



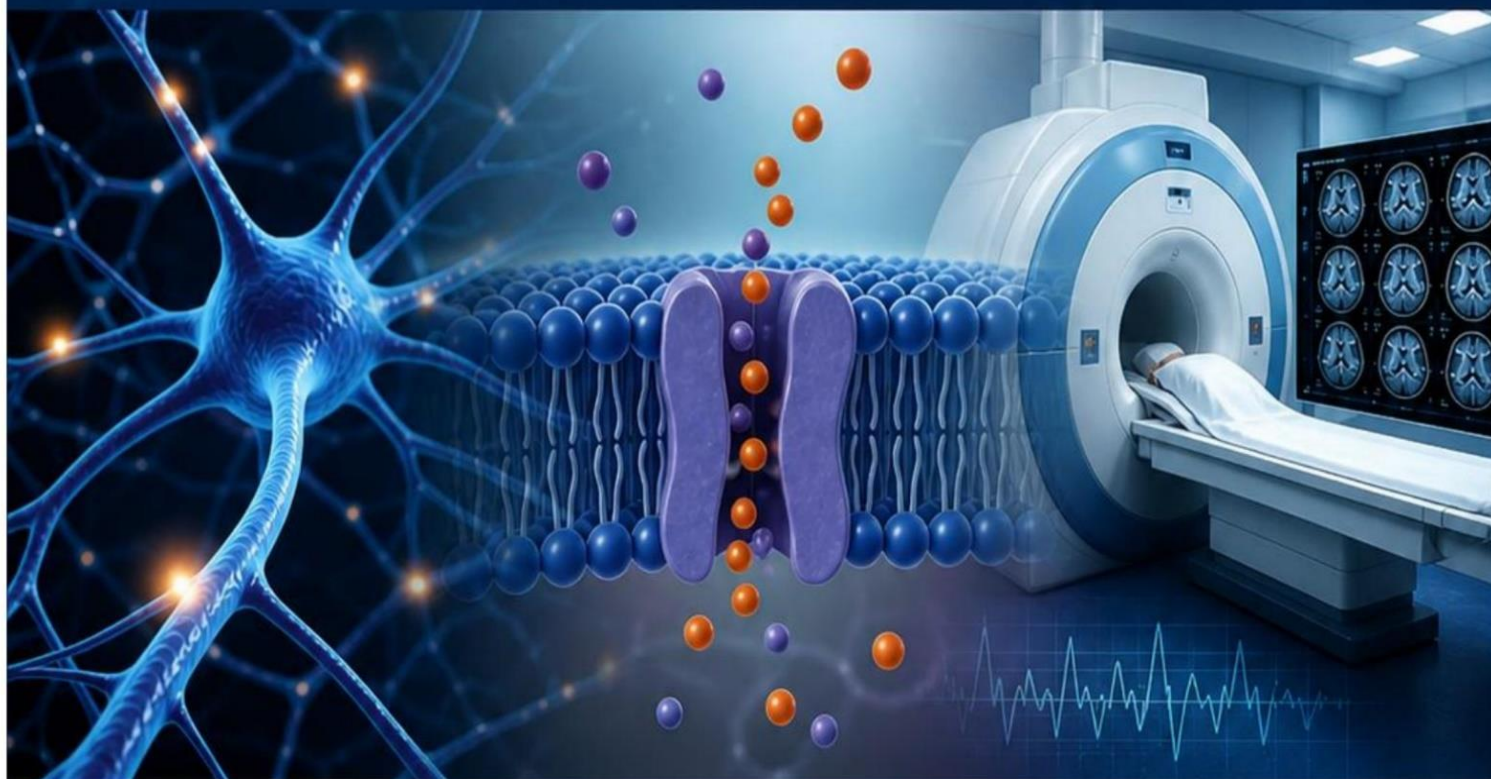
University of Sciences and Technologies Mohamed Boudiaf Oran

Faculty of Physics

Department of Materials and Technologies

LECTURE NOTES IN BIOPHYSICS

Understanding life through the laws of physics



INTENDED FOR:
Undergraduate
Students

Specialty:
· Biotechnology
· Food Sciences
· Biological Sciences



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Preface

Biophysics is the science that studies the living world using the concepts and methods of physics. By applying these physical tools, it becomes possible to model and interpret a wide variety of biological phenomena. In general, several fields of biology have benefited from advances in biophysics. Ecology, the evolution of species, development, medicine, cell biology, and even molecular biology are examples of areas in which a biophysical understanding has been successfully applied.

The primary objective in preparing these lecture notes was to provide a comprehensive pedagogical resource that strictly adheres to the framework established by the Ministry of Education for the teaching of biophysics. Each chapter has been carefully developed to cover the essential concepts in a clear and concise manner, while taking into account the specific educational requirements and objectives.

These lecture notes constitute a summary of the Biophysics curriculum and are primarily intended for second-year students in the common core of the LMD Bachelor's program. We have endeavored to adhere to the content specified in the pedagogical framework, which is organized into four major chapters:

Since 2018, I have been teaching the Biophysics module in the Department of Biology, delivering courses to students specializing in Biotechnology and Food Science. Throughout these years, I have aimed to present biophysics as a bridge between fundamental physical principles and their applications in the life sciences, emphasizing its importance in understanding biological systems and technological processes.

This teaching experience has allowed me to adapt the content to the specific needs of these disciplines, highlighting practical applications in areas such as molecular interactions, transport phenomena, and the physical properties of biological systems. It has also provided an opportunity to continuously refine pedagogical approaches in order to make complex concepts more accessible and relevant to students.

The present work reflects both my teaching experience and my commitment to supporting students in developing a solid understanding of biophysics, which is essential for their academic and professional development in the fields of Biotechnology and Food Science.

Chapter 1: This chapter focuses on the study of the electrical properties of aqueous solutions and solubility, including the different types of electrolyte solution compositions.

Chapter 2 primarily focuses on the study of diffusion phenomena in aqueous solutions, including their applications in biological systems.

Chapter 3 presents the phenomena and effects of surface tension on various surfaces.

We conclude this work with Chapter 4, which covers the fundamental concepts of fluid dynamics and properties, with a particular focus on blood sedimentation velocity and blood transport within the cardiovascular system.

In conclusion, we sincerely hope that this book will serve as a valuable resource for students, educators, and researchers interested in biophysics, and that it will contribute to promoting a deep understanding and appreciation of its wonders

Introduction

Biophysics is a discipline that lies at the intersection of physics and biology. It aims to understand biological phenomena by relying on the fundamental laws and concepts of physics. Unlike a purely descriptive approach to life sciences, biophysics seeks to explain biological mechanisms in a quantitative and rigorous way. It therefore allows us to better understand not only *what happens* in an organism, but also *how* and *why* these phenomena occur.

Although biological systems are extremely complex, they still obey the same physical laws as non-living systems. Matter and energy exchanges, molecular interactions, and movements within cells and organisms can all be described using principles from mechanics, thermodynamics, electromagnetism, and statistical physics. For example, the diffusion of molecules across a cell membrane can be explained through concentration gradients, while nerve impulse propagation is based on electrical phenomena involving potential differences and ionic currents.

One of the major contributions of biophysics is its ability to model biological phenomena. Mathematical models simplify complex systems in order to identify their essential parameters. This approach makes it possible to predict the behavior of living systems under different con-

ditions, which is particularly valuable in scientific research and bioengineering. However, it should be noted that these models often rely on simplifying assumptions, which require careful interpretation of the results.

In the field of biological fluids, for instance, blood circulation can be described using fluid mechanics laws. Blood viscosity, arterial pressure, and vessel resistance are key physical parameters that influence the distribution of oxygen and nutrients throughout the body. Similarly, membrane transport processes such as diffusion, osmosis, and active transport play a crucial role in maintaining cellular homeostasis.

Electrical phenomena are also ubiquitous in biological systems. Excitable cells such as neurons and muscle cells use electrical signals to communicate and ensure proper body function. Membrane potential, ionic currents, and the electrical properties of tissues are fundamental concepts in biophysics. These ideas have direct medical applications, particularly in functional diagnostic techniques such as electrocardiography and electroencephalography.

Biophysics also plays a key role in modern technological development. Advances in medical imaging, such as magnetic resonance imaging (MRI) and ultrasound, are based on advanced physical principles applied to biological systems. Likewise, the design of biomaterials, biosensors, and medical devices requires a deep understanding of interactions between living matter and physical forces.

In biotechnology and food science, biophysics provides essential tools for analyzing and optimizing industrial processes. It allows the study of food physical properties, heat and mass transfer phenomena, and preservation mechanisms. Food texture, viscosity, and stability can all be explained and controlled using biophysical principles.

Teaching biophysics is therefore an important step in the education of biology students. It fosters analytical and critical thinking by encouraging students to connect different scientific disciplines. By integrating mathematical tools and quantitative reasoning, biophysics offers a more structured and rigorous approach to understanding living systems.

This course aims to provide a gradual and coherent introduction to the main concepts of biophysics. Fundamental notions will be presented clearly, supported by concrete examples and practical applications. Particular emphasis will be placed on understanding the underlying

physical mechanisms rather than simply memorizing formulas. Exercises will accompany each section to reinforce learning and help students apply their knowledge.

In conclusion, biophysics is an essential tool for understanding the complexity of living systems through the lens of physical laws. It connects experimental observations with explanatory models and opens the door to numerous scientific and technological applications. Its study provides an integrated and in-depth understanding of biological phenomena, which is essential for training future scientists.

CHAPTER 1



Chapter 1: Electrical Properties of Aqueous Solutions

1 Definition

An aqueous solution is a homogeneous mixture of chemical species, obtained by dissolving a solute (one or more substances in small quantities) in a solvent (water in excess). The solute can exist in three forms: solid, liquid, or gas. In this context, it should be noted that many substances are soluble in water; however, they do not all exhibit the same behavior.

Note: The properties of aqueous solutions depend on the characteristics of the substances (solute), their state—whether molecular or ionic—and, of course, their relative proportions.

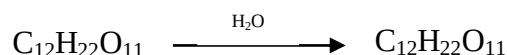
2 Classification Aqueous solutions

2.1 Molecular (or Non-Electrolyte) Solutions:

A solution is considered molecular when the solute is dissolved in the form of intact molecules. In this case, there is no significant interaction between the solvent molecules and those of the solute. In other words, a molecular aqueous solution does not produce free ions in water and preserves the molecular structure of the original solute. Such solutions may include a variety of organic and inorganic compounds dissolved in water.

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Example: A sugar solution (containing sucrose molecules).

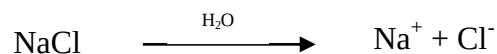


2.2 Ionic (or Electrolyte) Solutions:

An ionic aqueous solution is one in which the dissolved solutes exist primarily in the form of ions. Ionic solutes have the ability to dissociate into positive (cations) and negative (anions) ions when dissolved in water due to interactions with water molecules. This ionic dissociation

results in the presence of free ions in the solution. Ionic electrolytes, such as inorganic salts, acids, and bases, are common examples of ionic solutes. Unlike molecular aqueous solutions, ionic solutions can conduct electricity because of the mobility of the ions.

Example: Salt water, an ionic solution, contains sodium chloride (NaCl).



Depending on the degree of solute dissociation (ionization), this type of solution can be divided into two categories:

2.2.1 Strong Electrolytes

The solute dissolves in water in a manner that produces a high concentration of free ions. These free ions result from the complete dissociation of the substance in solution, forming positive cations and negative anions. Due to their ability to dissociate fully, strong electrolytes are excellent conductors of electricity in aqueous solution. When an electric potential is applied to a solution containing a strong electrolyte, the positive and negative ions migrate toward the electrodes, allowing the electric current to pass through the solution.

