### Definition 2.1

A *group* is set $G$ equipped with an operation that assigns to each pair of elements $a, b \in G$ an element $a \cdot b \in G$ in such way, that the following conditions are satisfied:

**1)** For any $a, b, c \in G$ we have

$$(a \cdot b) \cdot c = a \cdot (b \cdot c)$$

(associativity).

**2)** There exists an element $e \in G$ such that

$$e \cdot a = a \cdot e = a$$

for all $a \in G$. The element $e$ is called the *identity element* or the *trivial element*.

**3)** For each element $a \in G$ there exists an element $b \in G$ such that

$$a \cdot b = b \cdot a = e$$

Such element $b$ is called the *inverse* of $a$ and it is denoted by $a^{-1}$.

**Note.** The first condition in the definition of a group implies that if we want to multiply several elements, then it does not matter how we place parentheses. E.g.:

$$((ab)c)d = (ab)(cd) = a(b(cd)) = a((bc)d) = (a(bc))d$$

### Definition 2.2

A *abelian group* is a group $G$ where the multiplication is commutative:

$$a \cdot b = b \cdot a$$

for all $a, b \in G$.

## Notation

**Multiplicative:**

- $a \cdot b$, $a \times b$, $a * b$, $a \circ b$, $a \odot b$, ...
- **Inverse element:** $a^{-1}$.
- **The identity element:** $e$, 1, ...

**Additive:**

- $a + b$
- **Inverse element:** $-a$.
- **The identity element:** 0.

**Note:** The additive notation is only used for abelian groups.

## Some examples of groups

- $\mathbb{Z}$ - the group of integers (with addition)
- $\mathbb{Q}$ - the group of rational numbers (with addition)
- $\mathbb{R}$ - the group of real numbers (with addition)
- $\mathbb{C}$ - the group of complex numbers (with addition)

- $\mathbb{Q}^*$ - the group of non-zero rational numbers (with multiplication)
- $\mathbb{R}^*$ - the group of non-zero real numbers (with multiplication)
- $\mathbb{C}^*$ - the group of non-zero complex numbers (with multiplication)

- $\mathbb{Q}^+$ - the group of positive rational numbers (with multiplication)
- $\mathbb{R}^+$ - the group of positive real numbers (with multiplication)

- The trivial group $\{e\}$.

**Example: General linear groups $GL(n, \mathbb{R})$.**

- **Elements of $GL(n, \mathbb{R})$:** invertible $n \times n$ matrices with real entries.
- **Group operation:** matrix multiplication.
- **The identity element:** the identity matrix $I_n$.

**<u>Example:</u> Groups $\mathbb{Z}_n$**

**Notation:** Let $n > 0$ be an integer. For any integer $m$ we have

$$m = qn + r$$

where $q, r \in \mathbb{Z}$ and $0 \leq r < n$. Then we write

$$m \bmod n = r$$

For an integer $n \geq 2$ the group $\mathbb{Z}_n$ is defined as follows:

- **Elements of $\mathbb{Z}_n$:** numbers $0, 1, \ldots, n-1$
- **Group operation $\oplus$:** For $k, l \in \mathbb{Z}_n$ we set

$$k \oplus l := (k + l) \bmod n$$

- **The identity element:** 0.
- **Inverses:** The inverse of an element $k \in \mathbb{Z}_n$ is the element $n - k$.

**<u>Example:</u> Groups $U(n)$**

**Recall:**

- If $m, n$ are integers then the *greatest common divisor* of $m$ and $n$, denoted $\gcd(m, n)$, is the greatest integer that divides both $m$ and $n$.

- $\gcd(m, n) = \gcd(m + kn, n)$ for any $k \in \mathbb{Z}$.

- For any $m, n \in \mathbb{Z}$ there exists $p, q \in \mathbb{Z}$ such that

$$pm + qn = \gcd(m, n)$$

  Moreover, $\gcd(m, n)$ is the smallest positive integer that can be obtained for any choice of $p$ and $q$.

For an integer $n \geq 2$ the group $U(n)$ is defined as follows:

- **Elements of $U(n)$:** integers $1 \leq k < n$ such that $\gcd(k, n) = 1$
- **Group operation $\odot$:** For $k, l \in U(n)$ we set

$$k \odot l := (k \cdot l) \bmod n$$

- **The identity element:** 1.
- **Inverses:** If $k$ is en element of $U(n)$, then we can find $p, q \in \mathbb{Z}$ such that $pk + qn = \gcd(k, n) = 1$. Let $\overline{p} = p \mod n$. Notice that we have $\gcd(p, n) = 1$, so also $\gcd(\overline{p}, n) = 1$. Also,

$$(\overline{p} \cdot k) \mod n = (pk) \mod n = (pk + qn) \mod n = 1$$

This means that $\overline{p} = k^{-1}$ in the group $U(n)$.