Abdelhafid Boussouf University Center - Mila **Academic year 2024–2025**

Institute of Natural and Life Sciences

Department of Biotechnology

Module: Biophysics

Dr.DOULA Aicha

CHAPTER 1: States of matter

Introduction:

Matter is composed of a vast number of particles (atoms or molecules). Atoms and molecules are held together by electrostatic forces, which result from attractive and repulsive interactions between electric charges. To separate two molecules (to break a molecular bond between two molecules), it is necessary to provide an energy E_L, known as bond energy. E_L ranges from 0.5 to 20 k J/mol depending on the substance, but it is still significantly lower than the covalent bond energy between two atoms within the same molecule. Covalent bond energy ranges from 400 to 800 kJ/mol.

However, molecules are not static but are subjected to a state of disordered motion known as thermal agitation, the magnitude of which is measured by the average kinetic energy of a molecule. This kinetic energy, denoted as E_C, is proportional to the absolute temperature and is expressed by:

$$E_C = \frac{3}{2} K_B\, T \quad \text{(kJ/mol)}$$

$k_B = 1.38\times10^{-23}$ J/K (Boltzmann constant)

T: absolute temperature.

Based on the predominant tendency, there are three fundamental physical states of matter: solid, liquid, and gas.

If E_C is much smaller than E_L ($E_C \ll E_L$), the molecules cannot separate from each other, and their kinetic energy only results in rotations and vibrations around a fixed average position. This is the **solid state.**

If E_C is of the same order of magnitude as E_L ($E_C \approx E_L$), the molecules can move relative to each other without detaching, and they remain grouped together. This is the **liquid state.**

As the temperature increases, the molecules rotate and vibrate faster, causing E_C to increase. When E_C becomes sufficiently greater than E_L ($E_C \gg E_L$), the intermolecular bonds eventually break. The molecules then become independent of each other in a disordered state (Brownian motion). This is the **gaseous state.**

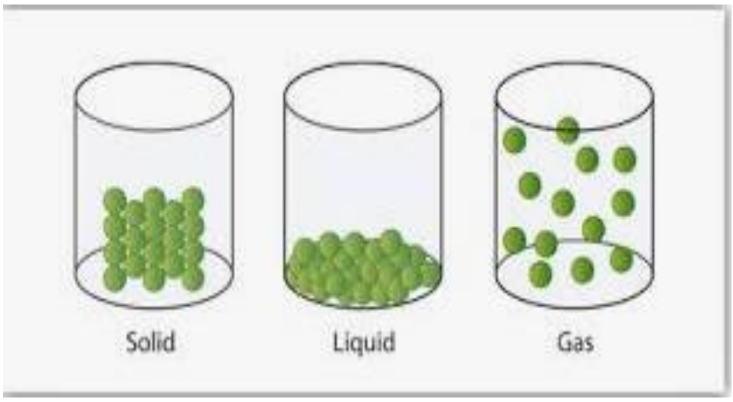

Figure 1: The Different States of Matter

1-Gas:

The gaseous state is a dispersed state. It represents perfect disorder. The distance between molecules is very large, so intermolecular bonds are often negligible. There are two types of gases: ideal and real.

1-1 Real Gases:

In real gases, the molecules are more concentrated (high pressure) and occupy a non-negligible portion of the available volume (interactions are possible). This is a non-condensed state (incoherent or completely disordered, with no fixed shape; it is a fluid).

1-2 Ideal Gases :

In ideal gases, the molecules are sparsely concentrated (low pressure) and have small volumes compared to the available volume (molecules with no interactions between them).

1-2-1 Pressure of an Ideal Gas:

The pressure of an ideal gas is due to the collisions of the gas molecules with the walls of the container that holds it. It is proportional to the temperature T and to the number of molecules per unit volume. This is known as Boyle's Law.

P V= n R T

With

R= 8.314 J/(mol·K) ideal gas constant.

V: the volume in m^3.

T; the temperature in K.

n: the number of moles.

P: the pressure in pascals.

Consider two gases, G_1 and G_2, with concentrations n_1 and n_2, respectively.

For gas G_1, we have: $\frac{P_1 V}{n_{1T}} = R$

For gas G_2, we also have: $\frac{P_{2V}}{n_{2T}} = R$

The pressures P_1 and P_2 exerted by the molecules of gases G_1 and G_2, respectively, are called partial pressures.

A mixture of ideal gases is also an ideal gas.