Example

Examples of strong electrolytes include sodium chloride (NaCl), hydrochloric acid (HCl), and sodium hydroxide (NaOH). These substances dissociate completely into ions when dissolved in water, making them highly effective at conducting electricity.

2.2.2 Weak Electrolytes

A weak electrolyte solution is one in which the solute, when dissolved in water, dissociates only partially into ions. Unlike strong electrolytes, which dissociate completely, weak electrolytes undergo partial dissociation, leaving a portion of the substance in molecular form within the solution. Weak electrolytes generally include compounds such as certain acids, bases, or inorganic salts that dissociate only partially into ions. These substances do not produce as high a concentration of free ions as strong electrolytes, and consequently, solutions of weak electrolytes conduct electricity less efficiently.

Example

A common example of a weak electrolyte is acetic acid (CH_3COOH), which is the acid present in vinegar. When acetic acid dissolves in water, only a fraction of its molecules dissociates into acetate ions (CH_3COO^-) and hydrogen ions (H^+), while the remainder remains in molecular form.

3 Dissolution of Ionic Crystals in Water**3.1 Origin of Cohesion in an Ionic Solid – Coulomb's Law**

The attractive force responsible for the cohesion between cations and anions within a crystal is described by Coulomb's law. Consequently, this law can be used to explain the cohesion of ionic crystals. The expression of Coulomb's law for two point charges, A and B, with charges q_A and q_B , is given by the following equation:

$$F = \frac{1}{4 * \pi \epsilon_0} * \frac{q_A * q_B}{r^2}$$

Where : $q_A * q_B$ are the Charges of the anion and cation, respectively

r : distance between the two ions

ϵ_0 : permittivity of free space

According to Coulomb's law, charges of the same sign repel each other. That is, either $q_A < 0$ and $q_B < 0$ or $q_A > 0$ and $q_B > 0$. On the other hand, a negative charge $q_A < 0$ and a positive charge $q_B > 0$ attract each other, as shown in Figure 1. The force exerted by B on A can be represented as follows:

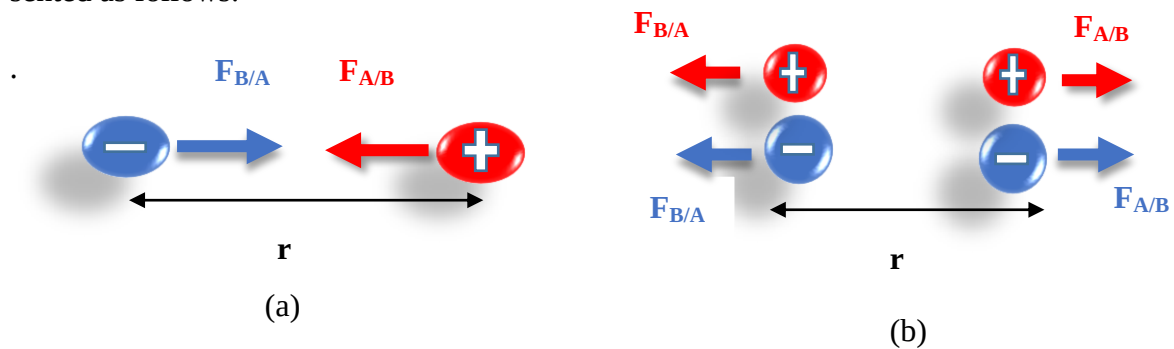


Figure 1: Cohesive forces in an ionic crystal, (a) Attractive forces, (b) Repulsive forces

In fact, a crystal is a solid-state material in which the constituent entities are arranged in an orderly manner. In the case of ionic crystals, which are composed of ions, we can consider the example of copper(II) chloride (CuCl_2).

Copper(II) chloride (CuCl_2) consists of two types of ions: a positively charged copper ion (Cu^{2+}) and two negatively charged chloride ions (Cl^-). Similarly, the microscopic structure of sodium chloride (NaCl) is shown in the figure below:

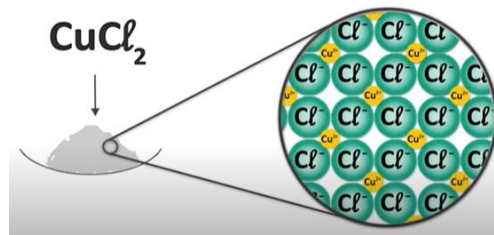


Figure 2 : microscopic structure of ionic Crystal

It can be observed that the ions are arranged alternately: a chloride ion (Cl^-), a copper ion (Cu^{2+}), and so on. According to Coulomb's law, two anions repel each other, while an anion and a cation attract each other. In the case of an ionic crystal, the attractive force is twice as strong as the repulsive force. This is the reason the solid exists: the net attraction between ions exceeds the repulsion, maintaining the crystal structure.

.

3.2 Solvation Phenomenon

When a small piece of this ionic crystal (CuCl_2) is placed in water, dissolution occurs. The proximity of polar water molecules weakens the electrostatic bonds within the crystal, which eventually break. Consequently, the crystal dissociates; this step is called dissociation. At the same time, the electrostatic interaction between the water molecules and the ions surrounds the ions of the crystal **Figure 3**, as water molecules behave like dipoles. The ions are said to be solvated, and when water is the solvent, this process is referred to as hydration.

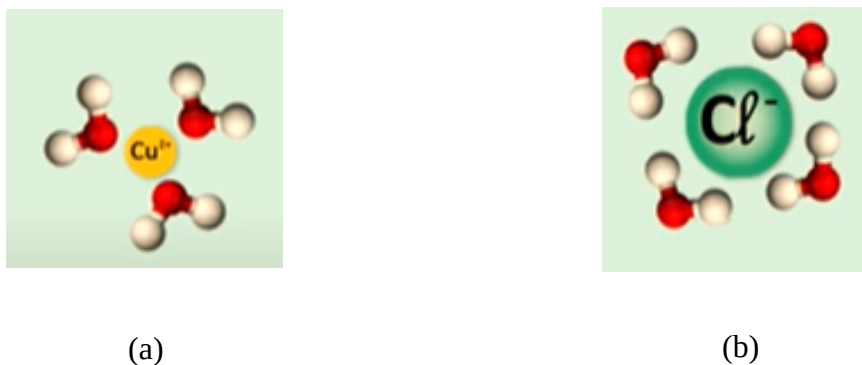


Figure 3 : Solvation Phenomenon of ionic Crystal CuCl_2 , (a) Cu^{2+} ion, (b) chloride ion Cl^-

Once hydrated, the cations (Cu^{2+}) and anions (Cl^-) cannot recombine. They become dispersed throughout the liquid; this step is called dispersion. These three steps repeat until the complete dissolution of the ionic crystal (CuCl_2) is achieved.

4 Quantitative Characteristics of Aqueous Solutions

The quantitative characteristics of aqueous solutions refer to the measurable properties of these solutions, which can be expressed in numerical terms. The following are some of the important quantitative characteristics of aqueous solutions:

4.1 Molecular Molar Concentration (Molarity) (C^M)

The molar concentration of a solute is the amount of substance of the chemical species dissolved in one liter of solution. It is given by the following formula:

$$C^M = \frac{n}{V_{\text{solution}}} \quad (\text{mol/l}^{-1})$$

4.2 Molal Concentration (Molality) (C_m)

It is defined as the number of moles of solute contained per kilogram of solvent (water):

$$C_m = \frac{n}{m_{solv}} \quad (mol/Kg^{-1})$$

4.3 Mass or Weight Concentration (C^p)

The mass (or weight) concentration of a solute is defined as the mass of solute contained in one liter of solution. It is expressed by the following formula:

:

$$C^p = \frac{m}{V} \quad (Kg/l^{-1})$$

❖ Relation between C et C_p

$$n = \frac{m}{M} \quad \Longrightarrow \quad C_p = \frac{m}{V} = \frac{n}{V} \cdot M \quad \Longrightarrow \quad C_p = C \cdot M$$

M : Molar mass of solute.

4.4 Molare Fraction

The mole fraction f of a chemical substance is defined as the ratio of the number of moles n_i of that substance to the total number of moles n_{Tot} present in the solution.

$$f_i = \frac{n_i}{n_{tot}} = \frac{n_i}{\sum_i n_i} \quad \text{avec } \sum_i n_i = 1 \quad (\text{sans unité})$$

4.5 Mass Fraction

It is given by the following expression:

$$M_i = \frac{m_i}{m_{tot}} = \frac{m_i}{\sum_i m_i} \quad \text{avec } \sum_i m_i = 1 \quad (\text{sans unité})$$

- $\sum_i m_i$: The total mass present in the solution ($= m_{H_2O} + m_{solutés}$).
- m_i : The solute masse (i).

4.6 Particle Concentration (Osmolarity) ω

Particle concentration refers to the total number of osmoles (non-dissociable molecules and ions) per liter of solution:

$$C_0 = \frac{n_{osmol}}{V} \quad (osmol.l^{-1})$$

Or :

$$C_0 = i.C$$

- **i** : The Van't Hoff ionization coefficient is given by the following relation:

$$i = 1 + \alpha(v - 1)$$

- **α** : Molecular Dissociation Rate ($0 < \alpha < 1$).
- **v** : Number of ions released by the dissociated molecule.

4.6.1 In the Case of a Molecular Solution

$$\alpha = 0 ; i = 1 \Rightarrow C_0 = C$$

4.6.2 In the Case of an ionic solution (Electrolyte solution)

Each molecule $\Rightarrow$ generates multiple particles (ions).

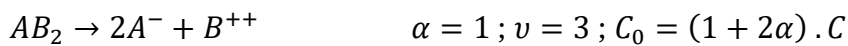
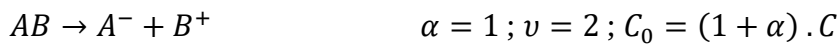
$$\text{So that: } i = 1 + \alpha(v - 1) \quad \Rightarrow \quad C_0 = i.C \quad \Rightarrow \quad C_0 = 1 + \alpha(v - 1).C$$

❖ **If the electrolyte is strong : (Complete dissociation: $\rightarrow$)**

$$\alpha = 1 ; i = v = N_{ions} = N_{anions} + N_{cations}$$



❖ **If the electrolyte is weak (partial dissociation: $\leftrightarrow$) : ($0 < \alpha < 1$)**



4.7 Equivalent Concentration : Ceq

Equivalent concentration refers to the number of gram-equivalents per liter of solution, with a gram-equivalent defined as the amount of substance that carries an electric charge equal to one Faraday.

$$1F = N_A \cdot e = 6.023 \cdot 10^{23} \cdot 1.6 \cdot 10^{-19} = \mathbf{96500} \text{ Colombs.}$$

$$C_{eq} = \frac{\text{number of gram - equivalents}}{\text{volume of solution}} = \frac{\text{Nombre of electrical charges}}{\text{volume of solution}}$$

Example

23g de Na^+ (1 mol de Na^+) carry 1F thus corresponding to 1Eq.

40g de Ca^{++} (1 mol de Ca^{++}) // 2F // 2Eq.

58,5g de $NaCl$ (1 mol de $NaCl$) // 2F // 2Eq.

In other words, for an ionic solution, the equivalent concentration $C_{eq(i)}$ of an ionic species i is equal to the product of the ionic molar concentration C_i and the absolute value of the ion's valence Z_i as follows :

$$C_{eq(i)} = C_i |Z_i| \text{ (Eq. } l^{-1} \text{)}$$

Thus, for a solution containing several different ionic species, the equivalent concentration is equal to the sum of the equivalent concentrations of the anionic and cationic forms :

$$C_{eq(i)} = \sum_i C_i^- |Z_i^-| + \sum_j C_j^+ |Z_j^+|$$

Note: According to the principle of electroneutrality, we have::

$$\sum_i C_i^- |Z_i^-| = \sum_j C_j^+ |Z_j^+|$$

Example

Consider a solution of Na_2SO_4 (142 g/mol) obtained by dissolving a mass $m=14.2m = 14.2m=14.2$ g of Na_2SO_4 crystals in 500 mL of water. Calculate the equivalent concentration of the solution.

