is it an operation, if not, why?

1. $a * b = \sqrt{|ab|}$, on the set \mathbb{Q}
No. If $a = b = 1$, then $1 * 1 = \sqrt{2} \notin \mathbb{Q}$
2. $a * b = a \ln b$, on the set $\{x \in \mathbb{R} : x > 0\}$.
No. It is not closed under $*$, e.g. $0 < b < 1$, then $a * b = a \ln b < 0$
3. $a * b$ is a root of the equation, $x^2 = a^2 b^2$, on the set \mathbb{R}
No. The operation isn't uniquely defined. $x^2 = a^2 b^2$ has two roots, namely $+ab$ and $-ab$
4. Subtraction, on the set \mathbb{Z} .
Yes.
5. Subtraction, on the set $\{n \in \mathbb{Z} : n \geq 0\}$.
No. e.g. $b = a + 1$ then $a * b = -1$ which is not in the set.
6. $a * b = |a - b|$, on the set $\{n \in \mathbb{Z} : n \geq 0\}$
Yes. (distance metric)

Exercise 2. Indicate whether or not :

- I it is commutative,
 - II it is associative,
 - III \mathbb{R} has an identity element with respect to $*$
 - IV every $x \in \mathbb{R}$ has an inverse with respect to $*$
1. $x * y = x + 2y + 4$

I Commutativity:

$$y * x = y + 4x + 4 \neq x + 4y + 4 \quad \forall x, y \in \mathbb{R} \quad (1)$$

Not commutative

II Associativity:

$$\begin{aligned}
 x * (y * z) &= x * (y + 2z + 4) = x + 2(y + 2z + 4) + 4 \\
 (x * y) * z &= (x + 2y + 4) * z = x + 2y + 4 + 2z + 4 \\
 x * (y * z) &\neq (x * y) * z
 \end{aligned} \tag{2}$$

Not associative

III Existence of identity:

$$\begin{aligned}
 x * e &= x + 2e + 4 = x \\
 2e &= 4 \implies e = -2
 \end{aligned} \tag{3}$$

Check

$$\begin{aligned}
 x * 2 &= x + -2 * 2 + 4 = x \\
 2 * x &= -2 + 2x + 4 = 2 * (x + 1)
 \end{aligned} \tag{4}$$

No identity element, and thus no inverses.

$$2. \ x * y = x + 2y - xy$$

I Commutativity:

$$y * x = y + 2x - yx \neq x + 2y - xy \quad \forall x, y \in \mathbb{R} \tag{5}$$

II Associativity:

$$\begin{aligned}
 x * (y * z) &= x * (y + 2z - yz) = x + 2(y + 2z - yz) - x(y + 2z - yz) \\
 &= x + 2y + 4z - 2yz - xy - 2xz + xyz \\
 (x * y) * z &= (x + 2y - yx) * z = x + 2y - yx + 2z - (x + 2y - yx)z \\
 &= x + 2y - yx + 2z - xz - 2yz + yxz \\
 x * (y * z) &\neq (x * y) * z
 \end{aligned} \tag{6}$$

III Existence of identity:

$$\begin{aligned}
 x * e &= x + 2e - xe = x \\
 2e - xe &= e(2 - x) = 0 \implies e = 0
 \end{aligned} \tag{7}$$

Check

$$\begin{aligned}
 x * 0 &= x + 0 - 0 = x \\
 0 * x &= 0 + 2x - 0 = 2x
 \end{aligned} \tag{8}$$

No identity element, thus no inverses.

$$3. \ x * y = |x + y|$$

I Commutativity:

$$y * x = |y + x| = |x + y| = x * y \quad (9)$$

II Associativity:

$$\begin{aligned} x * (y * z) &= x * |y + z| = |x + |y + z|| \\ (x * y) * z &= |x + y| * z = ||x + y| + z| \end{aligned} \quad (10)$$

$x * (y * z) \neq (x * y) * z$, to see this set $x = 1, y = -2, z = 0$

$$|1 + |-2|| \neq ||1 - 2||$$

III Existence of identity:

$$x * e = |x + e| = x \implies e = 0 \quad (11)$$

Check

$$\begin{aligned} x * 0 &= |x + 0| = x \\ 0 * x &= |0 + x| = x \end{aligned} \quad (12)$$

IV Existence of inverses:

$$x * x' = |x + x'| = 0 \implies x' = -x \quad (13)$$

Check

$$\begin{aligned} x * (-x) &= |x + (-x)| = 0 \\ (-x) * x &= |(-x) + x| = 0 \end{aligned} \quad (14)$$

4. $x * y = |x - y|$

I Commutativity:

$$y * x = |y - x| = |-(x - y)| = |x - y| \quad (15)$$

II Associativity:

$$\begin{aligned} x * (y * z) &= x * |y - z| = |x - |y - z|| \\ (x * y) * z &= |x - y| * z = ||x - y| - z| \end{aligned} \quad (16)$$

$x * (y * z) \neq (x * y) * z$, to see this set $x = 1, y = -2, z = 0$

III Existence of identity:

$$x * e = |x - e| = x \implies e = 0 \quad (17)$$

Check

$$\begin{aligned} x * e &= |x - 0| = x \\ e * x &= |0 - x| = x \end{aligned} \quad (18)$$

IV Existence of inverses:

$$x * x' = |x - x'| = 0 \implies x' = x \quad (19)$$

Check

$$\begin{aligned} x * x' &= |x - x'| = |x - x| = 0 \\ x' * x &= |x' - x| = |x - x| = 0 \end{aligned} \quad (20)$$

5. $x * y = xy + 1$

i Commutativity:

$$y * x = yx + 1 = xy + 1 = x * y \quad (21)$$

ii Associativity:

$$\begin{aligned} x * (y * z) &= x * (yz + 1) = x(yz + 1) + 1 = xyz + x + 1 \\ (x * y) * z &= (xy + 1) * z = (xy + 1)z + 1 = xyz + z + 1 \end{aligned} \quad (22)$$

$$(x * y) * z \neq x * (y * z)$$

iii Existence of identity:

$$\begin{aligned} x * e &= xe + 1 = x \\ xe &= x - 1 \\ e &= \frac{x - 1}{x} \end{aligned} \quad (23)$$

Check

$$\begin{aligned} x * e &= x \frac{x - 1}{x} + 1 = x - 1 + 1 = x \\ e * x &= \frac{x - 1}{x} x + 1 = x - 1 + 1 = x \end{aligned} \quad (24)$$

6. $x * y = \max \{x, y\}$

I Commutativity:

$$y * x = \max \{y, x\} = x * y \quad (25)$$

II Associativity:

$$\begin{aligned} x * (y * z) &= x * \max \{y, z\} = \max \{x, \max \{y, z\}\} \\ (x * y) * z &= \max \{x, y\} * z = \max \{\max \{x, y\}, z\} \end{aligned} \quad (26)$$

Regardless of the how three numbers are compose with $*$, they produce the same result; that is larger of three numbers. 0Thus $x * (y * z) = (x * y) * z$.

III Existence of identity:

$$x * e = \max \{x, e\} = x \implies e \leq x \quad \forall x \in \mathbb{R} \quad (27)$$

No such element in \mathbb{R} unless you extend it to include $-\infty$ and ∞ . By this no inverses.