Consider P to be the total pressure of the mixture.

$$P = \frac{n_1 + n_2}{V} RT = \frac{n_1}{V} RT + \frac{n_2}{V} RT = P_1 + P_2$$

It can be deduced that the pressure exerted by a mixture of several ideal gases is the sum of the partial pressures of each of its components within the mixture.

$$P = \sum_{i=1}^{N} P_i$$

P is the total pressure of N ideal gases, and p_i is the partial pressure of gas G_i.

We are seeking the relationship between the partial pressure and the total pressure.

Mixtures of Ideal Gases:

Consider two gases, $G_1$and G_2, with concentrations n_1 and n_2 respectively. Let

P be the total pressure of the gas mixture and n be the total number of moles of the gas mixture. We have:

$$P_1=\frac{n_1}{V}RT$$

$$P_2=\frac{n_2}{V}RT$$

From these two equations, we can write that

$$P_1=\frac{n_1}{n_1+n_2}P$$

If we have a mixture of several ideal gases, we will have:

$$P_i=\frac{n_i}{n_{total}}P_T$$

Where

n_i: is the number of moles of gas G_i

n_{total}: is the total number of moles in the mixture $n=\sum_{i=1}^{N}n_i$

P: Total pressure of the mixture.

Pi: Partial pressure of gas where

The mole fraction of a gas is defined as:

$$Xi=\frac{n_i}{n_{total}}$$

2- Liquids

2- 1 Structure of Water

The water molecule H_2O consists of two OH bonds, each with a length of 0.96 Å, forming an angle of 104.28° between them. This asymmetric structure, with an excess of negative charge on the oxygen and positive charge on the hydrogen, gives the water molecule a high dipole moment of 1.84 Debye (1 Debye = 1 D = 3.336×10^{-30} C·m).

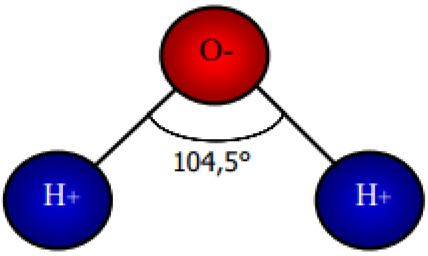

Figure 2: Dipole of the Water Molecule

The positive charges carried by the hydrogen atoms in water lead to a particular type of electrostatic bonding with the electronegative atoms of neighboring molecules. These are hydrogen bonds, which are responsible for the physical and chemical properties of water, including the association of water molecules with each other.

- In the liquid state, water has a pseudocrystalline structure where each water molecule is bonded to four neighboring molecules.
- In the solid state, ice exhibits a more organized hexagonal structure.

Temperature is defined on the Celsius scale, ranging from 0°C to 100°C:

- 0°C: Freezing point of water.
- 100°C: Boiling point of water under normal atmospheric pressure.

2- 2-Dissolution:

When a solid forms a homogeneous mixture with water, we say that:

- The solid dissolves in water.
- The solid is soluble in water.

Examples include salt and sugar, which are soluble in water.

The mixture obtained from a dissolution is called an aqueous solution.

The water that dissolves the solid acts as the solvent, while the solid that is dissolved acts as the solute.

3-Solid

A solid corresponds to a crystalline structure in which the elements (atoms, ions, or molecules) are periodically arranged in space.

Example: a body-centered cubic crystal.

Depending on the physical nature of the elements located at the nodes of the crystal, three types of crystals are distinguished:

Ionic crystals: For example, sodium chloride (NaCl) and more generally electrolytes, as the crystal is composed of Na^+ and Cl^- ions.

Atomic crystals: For example, diamond (C).

Molecular crystals: For example, benzene.

In a crystalline state, atoms, ions, or molecules remain in a well-defined position. The only factor causing disorder is the vibration or oscillation of the atoms around their equilibrium position (thermal agitation). In molecular crystals, there is also rotation of the molecules in place.

4-Intermediate States:

4-1 Liquid Crystals:

A liquid crystal is a complex fluid that combines properties of both the liquid phase and the crystalline solid phase.

4-2 Granular States:

Granular materials can exhibit behaviors that resemble either a solid, a fluid, or a gas, depending on the energy supplied to them.

4-3 Polymer:

A polymer is a macromolecule formed by the covalent bonding of a very large number of repeating units derived from one or more monomers (also called motifs), and is prepared from molecules known as monomers.