We have : $Na_2SO_4 \rightarrow 2Na^+ + SO_4^{-2}$

The molar concentration of the solute Na_2SO_4 is given by:

$$C_{\text{Na}_2\text{SO}_4} = \frac{n_{\text{Na}_2\text{SO}_4}}{V_{\text{solution}}} = \frac{m_{\text{Na}_2\text{SO}_4} / M_{\text{Na}_2\text{SO}_4}}{V} = \frac{14.2 / 142}{0.5} = 0.2 \text{ mol.l}^{-1}.$$

5 Electrical Characteristics of Aqueous Solutions.

The electrical characteristics of aqueous solutions refer to the properties related to the electrical conductivity of the solutions when subjected to an electric potential. These characteristics are influenced by the presence of ions in the solution.

To determine the conductivity of an aqueous solution, it is subjected to a test based on the same principle applied to solid materials. The solution is placed in a cell equipped with two metal rods **Figure 4**, called electrodes. When the solution is conductive, an electric current flows, which is indicated by the illumination of a lamp. It is important to note that the lamp lights up only when the current passing through it reaches or exceeds its nominal value. Therefore, the lamp does not constitute a perfect indicator of current flow.

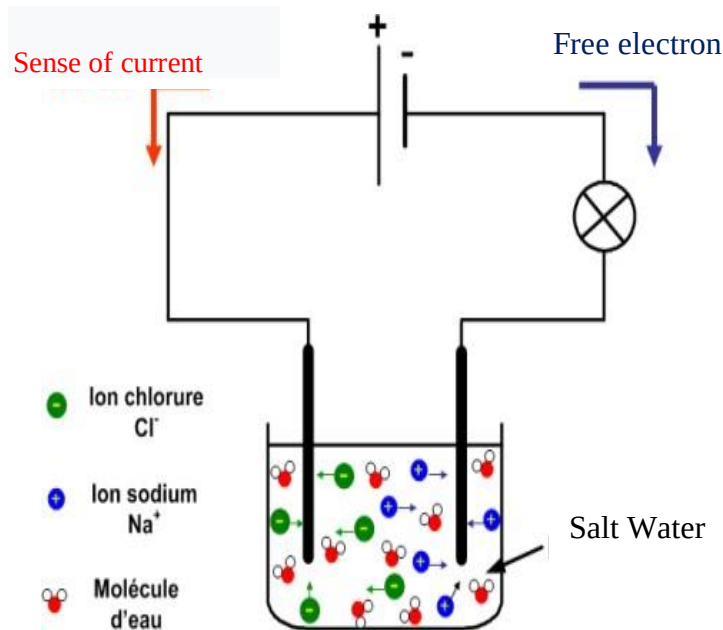


Figure 4 : Electrolyzer.

5.1 Current Flow

Liquids such as oil, pure water, and solutions of glucose or urea allow little or no electric current to pass. In contrast, aqueous ionic solutions conduct electric current.

The electrical resistance R of an electrolytic solution with resistivity ρ , placed in a cell of length l and cross-sectional area S , is given by: **Figure 5**.

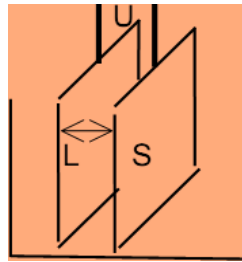


Figure 5 : The two graphite electrodes (anode (-) and cathode (+))

$$R = \rho * \frac{1}{S}$$

R is measured in ohms, and ρ in ohm *m, l in m et S en m²

The electrical conductivity χ is expressed in ohm⁻¹*m⁻¹, it is the inverse of resistivity, hence the expression for conductivity:

$$\chi = \frac{1}{\rho}$$

Note: Instead of ohm⁻¹·m⁻¹, the unit Siemens·m⁻¹ is also used.

5.2 Ionic mobility U

By definition, the ionic mobility U of an ion is the velocity v of that ion in a unit electric field ($E=1V*m^{-1}$)

An ion with charge q placed in an electric field E is subjected to a force: $\vec{F} = q \vec{E}$.

Under the influence of this force, the ion moves through the solvent, but it is hindered by the viscosity of the medium, which is manifested as a force $\vec{f}$ defined according to Stokes' law:

$$\vec{f} = -6\pi \eta r \vec{v}$$

When the two forces $\vec{F}$ et $\vec{f}$ are equal, the ion moves at a constant velocity, hence:

$$\vec{v} = \frac{q \vec{E}}{6\pi \eta r} \text{ and by definition } U = \frac{q}{6\pi \eta r}$$

With: $\vec{v} = U \vec{E}$

Note:

in the SI system, U is expressed in $m^2 \cdot V^{-1} \cdot s^{-1}$, but it can also be expressed in $m \cdot s^{-1}$, specifying that it is in a unit electric field ($E=1V \cdot m^{-1}$)

Some values of U to illustrate the concept:

$$U_{H+} = 36 \cdot 10^{-8} m^2 \cdot V^{-1} s^{-1}$$

$$U_{OH-} = 20 \cdot 10^{-8} m^2 \cdot V^{-1} s^{-1}$$

$$U_{K+} = 7.62 \cdot 10^{-8} m^2 \cdot V^{-1} s^{-1}$$

$$U_{K+} = 7.91 \cdot 10^{-8} m^2 \cdot V^{-1} s^{-1}$$

η : The viscosity coefficient of the medium is inversely proportional to temperature.

η has the dimensional equation $[M] [L]^{-1} [T]^{-1}$; it is expressed in pascal-seconds ($kg \cdot m^{-1} s^{-1}$) in the SI system and in poise ($g \cdot cm^{-1} s^{-1}$), in the c.g.s system.

r : represent the radius of the solvated ion.

5.3 Transport number

Based on the experimental determination of U^+ and U^- for any electrolyte, two ratios t^+ et t^- are defined

$$t_+ = \frac{I_+}{I} = \frac{U_+}{U_+ + U_-} = \text{Cation transport number}$$

$$t_- = \frac{I_-}{I} = \frac{U_-}{U_+ + U_-} = \text{Anion transport number}$$

With **I**: The total current between electrodes.

I_+ : Fraction of the current carried by positive charges.

I_- : Fraction of the current carried by negative charges

5.4 Conductivity of an Aqueous Ionic Solution

The conductivity can be calculated using Kohlrausch's relation, knowing U^+ and U^- for a binary electrolyte (two types of ions) of valence Z (number of bonds between anions and cations).

The expression is :

$$\chi = F C^M |z| \alpha (U_+ + U_-)$$

Where **C^M** is the molar concentration of the electrolyte in mole * m⁻³

U_- is the mobility of anion, and

U_+ is the mobility of cation en

F: 1 faraday=96500 coulombs= $N \cdot e^-$

(**N** The Avogadro number ; e^- =the charge of electron)

Z : is the valence of electrolyte

We define the equivalent conductivity as:

$$\Lambda = \frac{\chi}{C^M Z} \quad \Lambda \text{ is expressed in } \text{ohm}^{-1} \cdot \text{m}^2 \cdot \text{Eqg}^{-1}$$

For a weak binary electrolyte with dissociation coefficient α and dissociation equilibrium constant K , we also have:

$$\Lambda = \frac{\sqrt{K}}{\sqrt{C^M}} F (U_+ + U_-)$$

6 Area of Application: Human Physiology and Cell Biology

Electrolyte solutions play a vital role in the functioning of living organisms, particularly in the following processes:

6.1 Nerve transmission

Ions such as Na^+ , K^+ , Ca^{2+} , and Cl^- are essential for the generation and propagation of action potentials along neurons.

Without proper electrolyte balance, nerve signal transmission becomes impossible.

6.2 Water balance and osmolarity

Electrolytes regulate:

- osmotic pressure
- the distribution of water between intracellular and extracellular compartments

Examples include dehydration, diarrhea, and intravenous fluid therapy.

6.3 Membrane transport

Electrolytes are involved in key membrane processes such as diffusion, osmosis, and active transport across cell membranes.

Tutorial N°1

Exercise 1

A mass $m=17.1$ g of solid aluminum sulfate is dissolved in $V=250$ mL of water.

- What is the molar mass of aluminum sulfate?
- What are the mass concentration (titre) and the concentration of solute provided by aluminum sulfate?
- What are the effective concentrations of the ions Al^{3+} and SO_4^{2-} ?
- Verify that the solution is electrically neutral.

Data: Molar masses in $\text{g}\cdot\text{mol}^{-1}$: $\text{Al}=27$, $\text{S}=32$, $\text{O}=16$.

.

Exercise 2

A zinc sulfate solution is prepared by dissolving $m=32.3$ g of zinc sulfate in $V=250$ mL of water.

1. What is the molar mass of zinc sulfate?
2. What are the mass concentration (or titre) and the concentration of solute provided by zinc sulfate?
3. What are the effective concentrations of the ions Zn^{2+} and SO_4^{2-} ?
4. Verify that the solution is electrically neutral.

Data: Molar masses in $\text{g}\cdot\text{mol}^{-1}$: $\text{Zn}=65.4$, $\text{S}=32$, $\text{O} = 16$.

Exercise 3

0.20 g of barium chloride (II), BaCl_2 , is dissolved in a sufficient amount of water to obtain 500 mL of solution.

- What is the amount of substance of solute dissolved in the water?
- Deduce the molar concentration of solute in the resulting solution.
- Write the overall equation for the dissolution of barium chloride (II) in water.
- Deduce the molar concentrations of barium ions $\text{Ba}(\text{aq})^{2+}$ and chloride ions $\text{Cl}(\text{aq})^-$ in the solution.

Data: Molar masses in $\text{g}\cdot\text{mol}^{-1}$: $\text{Ba}=137\text{g/mol}$, $\text{Cl}=35.5\text{g/mol}$

Exercise 4

In a container containing 1 L of water, the following are added:

- 0.6 g of urea ($M = 60\text{ g/mol}$)
- 9 g of glucose ($M = 180\text{ g/mol}$)
- 5.85 g of NaCl ($M = 58.5\text{ g/mol}$)
- 3.28 g of Na_3PO_4 ($M = 146\text{ g/mol}$)

Complete the table.

1. Calculate the overall osmolarity of the solution in milliosmol/L, then in osmol/L.
2. Calculate the overall molarity of the solution in mol/L.
3. Calculate the overall ionization coefficient $i_{\text{Gi_GiG}}$.

Data: Molar masses: $\text{Na}=23\text{ g/mol}$, $\text{C}=12\text{ g/mol}$, $\text{O}=16\text{g/mol}$

	Molarity (mole/l)	Coefficient d'ionisation i	Osmolarity (osmol/l)	Concentration pondérale (g/l)	Equivalent Concentration (Eq.L ⁻¹)
Urea					
Glucose					
NaCl					
PO_4Na_3					

Exercise 5

Consider a sodium chloride (NaCl) solution with a concentration $C=5.0 \times 10^{-3} \text{ mol.L}^{-1}$.

- Write the dissolution equation.
- Calculate the molar concentrations of the ions.
- Calculate the electrical conductivity of the solution.
- Determine the resistivity of the solution.

Data: $\Lambda(\text{Na}^+) = 5.0 \cdot 10^{-3} \text{ S} \cdot \text{m}^2 \cdot \text{mol}^{-1}$,

$$\Lambda \text{Cl}^{-1} = 7.8 \cdot 10^{-3} \text{ S} \cdot \text{m}^2 \cdot \text{mol}^{-1}.$$

Exercise 6

Consider a conductometric cell consisting of two electrodes with surface area $S=1.0 \text{ cm}^2$ separated by $L=1.0 \text{ cm}$ in an ionic solution. The potential difference applied between the two electrodes of the cell is $U=2.00 \text{ V}$, and the measured electric current is $I=15.0 \text{ mA}$.

