Matter

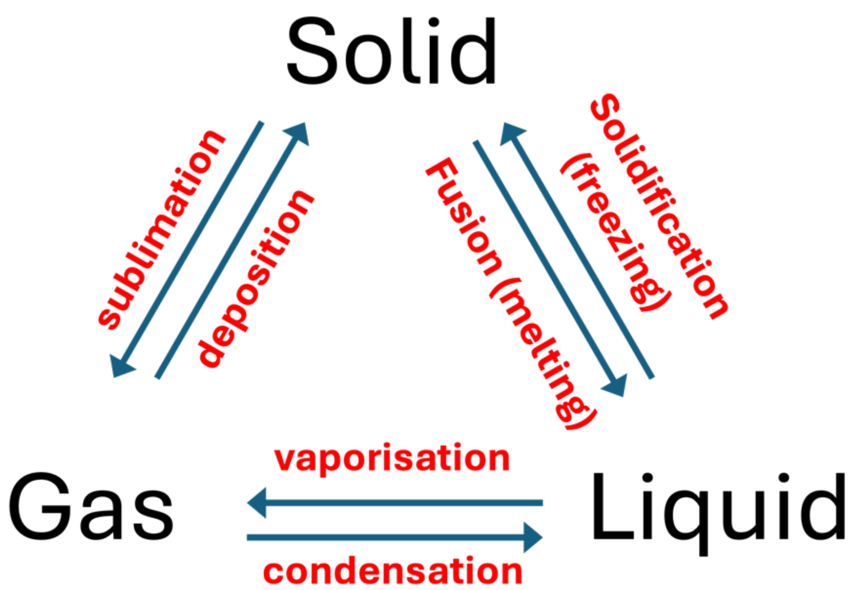
States of matter

Depending on the interactions between the entities constituting it, matter can be classified in 3 major categories:

- **Solid:**
  - Proper volume and proper shape at macroscopic level
  - Vibrating entities that are close to each other, with no displacement at microscopic level
- **Liquid:**
  - Proper volume, but takes the shape of the container at macroscopic level
  - Entities that are close to each other, but which move relative to each other at microscopic level
- **Gas:**
  - Volume and shape of the container at macroscopic level
  - Entities that are independent from each other and move freely in the container

Note: There are more than these 3 states, but the others correspond to specific and often extreme conditions:

- *A plasma, where electrons are free from atoms, is found in very high-energy environment, like stars.*
- *A Bose-Einstein Condensate, where atoms behave a single entity, is found at extremely low temperatures.*
- *A supercritical fluid, a substance that behaves as both a liquid and a gas, is found at very high temperature and pressure.*



Focus on the gaseous state

1. What is a gas?

a. Description at a microscopic level

On a microscopic scale, the gaseous state can be described as a collection of entities (molecules, atoms, and sometimes ions) in disordered motion throughout the available space.
Since entities move randomly, it is not possible to give characteristics for each of them. However, it is possible to obtain average values of characteristics from the measurement of macroscopic quantities.

b. Macroscopic quantities and microscopic characteristics

A gas can be characterized by 4 macroscopic quantities:

- The quantity of matter of the gas gives access to the number of entities that make it up.
- The temperature of the gas is a macroscopic measure of the average kinetic energy of its constituent entities.

The higher the temperature of the gas, the higher the average kinetic energy of the entities, and therefore the average value of their velocity.

- The volume of the gas is equal to the volume of the container in which it is contained.

The greater the volume occupied by the gas, the greater the average distance between entities.

- The pressure of the gas corresponds to the average frequency of collisions per unit area of the entities that constitute it with the walls of the container that contains it.

The greater the pressure, the higher the frequency of collisions with the container walls.

Note: *When these 4 quantities are constant (they do not vary over time) and uniform (they are identical at every point of the gas), the gas is said to be in thermodynamic equilibrium*

2. Ideal gases

a. Working assumptions

A gas is said to be perfect when its constituent entities are of negligible size compared to the average distance separating them. They can then be considered as point-like.
Consequently, they do not interact with each other (the only existing collisions are those with the walls of the container) and each acts as if it occupied the entire volume of the container.

Note: *The perfect gas model is valid for all gases whose pressure is less than 1 MPa.*

b. Equation of state for an ideal gas

In 1834, Frenchman Émile Clapeyron combined laws previously established by Boyle (P and V are inversely proportional, with n and T constant), Charles (T and V are proportional, with P and n constant), Gay-Lussac (P and T are proportional, with V and n constant) and Avogadro (V and n are proportional, with P and T constant) to show that the macroscopic quantities that describe a gas in thermodynamic equilibrium are all related and satisfy the equation of state for ideal gases:

$$\boldsymbol{PV = \mathrm{nRT}}$$

with:

- P, the pressure in Pa
- V, the volume in m^3
- n, the quantity in mol
- T, the temperature in K
- R, the ideal gas constant: $R = 8.314\, J.K^{-1}.mol^{-1}$

Note: *Real gases deviate from the ideal gas model at high pressure and low temperatures. The individual volume of the entities cannot be neglect anymore, neither the collisions between them.*
The ideal gas law is then changed as follows: $\left(\mathrm{P}+\frac{\mathrm{A}}{\mathrm{V}^2}\right)(\mathrm{V}-\mathrm{B})=\mathrm{nRT}$, *with A and B 2 coefficients depending on the nature of the gas*

c. Molar volume of a gas

The molar volume of a gas is the volume occupied by 1 mole of that gas. Its expression can be derived from the law of ideal gases:

$$V_m = \frac{RT}{P}$$

Note: *Its value depends only upon temperature and pressure. It is independent of the composition of the gas: At a same temperature and a same pressure, all gases have the same molar volume.*