1. Determine the resistance and conductance of the solution.
2. Calculate the conductivity of the solution.
3. What would be the value of the conductance if the distance separating the fully immersed electrodes were halved in the same solution?

Exercise 7

A calcium hydroxide (Ca(OH)_2) solution is prepared by dissolving 50 mg of the solid compound in 100 mL of water.

1. Calculate the molar concentration of the solution.
2. Write the dissolution equation.
3. Calculate the conductivity of the solution

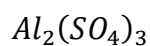
Data: $\Lambda(\text{Ca}^{2+}) = 3,9.10^{-3} \text{ S.m}^2.\text{mol}^{-1}$ $\Lambda(\text{HO}^-) = 2,0.10^{-2} \text{ S.m}^2.\text{mol}^{-1}$ $M_{Ca} = 40,0 \text{ g.mol}^{-1}$ $M_H = 1,0 \text{ g.mol}^{-1}$ $M(O) = 16,0 \text{ g.mol}^{-1}$

Exercise solutions of tutorial N°1

Exercise 1

1) Molar mass of aluminium sulfate

The chemical formula is:



Calcul :

$$M = 2 * 27 + 3 * (32 + 4 * 16)$$

$$M = 54 + 3 * 96 = 54 + 288 = 342g/mol^{-1}$$

2) Molar concentration and mass concentration

a) Number of moles:

$$n = \frac{m}{M} = \frac{17.1}{324} = 0.05 \text{ mol}$$

b) Volume in liters:

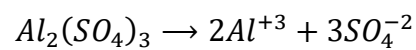
$$V=250 \text{ mL}=0.250 \text{ L}$$

c) Molar concentration :

$$C = \frac{n}{V} = \frac{0.05}{0.25} = 0.20 \text{ mol. L}^{-1}$$

d) Mass Concentration :

$$C_m = \frac{m}{V} = \frac{17.1}{0.25} = 68.4 \text{ g.L}^{-1}$$

3) Ions ConcentrationDissociation :

Therefore:

$$[Al^{+3}] = 2 \times 0.20 = 0.40 \text{ mol.L}^{-1}$$

$$[SO_4^{-2}] = 3 \times 0.20 = 0.60 \text{ mol.L}^{-1}$$

4) Verification of electrical neutrality

total positive Charge :

$$0.40 \times (+3) = +1.20$$

total negative Charge:

$$0.60 \times (-2) = -1.20$$

Exercise 2**1) Molar mass of zinc sulfate**Formula: $ZnSO_4$

$$M = 65.4 + 32 + 4 \times 16 = 161.4 \text{ g/mol}$$

2) Mass concentration and molar concentration**a) Volume**

$$V=250 \text{ mL}=0.250 \text{ L}$$

a) Number of moles:

$$n = \frac{m}{M} = \frac{32.3}{161.4} = 0.2 \text{ mol}$$

b) Molar concentration :

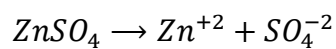
$$C = \frac{n}{V} = \frac{0.20}{0.25} = 0.80 \text{ mol. L}^{-1}$$

c) Mass concentration (titre)

$$C_m = \frac{m}{V} = \frac{32.3}{0.25} = 129.2 \text{ g. L}^{-1}$$

d) Ions Concentration

Dissociation :



Therefore:

$$[\text{Zn}^{+2}] = 1 \times 0.80 = 0.80 \text{ mol. L}^{-1}$$

$$[\text{SO}_4^{-2}] = 1 \times 0.80 = 0.80 \text{ mol. L}^{-1}$$

4) Verification of electrical neutrality

total positive Charge :

$$(+2) \times 0.80 = +1.60$$

total negative Charge:

$$(-2) \times 0.80 = -1.60$$

Exercise 3**1) Molar mass of Barium chloride (BaCl₂)**

The chemical formula is:



Calcul :

$$M = 137.33 + 2 * 35.5$$

$$M = 137.33 + 70.90 = 208.23 \text{ g/mol}$$

2) Molar and mass concentration**a) Number of moles :**

$$n = \frac{m}{M} = \frac{0.20}{208} = 9.6 * 10^{-4} \text{ mol}$$

b) Volume in litres :

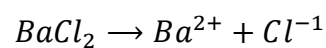
$$V = 500 \text{ mL} = 0.5 \text{ L}$$

c) Molar Concentration :

$$C = \frac{n}{V} = \frac{9.6 * 10^{-4}}{0.5} = 1.92 * 10^{-3} \text{ mol.L}^{-1}$$

3) Ions concentration

Dissociation :



Therefore :

According to the equation :

- 1 mole de BaCl_2 gives 1 mole of Ba^{2+}
- 1 mole de BaCl_2 gives 2 moles of Cl^-

Therefore :

$$[\text{Ba}^{+2}] = C = 1.92 \times 10^{-3} \text{mol. L}^{-1}$$

$$[\text{Cl}^{-1}] = 2C = 3.84 \times 10^{-3} \text{mol. L}^{-1}$$

Exercise 4

Preliminary calculations

Formula used for each solute:

$$n = \frac{m}{M}$$

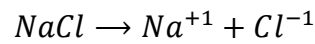
$$C = \frac{n}{V} \quad \text{with} \quad (V=1 \text{ L})$$

$$C_m = MC$$

$$\text{Osmolarity} = i * C$$

$$C_{eq} = \sum |Z_i| C_i$$

	Molarity (mole/l)	Ionisation Coefficient i	Osmolarity (osmol/l)	Mass Concon- centration (g/l)	Equivalent Concentration (Eq.L ⁻¹)
Urea	0.01	1	0.01	0.6	0
Glucose	0.05	1	0.05	9	0
NaCl	0.10	2	0.20	5.85	0.2
PO ₄ Na ₃	0.0225	4	0.09	3.712	0.135

Exercise 5**1) Dissolution equation****2) Ions Concentration**

We give :

$$C = 5 * 10^{-3} mol.L^{-1}$$

NaCl dissociates completely, so:

$$[Na^{+1}] = 5.0 \times 10^{-3} mol.L^{-1}$$

$$[Cl^{-1}] = 5.0 \times 10^{-3} mol.L^{-1}$$

3) Electrical Conductivity

$$\sigma = \lambda_{Na+}[Na^{+}] + \lambda_{Cl-}[Cl^{-1}]$$

Therefore :

$$[Na^{+1}] = [Cl^{-1}] = 5.0 \times 10^{-3} \times 1000 = 5 mol.m^{-3}$$

Calcul :

$$\sigma = (5.0 \times 10^{-3} \times 5) + (7.8 \times 10^{-3} \times 5)$$

$$\sigma = 0.025 + 0.039 = 0.064 S.m^{-1}$$

4) Resistivity

$$\rho = \frac{1}{\sigma}$$

$$\rho = \frac{1}{0.064} = 15.6 \Omega.m$$

Exercise 6**1) Resistance and conductance****a) Resistance:**

$$R = \frac{U}{I}$$

$$R = \frac{2}{0.015} = 133.3\Omega$$

b) Conductance

$$G = \frac{1}{R}$$

$$G = \frac{1}{133.3} = 7.5 * 10^{-3} \text{ s}$$

2) Conductivity of the solutionRelation:

$$\sigma = G \cdot \frac{L}{S}$$

Substitute values:

$$\sigma = 7.5 * 10^{-3} \cdot \frac{1 * 10^{-2}}{1 * 10^{-4}}$$

$$\sigma = 0.75 \text{ s.m}^{-1}$$

Effect of halving the distance

If L is divided by 2:

$$G \propto \frac{1}{L}$$

So conductance doubles:

$$G' = 2G = 2 * 7.5 * 10^{-3}$$

$$G' = 1.5 * 10^{-2} \text{ s}$$

Exercise 7**1) Molar mass of $Ca(OH)_2$**

$$M = 40 + 2 * (16 + 1)$$

$$M = 40 + 34 = 74 g.mol^{-1}$$

2) Molar concentration**a) Convert data:**

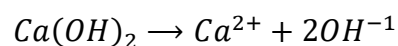
- $m = 50 \text{ mg} = 0.050 \text{ g}$
- $V = 100 \text{ mL} = 0.100 \text{ L}$

b) Number of moles:

$$n = \frac{m}{M} = \frac{0.05}{74} = 6.67 * 10^{-4} mol$$

c) Concentration

$$C = \frac{n}{V} = \frac{6.67 * 10^{-4}}{0.1} = 6.67 * 10^{-3} mol.L^{-1}$$

3) Dissolution equation**a) Ionic concentrations**

From the equation:

- $[Ca^{2+}] = C = 6.76 * 10^{-3} mol.L^{-1}$
- $[OH^{-1}] = 2C = 2 * (1.35 * 10^{-2}) mol.L^{-1} = 2.7 * 10^{-2} mol.L^{-1}$

Convert to mol/m³ (×1000):

$$[Ca^{2+}] = 6.76 \text{ mol. m}^{-3}$$

$$[OH^{-1}] = 27 \text{ mol. m}^{-3}$$

5) Conductivity

Formula:

$$\sigma = \lambda_{Ca+}[Ca^{+}] + \lambda_{OH-}[OH^{-1}]$$

$$\sigma = (3.9 \times 10^{-3} \times 6.76) + (2.0 \times 10^{-2} \times 27)$$

$$\sigma = 0.0264 + 0.54 = 0.56 \text{ S. m}^{-1}$$

CHAPTER 2



Chapter 2 : Diffusion Phenomena

1 Concept

What is diffusion ?

We will observe a small experiment that highlights the diffusion phenomenon. When a drop of dye is added to a beaker filled with water, it can be observed that, after a certain time, the dye disperses or diffuses throughout the solution, as shown in **Figure 6** below. This demonstrates that the solute molecules spread uniformly throughout the solution.

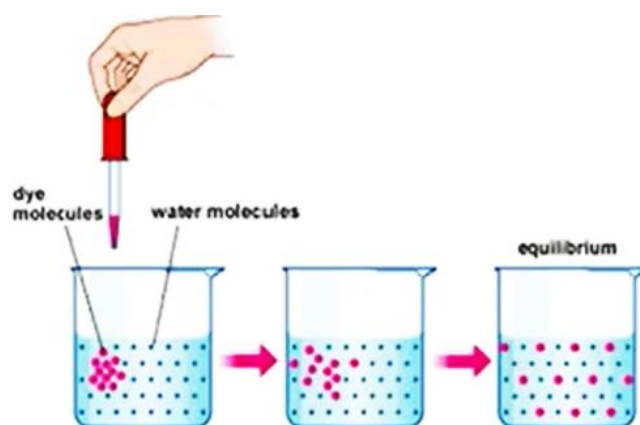


Figure 6: Dispersion of a red dye in a solution.

Thus, diffusion is a particle transport phenomenon. It should be noted that diffusion processes are faster at higher temperatures. This diffusion can also occur through a membrane, which will be of particular interest to us. It should be noted that the membrane can be permeable or semi-permeable.

Figure (6) shows two different compounds located on the two sides of the membrane with different concentrations. In this experiment, we are interested in the manner in which the transfer of the two compounds occurs across the membrane surfaces.

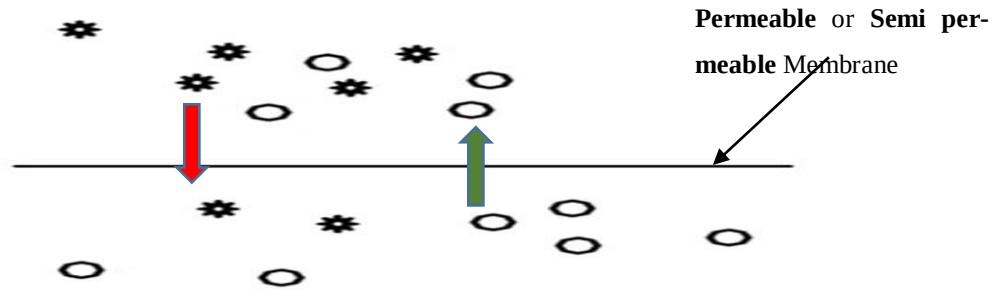


Figure 7: Particle Transfer Across a Membrane.

It should be noted that in the case of diffusion, the transfer always occurs along the concentration gradient, that is, from the region of higher concentration to the region of lower concentration. For example, for (*), the region of highest concentration is located at the top, while the region of lowest concentration is at the bottom. Conversely, for the compound indicated in (o), the concentration is higher at the bottom than at the top, and therefore, if the membrane is permeable, diffusion will occur in the opposite direction, as shown in **Figure 7**.

This small experiment leads us to conclude that the diffusion phenomenon depends on the concentration gradient; in other words, each solute moves according to its concentration gradient, and this process continues until equilibrium is reached.

Note: The effects of the diffusion mechanism on biological cells, both animal and plant, are multiple.

2 Mathematical Formulation of the Diffusion Phenomenon

The various structures of the organism are separated by biological membranes. Diffusion, also known as dialysis, occurs when there is a difference in concentration on either side of a membrane.

The movement of solute molecules always occurs from the region of higher concentration to the region of lower concentration. Fick's law provides a mathematical expression for this mass transfer.

$$\frac{\Delta m}{\Delta t} = -D * s * \frac{\Delta c^M}{\Delta x}$$

It is a partition coefficient, which equals 1 when the two liquids are miscible, which is practically always the case. We also have:

$$\Phi = flux = \frac{\Delta m}{S \Delta t} = -D * \frac{\Delta c^M}{\Delta x}$$

$$\mathbf{P} = \text{permeability} = \frac{D}{\Delta x} * (\beta) = -\frac{\Delta m}{\Delta t} * \frac{1}{S} * \frac{1}{\Delta c^M}$$

Δm : Represents the mass of solute that has moved during the time Δt from the plane at x_1 with mass concentration c_1^M to the plane at x_2 with mass concentration c_2^M

c^M : is the mass concentration, expressed in $g \cdot cm^{-3}$ ou $kg \cdot m^{-3}$

S : is the surface of diffusion in cm^2 ou m^2

D : represents the diffusion coefficient, which has the dimensional equation

$[L]^2 [T]^{-1}$; it is expressed in $cm^2 \cdot s^{-1}$ ou $m^2 \cdot s^{-1}$.

$$\text{We have also } D = \frac{kT}{6\pi\eta r}$$

Where T = Absolute temperature of the medium in K^0

$$k = \frac{R}{N} = 1.38 * 10^{-23} J/K = \text{cte of Boltzmann}$$

$$R = 0.082 \text{ atm } K^{-1} \text{ mole}^{-1}$$

$N = 6.023 * 10^{23}$ is the number of Avogadro.

$6\pi\eta r$: Represents the friction coefficient for spherical particles of radius r moving in a medium with viscosity η .

For particles of any shape, of a solute with molar mass M , we also have:

$$D = \frac{K(T)}{\sqrt[3]{M}}$$

3 Colligative properties

In a solution, solvent molecules are present in excess compared with solute molecules. The term *colligative* comes from the Latin word *colligatus*, meaning 'bound together'.

This means that solute molecules are associated with solvent molecules. Thus, the interactions between solute and solvent are electrostatic interactions of different types:

- Solvent–solvent interactions.
- Solvent–solute interactions.
- Solute–solute interactions.

Colligative properties refer to the physicochemical properties of solutions that depend on the number of particles present in the solution.

We will consider successively cryoscopy and then osmotic pressure.

3.1 Lowering of the Vapor Pressure of a Solution: (Tonometry)

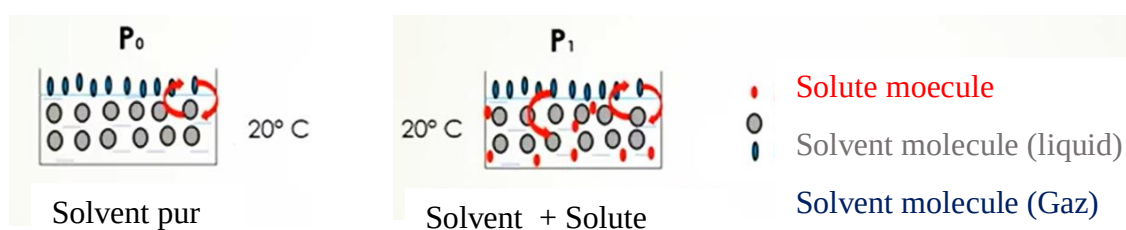


Figure 8: Vapor Pressure Phenomenon of an Aqueous Solution.

Experimental observations show that the introduction of a solute into a solvent lowers the saturated vapor pressure at the onset of heating **Figure 8**. Consequently, $P_1(\text{solution}) < P_0(\text{solvent})$. This decrease in pressure, or vapor pressure lowering, is given by the following expression:

$$\Delta P = P_0 - P_1 = P_0 * \frac{n_1}{n_1 + n_0}$$

n_1 : Number of moles of the solute in the solution.

n_0 : Numbre of moles of the solvent in the solution.

$$f_1 = \frac{n_1}{n_1 + n_0}$$

P_1 : Vapor pressure of the solution.

P_0 : Vapor pressure of the solvent.

ΔP : The vapor pressure lowering is expressed in N/m^2

a. Ebullioscopy

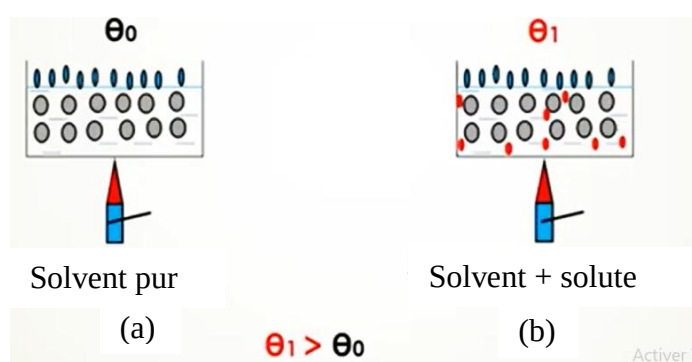


Figure 9: Ebullioscopy Phenomana, (a) solvent, (b) solvent+solute.

In this study, we are interested in comparing the boiling point of the liquid solution (solvent + solute) on the left with that of the pure solvent (on the right) **Figure 9**. It has been observed that the boiling temperature of the solution, θ_1 , is higher than that of the pure solvent, θ_0 , which means that the solution must be heated further to reach its boiling point. This is explained by the fact that the solvent molecules are less free in the presence of the solute. Raoult's law for ebullioscopy, or the elevation of the boiling point, is given by the following formula:

$$\Delta\theta = \theta_s - \theta_0 = K_e * C_m$$

Raoult's law for ebullioscopy is applicable to ideal (dilute) solutions where the solute is neutral (non-dissociated).

C_m : Molality in mole/Kg of solvent.

K_e : Ebullioscopic constant.

If the solvent is water (aqueous solution), $K_e = 0.52 \text{ } ^\circ\text{C kg/mol}^{-1}$

θ_0 : boiling point of the pure solvent.

θ_s : boiling point of the solution.

$\Delta\theta$: boiling point elevation, expressed in ($^\circ\text{C}$ or K).

3.2 Cryoscopy – Raoult's Law

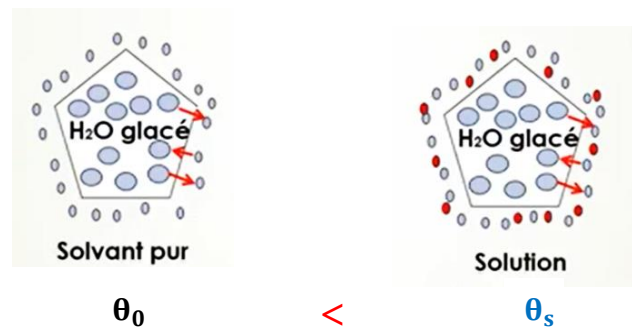


Figure 10: cryoscopy Phenomenon of the Aqueous solution.

Experimental observations show that the introduction of a solute into a solvent lowers the freezing onset temperature **Figure 10**. This cryoscopic lowering is proportional to the osmolarity of the solution according to Raoult's law

$$\Delta\theta_c = \theta_s - \theta_0 = K_c * C^0$$

$\Delta\theta_c$: Cryoscopic depression, expressed in $^\circ\text{C}$.

K_c : cryoscopic constant, which depends only on the solvent and is expressed in $\text{en}^\circ\text{C} * \text{Kg}^{-1} * \text{osmole}^{-1}$.

θ_0 : freezing temperature of the pure solvent.

θ_s : freezing temperature of the solution.

It should be noted that always $\theta_0 > \theta_s$.

We have : $C^0 = iC^m$

C^m is the molality in mole/Kg of solvent.

$I = 1 + \alpha * (v - 1)$ = Van't Hoff ionization coefficient.

Note : Raoult's law can be used to:

- Measure the osmolality of a solution.
- Determine the ionization coefficient and thus the degree of dissociation of an electrolyte.
- For dilute aqueous solutions, or:

:

$$\rho_{solution} = \rho_{eau} \simeq 1g/ml$$

$$\Delta\theta_c = K_c * \sum C^0_{osmolaire}$$

$C^0_{osmolaire}$: is in osmol/l

K_c : is the cryoscopic constant where $K_c = -1.86 \text{ } ^\circ\text{C} * \text{Kg}^{-1} * \text{osmole}^{-1}$

3.3 Osmosis (Osmotic Pressure)

Osmosis refers to the spontaneous passage of a solvent, usually water, across a semi-permeable membrane, that is, a membrane that allows solvent molecules to pass but blocks dissolved solute molecules. As illustrated in the figure, this process occurs when a solution and a pure solvent are separated by such a membrane: water naturally migrates from the compartment containing the pure solvent to the compartment containing the solution.

This movement aims to balance concentrations on both sides of the membrane and results from a simple diffusion mechanism driven by a concentration gradient. This solvent transfer causes a visible change in liquid levels: the compartment containing the solution experiences an increase in volume solely due to the influx of water molecules. This flux continues until the osmotic pressures reach equilibrium, where the force generated by the concentration difference is counterbalanced by the hydrostatic pressure that develops.

It should also be noted that while the solvent crosses the membrane, the solute cannot diffuse in the opposite direction due to the membrane's selectivity. This phenomenon creates a 'unidi-

rectional filtration' effect, where only the solvent flux is permitted. The membrane effect therefore plays a crucial role: it restricts the diffusion process to a single direction, preventing rebalancing through bidirectional exchange.

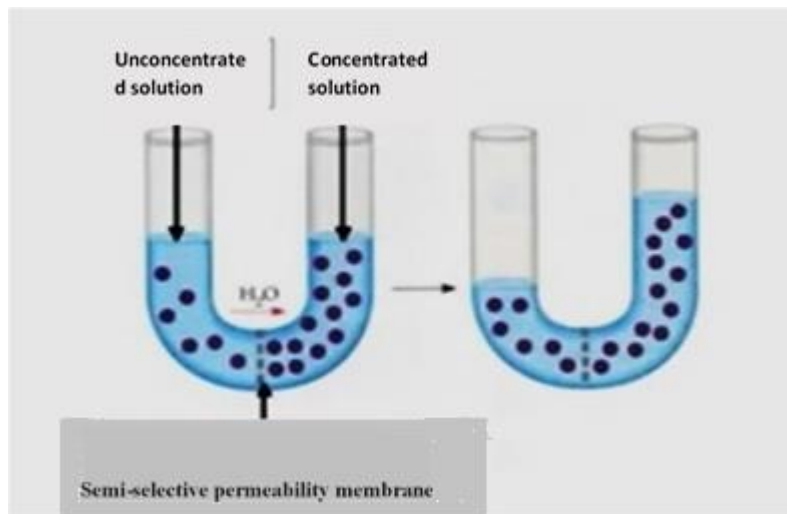


Figure 11: Osmosis phenomena

The osmotic pressure of a solution is the (hydrostatic) pressure that must be applied to the solution to prevent its pure solvent from passing through the membrane separating the two phases. Consequently, the osmotic pressure of a dilute solution, opposed to a solvent by a semi-permeable membrane, is proportional to its osmolarity and to the absolute temperature of the medium. This physical quantity is denoted by the letter Π :

$$\pi = iC^M T$$

iC^M is the osmolarity of solute in mol/l

T is the temperature of solution in $^{\circ}K$

i. Biological Applications

One of the most common applications of osmometry is the measurement of the molar masses of macromolecules, such as proteins and synthetic polymers. Hemoglobin

The molar mass of hemoglobin can thus be determined from the following osmotic pressure measurement: by dissolving 4.00 g of human hemoglobin in 100 mL of water, a solution is obtained whose osmotic pressure at 7.4 °C is 13.4 mbar.

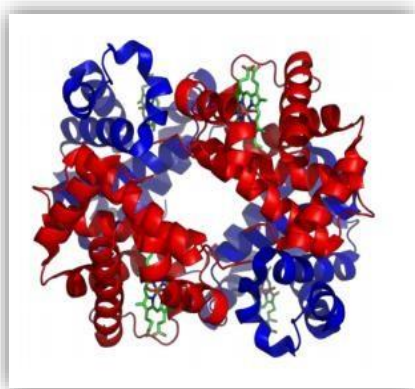


Figure 12: Hemoglobin Macromolecule.

ii. Experimental Demonstration

Dutrochet Osmometer for Measuring the Molar Mass of Polyvinyl Chloride

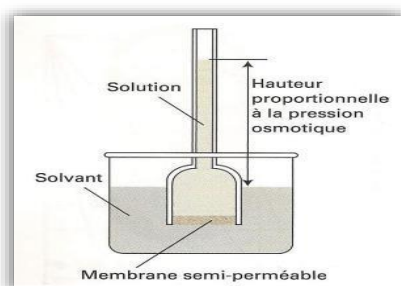


Figure 13 : Dutrochet Osmometer

Performing a series of measurements at different concentrations allows for improved accuracy in the determined molar mass. Thus, to measure the average molar mass of a PVC (polyvinyl chloride) sample, researchers prepared various solutions (non-ideal due to the size of the macromolecules) at 25 °C in cyclohexanone. The following table shows the solution heights ($\rho=0.980 \text{ kgL}^{-1}$ in the osmometer as a function of the polymer mass concentration, which

allowed the researchers to determine that the average molar mass M^- of the polymer was $120 \text{ kg}\cdot\text{mol}^{-1}$ and that its average degree of polymerization nnn was 1920.

4 Area of application of diffusion phenomena:

4.1 Cell biology: transport across membranes

Diffusion is essential for exchanges between the cell and its environment:

- oxygen (O_2) enters the cell
- carbon dioxide (CO_2) leaves the cell
- small molecules pass through the membrane

Example: cellular respiration and cell survival.

4.2 Human physiology: gas exchange in the lungs

In the lungs:

- O_2 diffuses from the alveoli into the blood
- CO_2 diffuses from the blood into the alveoli

This is the fundamental mechanism of respiration.

4.3 Neurobiology: neurotransmitter diffusion

Neurotransmitters diffuse across the synaptic cleft to transmit signals between neurons.

Examples include dopamine and acetylcholine.

4.4 Pharmacology: drug action in the body

Drugs rely on diffusion to:

- pass through the intestinal wall (absorption)
- circulate in the blood
- reach target tissues

Diffusion is essential for drug effectiveness.

4.5 Biotechnology and cell culture

In culture media:

- nutrients diffuse toward cells
- metabolic waste diffuses away from cells

This ensures proper cell growth in vitro.

4.6 Plant physiology

In plants:

- CO₂ diffuses into leaves for photosynthesis
- gas exchange occurs through stomata

A key process for plant survival and growth

Tutorial N°2

Exercise 1

Let a permeable membrane separate two compartments of volumes $V_1=2.6\text{ L}$, $V_2= 2.6\text{L}$, containing respectively:

V₁: 1.5 mol of urea and 1.2 mol of mannitol.

V₂: 1.8 mol de glucose and 1.2 mol of mannitol

The membrane has a surface area **S=400 cm²** and a thickness **$\Delta x = 1.12\text{ mm}$** .

1. Determine the direction of diffusion (concentration gradient) of the molecules.
2. Calculate the mass flux of the diffusing molecules.

Data : $D_{\text{urea}} = 10^{-9}\text{ m}^2/\text{s}$ $D_{\text{glucose}} = 8 \cdot 10^{-10}\text{ m}^2/\text{s}$

$M_{\text{urea}} = 60\text{ g/mol}$ $M_{\text{glucose}} = 180\text{ g/mol}$

Exercise 2

Let the thickness of a pulmonary wall separating the blood from the air in a human be equal to 1.25 times the normal thickness. Using Fick's law, determine the diffusion flux of air passing through this wall relative to the normal flux taken as the unit.

Exercise 3

Consider a container divided into two compartments by a circular orifice of radius 3 mm that allows a solute to pass through. The wall thickness is 0.5 cm. Compartment 1 contains an aqueous solution (solvent + solute) with a concentration of 0.2 M, while compartment 2 con-

tains pure water. Determine the mass of solute, in mg, that passes from compartment 1 to compartment 2 during 1 second.

Exercise 4

A semipermeable membrane separates two solutions at 20 °C. The first contains 4 g of glucose ($M = 180 \text{ g}\cdot\text{mol}^{-1}$) completely dissolved in 10 L of water, and the second contains 9.5 g of MgCl_2 ($M = 95 \text{ g}\cdot\text{mol}^{-1}$) in the same volume of water, dissociated at 50%.

- What physical phenomenon is observed? Explain.
- What is the resulting osmotic pressure exerted on the membrane?

Exercise 5

Let the freezing point of a solvent be **268.4 °C** and its cryoscopic constant **$K_c = 60 \text{ C}^\circ\cdot\text{kg}/\text{osmol}$** .

- 1- Calculate the freezing point of a solution containing 2.5 g of a neutral compound with a molar mass **$M = 125 \text{ g/mol}$** , completely dissolved in 45 g of this solvent..

Exercise 6

2.6 g of urea is dissolved in **220 g** of pure solvent. The boiling point of this mixture is **0.12 °C** above that of the pure solvent.

- 1- Determine the ebullioscopic constant of this solvent.

(**$M_{\text{urée}} = 60 \text{ g/mol}$**)

Exercise solutions of tutorial N°2

Exercise 1

1) Direction of diffusion

a) Concentrations:

In compartment V₁:

- Urea:

$$C_{Urea,1} = \frac{1.5}{2.6} = 0.57 \text{ mol. L}^{-1}$$

- Mannitol:

$$C_{Mannitol,1} = \frac{1.2}{2.6} = 0.462 \text{ mol. L}^{-1}$$

In compartment V₂:

- Glucose:

$$C_{Glucose,2} = \frac{1.8}{2.6} = 0.6 \text{ mol. L}^{-1}$$

- Mannitol:

$$C_{Mannitol,2} = 0.46 \text{ mol. L}^{-1}$$

Conclusion (diffusion direction):

- **Urea**: only in V₁ → diffuses V₁ → V₂
- **Glucose**: only in V₂ → diffuses V₂ → V₁
- **Mannitol**: same concentration → **no net diffusion**

2) Mass flux (Fick's law)Formula:

$$J = -D \frac{\Delta C}{\Delta X}$$

a) Urea flux :

$$\Delta C = 0 - 0.577 = -0.577 \text{ mol. L}^{-1}$$

Convert to mol/m³

$$\begin{aligned} \Delta C &= -577 \text{ mol. m}^{-3} \\ J &= -(1.0 \times 10^{-9}) \times \frac{-577}{1.12 \times 10^{-3}} \\ J &= 5.15 \times 10^{-4} \text{ mol m}^{-2} \cdot \text{s} \end{aligned}$$

- Mass flux of Urea:

$$J_m = J * M$$

$$J_m = 5.15 \times 10^{-4} \times 60$$

$$J_m = 3.09 \times 10^{-2} \text{ g m}^{-2} \cdot \text{s}$$

b) Glucose flux

$$\Delta C = 0 - 0.692 = -0.692 \text{ mol. L}^{-1}$$

$$\Delta C = -692 \text{ mol. m}^{-3}$$

$$J = -(8.0 \times 10^{-10}) \times \frac{-692}{1.12 \times 10^{-3}}$$

$$J = 4.94 \times 10^{-4} \text{ mol m}^{-2} \cdot \text{s}$$

- Mass flux of glucose:

$$J_m = 4.94 \times 10^{-4} \times 180$$

$$J_m = 8.89 \times 10^{-2} \text{ g m}^{-2} \cdot \text{s}$$

Diffusion direction:

- Urea: $V_1 \rightarrow V_2$
- Glucose: $V_2 \rightarrow V_1$
- Mannitol: **no diffusion**

Exercise 2**1) Fick's law (important idea)**

$$J = D \cdot \frac{\Delta C}{\Delta X}$$

The key point here:

- The diffusion flux **J** is **inversely proportional to thickness ΔC**

$$J = \frac{1}{\Delta x}$$

2) Compare with normal conditions

Let:

- Normal thickness = Δx
- New thickness = $1.25\Delta x$

3) Ratio of fluxes

$$\frac{J_{new}}{J_{normal}} = \frac{\Delta x}{1.25\Delta x}$$

$$\frac{J_{new}}{J_{normal}} = 0.8$$

4) Final answer

The new diffusion flux is:

$$J_{new} = 0.8 \cdot J_{normal}$$

Since the normal flux = 1 (unit):

$$J_{new} = 0.8$$

Conclusion

- Increasing thickness by **25%** reduces diffusion flux by **20%**
- Final result: **0.8 (or 80% of normal flux)**

Exercise 3**1) Surface area of the orifice**

$$S = \pi \cdot r^2$$

$$S = \pi(3 \times 10^{-3})^2$$

$$S = 2.83 \times 10^{-5} \text{ m}^2$$

2) Fick's law (molar flux)

$$J = D \frac{\Delta C}{\Delta X}$$

Since the diffusion coefficient **D is not given**, we keep it symbolic:

$$J = D \frac{200}{5 \cdot 10^{-2}} = 4 \cdot 10^3 D$$

3) Amount transferred per second

$$n = J \cdot S \cdot t$$

$$n = (4.0 \times 10^3 D)(2.83 \times 10^{-5})(1)$$

$$n = 0.04 D \cdot \text{mol}$$

4) Mass transferred

$$m = n \cdot M$$

$$m = 1.13 D \cdot M$$

Final general result

$$m = 1.13D * M$$

- If D in m^2/s
- M in g/mol → result in **grams** → multiply by 1000 to get **mg**

Example (if typical values are used)

If:

- D=10⁻⁹ m²/s
- M=100 g/mol

$$m = 0.04 \times 10^{-9} \times 100 = 4 \times 10^{-9} \text{ g}$$

Exercise 4

1) Identify the physical phenomenon

A **semipermeable membrane** allows only the solvent (water) to pass.

Therefore, the phenomenon is **osmosis**:

- Water moves from the **lower osmotic pressure** side to the **higher osmotic pressure** side.

So we must compare osmotic pressures.

2) Calculate concentrations

Solution 1 (glucose)

$$n = \frac{4}{180} = 2.22 * 10^{-2} \text{ mol}$$

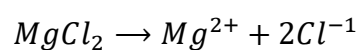
$$C_1 = \frac{n}{V} = \frac{2.22 * 10^{-2}}{10} = 2.22 * 10^{-3} mol.L^{-1}$$

Glucose does **not dissociate**, so: **Solution 2 (MgCl₂, 50% dissociation)**

$$n = \frac{9.5}{95} = 0.1 mol$$

$$C_2 = \frac{0.1}{10} = 0.01 mol.L^{-1}$$

Dissociation:



- Total ions = 3
- Degree of dissociation $\alpha=0.5$

$$i = 1 + \alpha(3 - 1) = 1 + 0.5 \times 2 = 2$$

3) Osmotic pressure formula

$$\pi = i * C * R * T$$

- $R=0.082 \text{ L. atm .mol}^{-1}.\text{K}^{-1}$
- $T=293 \text{ K}$

a) Osmotic pressure of glucose

$$\pi_1 = 1 \times 2.22 \times 10^{-3} \times 0.082 \times 293$$

$$\pi_1 = 0.053 atm$$

b) Osmotic pressure of MgCl₂

$$\pi_2 = 2 \times 0.01 \times 0.082 \times 293$$

$$\pi_2 = 0.48 atm$$

4) Direction of osmosis

$$\pi_2 > \pi_1$$

Water moves:

Glucose solution → MgCl₂ solution

5) Resulting osmotic pressure

$$\pi_{net} = \pi_2 - \pi_1$$

$$\pi_{net} = 0.48 - 0.053$$

$$\pi_{net} = 0.43 \text{ atm}$$

Exercise 5

1) Formula (freezing point depression)

$$\Delta T_f = K_c * m$$

Where:

- mmm = molality (mol/kg)
- Neutral compound ⇒ i=1

a) Number of moles of solute

$$n = \frac{2.5}{125} = 0.02 \text{ mol}$$

- Mass of solvent in kg

$$m_{solvent} = 45g = 0.045 \text{ Kg}$$

b) Molality

$$C_m = \frac{n}{m_{solvent}} = \frac{0.02}{0.045}$$

$$C_m = 0.444 \text{ mol. kg}^{-1}$$

c) Freezing point depression

$$\Delta T_f = 60 * 0.444$$

$$\Delta T_f = 26.7 \text{ } ^\circ\text{C}$$

d) New freezing point

$$T_f = T_f^0 - \Delta T_f$$

$$T_f = 268.4 - 26.7$$

$$T_f = 241.7^\circ\text{C}$$

Exercise 6**1) Formula (boiling point elevation)**

$$\Delta T_b = K_b * m$$

a) Number of moles of urea

$$n = \frac{2.6}{60} = 0.043 \text{ mol}$$

b) Mass of solvent in kg

$$m_{\text{solvent}} = 220\text{g} = 0.2\text{Kg}$$

c) Molality

$$C_m = \frac{n}{m_{\text{solvent}}} = \frac{0.043}{0.2}$$

$$C_m = 0.197 \text{ mol. kg}^{-1}$$

d) Calculate Kb

$$K_b = \frac{\Delta T_b}{m}$$

$$K_b = \frac{0.12}{0.197}$$

$$K_b = 0.61^\circ\text{C. Kg. mol}^{-1}$$

CHAPTER 3



GERRIS



feuille de lotus

Chapter 3 : Surface Tension

1 Definition

Have you ever wondered why a liquid like blood forms a drop at the tip of a syringe needle, or why we often see raindrops spreading on the surface of tree leaves, or even dew droplets on flower petals? To answer this question, one must understand the origin of these different types of surface phenomena. Consider a beaker filled with water, and let us examine the cohesive forces that exist between the different water molecules, which are schematically represented by red circles.

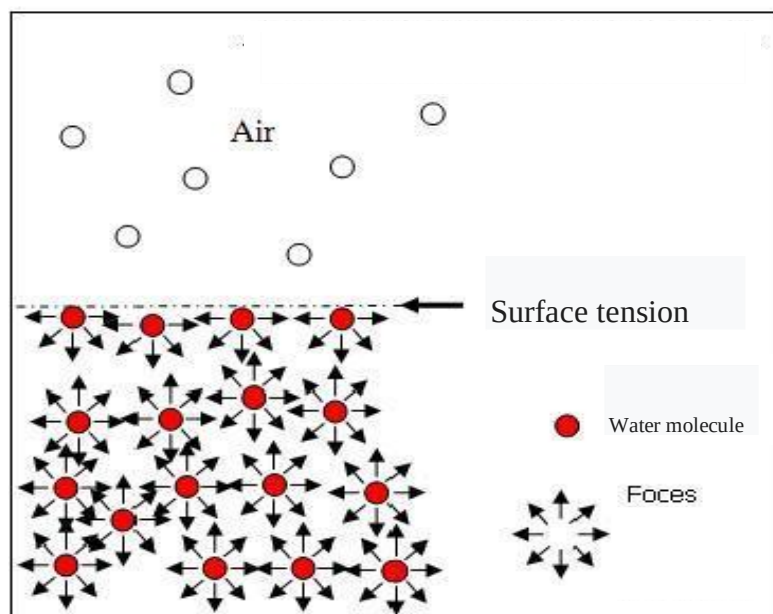


Figure 14 : Intermolecular forces of water

If we focus on a water molecule at the center of the container, we notice that the interactions are identical in all directions and the cohesive forces are balanced with all neighboring molecules. However, if we consider water molecules at the surface of the liquid, they have air above and water below. Therefore, they are no longer in an equilibrium situation as inside the liquid. This means that at the surface, cohesive forces exist only toward the bottom of the con-

tainer, tending to pull the surface molecules inward. Consequently, the molecules at the surface are slightly closer together, with slightly shorter bonds. The resulting compression effect causes the liquid to minimize its surface. This is why liquid droplets tend to adopt a spherical shape, which has the minimal surface area for a given volume.

Due to this effect, a membrane is stretched because of the attractive forces between molecules in the plane of the free liquid surface. The intensity of this force per unit length along a line on this surface is called the ‘surface tension’ and is denoted by σ . The expression for surface tension is given by the following equation:

:

$$\sigma = \frac{F}{l}$$

σ : The surface tension coefficient (which depends on the nature of the liquid) is expressed in N/m.

l : The contact length is expressed in (m).

F : The surface tension force, which is oriented in the direction that minimizes the surface, is expressed in (N).

It should be noted that this surface tension depends on the nature of the liquid. The values of the surface tension for some liquids are presented in the table below:

Liquid	$\sigma(N.m^{-1})$ at 20 ° C
Water à 20 ° C	$73 * 10^{-3}$
Water à 0 ° C	$75.6 * 10^{-3}$
Oil	$32 * 10^{-3}$
Ethanol	$22 * 10^{-3}$
Ether	$17 * 10^{-3}$
Mercure	$480 * 10^{-3}$

2 Effects of Surface Tension

a. Capillarity

Among the consequences of surface tension is what is called the phenomenon of capillarity. This phenomenon is observed when a thin tube is immersed in a liquid. Thanks to the surface tension forces acting between the liquid and the glass wall (cohesive forces), the liquid may either rise (capillary ascent) above the liquid level outside the tube, or fall below the external liquid level. Consequently, if the liquid wets the glass surface, a concave (or convex) meniscus forms with an angle θ .

The height of the rise (h) depends on the distance between the walls (R), the surface tension coefficient, the liquid density ρ , and also the contact angle θ between the liquid and the glass. To reach equilibrium, the vertical force due to surface tension equals the weight of the liquid in the tube, as shown by the following equation:

$$\rho\pi R^2 gh = 2\pi R\sigma\cos\theta$$

With ρ being the density of the liquid.

Hence, the height :

$$h = \frac{2\sigma\cos\theta}{\rho g R}$$

This law is called Jurin's law

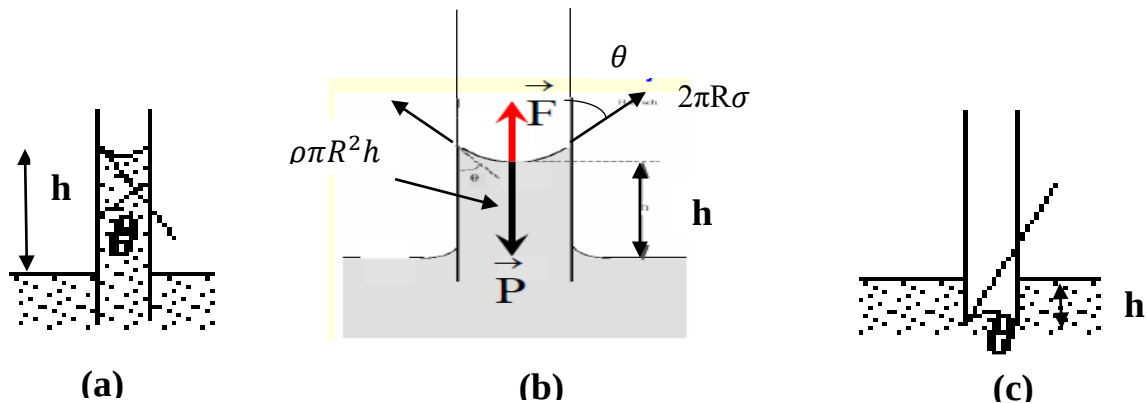


Figure 15: Capillary rise: (a) the elevation of the liquid in the capillary tube; (b) the equilibrium between the forces due to the weight of the liquid and the surface tension; (c) the fall or depression of the liquid in the capillary tube.

What can be observed from this law is that the smaller the gap, the greater the rise hhh, so the phenomenon of capillarity is more significant at small dimensions. If the angle θ is greater than 90° , the height of the rise is negative. In this case, it is a capillary depression, where the cohesive forces between the liquid molecules are stronger than the adhesive forces between the fluid molecules and the solid. This is the case for mercury in contact with glass and for all non-wetting liquids.

b. Pressure in Drops and Air Bubbles



We all made soap bubbles when we were children, but what do we know about the physics behind these objects? We will see that surface tension plays an important role.

i. Young–Laplace Equation

We are going to define Laplace's law, which explains the overpressure of air in a soap bubble in terms of surface tension. Let us make an analogy with a balloon: the fact that a balloon is inflated implies that there is an overpressure inside. This overpressure is reflected as tension in the balloon's envelope; the same applies to a droplet. Laplace's law allows us to quantify this overpressure in relation to surface tension.

Consider a spherical liquid droplet (Figure 16, curved interface due to surface tension) of radius R and surface tension σ . This droplet is characterized by an internal pressure p_i and an external pressure p_e .

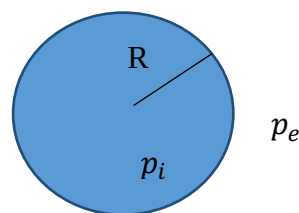


Figure 16: The spherical interface of a droplet.

$$V = \frac{4}{3}\pi R^3$$

$$S = 4\pi R^2$$

It should be noted that the internal pressure P_i of the droplet is higher than the pressure of the surrounding medium P_e .

If we increase the volume of this droplet by a small volume dV (**Figure 17**), this implies that the internal pressure increases by ΔP , and similarly the radius changes from R to $R+dR$, and S to $S+dS$, with :

$$dV = 4\pi R^2 dR$$

$$dS = 8\pi R dR$$

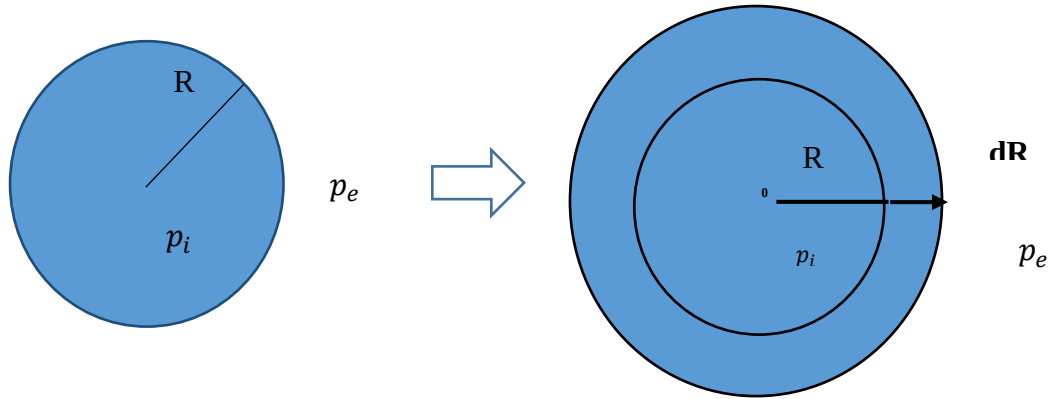


Figure 17: The increase in the volume of a liquid droplet.

Let us now focus on the work done by the forces involved during the expansion of the droplet:

$$dw = \sigma ds = \gamma 8\pi R dR$$

$$dw_p = (p_i - p_e)dv = \Delta p 4\pi R^2 dR$$

The work of the surface tension forces is proportional to the surface γ and to the increase in the droplet's surface area. Similarly, the work of the pressure forces is related to the droplet's volume, taking into account that the work of the internal force is opposed to the work of the external pressure forces.

From (1) and (2) :

$$\sigma 8\pi R dR = \Delta p 4\pi R^2 dR$$

The surface tension forces are balanced by the pressure forces. From this, we finally deduce the expression for the overpressure ΔP of the droplet as a function of the surface tension:

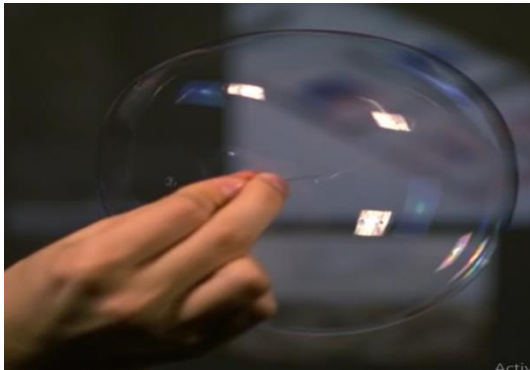
$$\Delta p = p_i - p_e = \frac{2\sigma}{R}$$

p_i : is the internal pressure of the soap bubble.

P_e : is the pressure of the surrounding medium (atmosphere).

Looking briefly at this expression, it shows that the overpressure depends only on the droplet's radius and the surface tension. Thus, if the surrounding medium is the atmosphere, this expression shows that the pressure inside the droplet decreases as its diameter increases.

ii. Laplace's Law for a Soap Bubble



Laplace's law is also valid for soap bubbles with a slight modification. To understand the application of Laplace's law in the case of soap bubbles, one must first understand their structure. The wall of a soap bubble is actually composed of two monomolecular detergent films enclosing a layer of water (Figure 18). Thus, the wall has two gas-

liquid interfaces: Air–Water and Water–Air:

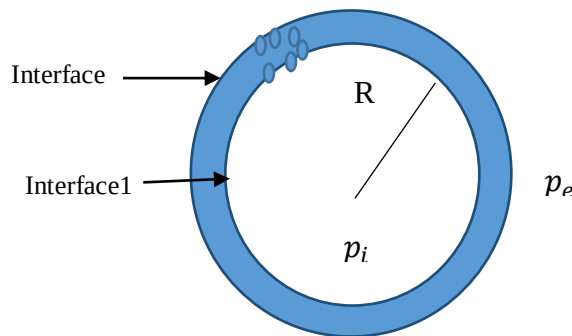


Figure 18: The inner and outer interfaces of a soap bubble.

It is therefore sufficient to take these two interfaces into account by multiplying by 2 in Laplace's expression:

$$\Delta p = p_i - p_e = 2 * \frac{2\sigma}{R}$$

3 The Contact Angle

If a drop of a liquid is placed on a solid **Figure 19**, it can take two different shapes depending on the materials in contact:

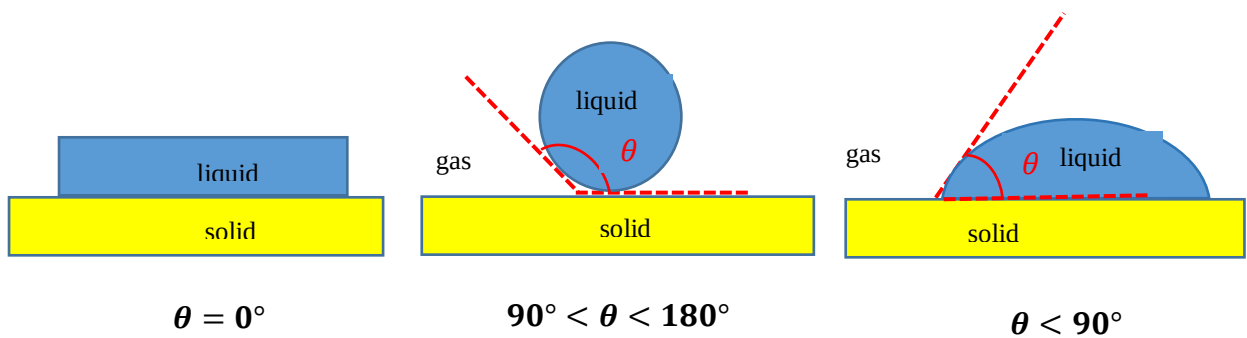


Figure 19: Contact angle of a droplet on the surface of a solid: (a) angle equals 0, (b) angles between, (c)

Contact angle : the angle formed between the solid surface and the tangent to the liquid droplet at the edge of the drop. It should be noted that this angle can vary.

The three interfaces mentioned above are responsible for the shape of the droplet. According to the figure, when the liquid perfectly wets the solid, the contact angle is zero ($\theta=0^\circ$). On the other hand, when there is poor wettability, the water droplet tends not to spread on the solid surface. In this case, the contact angle θ is greater than 90° ($90^\circ < \theta < 180^\circ$). Finally, there is imperfect or acute spreading of the water droplet on the solid surface, so the contact angle is less than 90° ($\theta < 90^\circ$).

Young–Dupre Law

To determine this contact angle θ that exists between the solid surface and the liquid, we consider **Figure 20** the three interfaces that are responsible for the shape of the water droplet:

Solid-liquid

Solid-gas.

Liquid-gas.

Each interface is associated with its surface tension coefficient:

$\sigma_{\text{sol.liq}}$

$\sigma_{\text{sol.liq}}$

$\sigma_{\text{sol.liq}}$

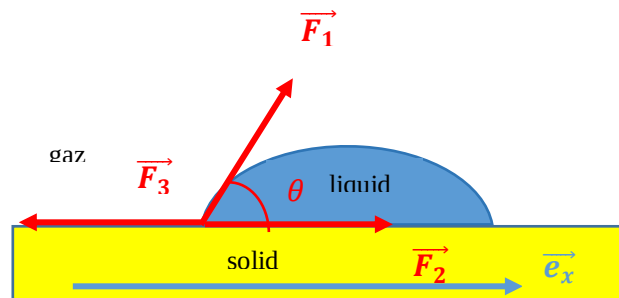


Figure 20: The three surface tension forces.

At equilibrium, we have:

$$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = \vec{0}$$

We project onto the horizontal axis:

$$F_{1x} + F_{2x} + F_{3x} = 0$$

The expression of each component along axis $\vec{e}_x$:

$$F_{1x} = F_1 \cos(\theta) = l\sigma_{\text{liq.gas}} \cos(\theta)$$

$$F_{2x} = F_2 = l\sigma_{\text{sol.liq}}$$

$$F_{3x} = -F_3 = l\sigma_{\text{sol.gas}}$$

By substituting into the equation, we find:

$$l\sigma_{\text{liq.gas}} \cos(\theta) + l\sigma_{\text{sol.liq}} + l\sigma_{\text{sol.gas}} = 0$$

If we simplify:

$$\sigma_{\text{liq.gas}} \cos(\theta) + \sigma_{\text{sol.liq}} + \sigma_{\text{sol.gas}} = 0$$

Finally, we obtain Young–Dupré’s law:

$$\cos(\theta) = \frac{\sigma_{\text{sol.gas}} - \sigma_{\text{sol.liq}}}{\sigma_{\text{liq.gas}}}$$

This equation states that the contact angle depends on the three surface tensions mentioned. It is particularly useful for characterizing the wetting of a surface by a liquid, that is, the ability of the liquid to spread or form a droplet. A small contact angle (close to 0°) indicates good wetting, where the droplet spreads widely on the surface. Conversely, a large angle (greater than 90°) suggests poor wetting, with the droplet tending to form a sphere, as observed on hydrophobic surfaces.

It should be noted that Young–Dupré’s law is also related to the spreading coefficient S , which measures the tendency of a liquid to spread on a solid surface. It is defined by the difference between the solid–vapor surface tension and the sum of the solid–liquid and liquid–vapor surface tensions.

4 Area of application

4.1 Cell biology: membrane and droplet behavior

Surface tension helps explain the behavior of biological membranes and small liquid structures:

- formation and stability of cell membranes
- shape of droplets in cytoplasm
- interaction between lipids and water

It contributes to maintaining cell structure and organization.

4.2 Respiratory system: lung alveoli stability

In the lungs, surface tension plays a crucial role in alveoli:

- it tends to collapse alveoli due to water lining
- pulmonary surfactant reduces surface tension

Without surfactant, breathing would require much more energy (important in newborn physiology).

4.3 Capillary action in plants

Surface tension is responsible for water movement in narrow tubes:

- water rises in xylem vessels
- helps transport water from roots to leaves

Combined with adhesion and cohesion, it supports plant hydration.

4.4 Biophysics and laboratory techniques

Surface tension is important in many lab processes:

- formation of droplets in pipettes and microfluidics

- behavior of liquids in capillary tubes
- mixing and dispersion of biological solutions

Essential in biotechnology and medical diagnostics.

4.5 Microbiology: interaction with liquid surfaces

Microorganisms are affected by surface tension:

- bacteria movement on liquid surfaces
- formation of biofilms at interfaces
- spreading of colonies on culture media

4.6 Insects and small organisms (biophysics examples)

Some small organisms interact directly with surface tension:

- insects walking on water (e.g., water striders)
- ability to stay on water surface without sinking

This is a classic example in biological physics.

Tutorial N°3

Exercise 1

A liquid perfectly wetting the glass, with a density $\rho = 1,05 \cdot 10^3 \text{ Kg m}^{-3}$, rises to an average height $h = 1,5 \text{ cm}$ in a vertical glass capillary tube with an internal diameter $d = 1,0 \text{ mm}$. Calculate the surface tension constant of the liquid ($g = 10 \text{ m s}^{-2}$).

Consider a tube with internal diameter immersed vertically in a liquid with surface tension (σ). We assume perfect wettability and denote by (h) the height of the liquid rise in the tube.

Exercise 2

With water, we find $h_0 = 92,3 \text{ mm}$ ($\rho_0 = 0,9973 \cdot 10^3 \text{ Kg m}^{-3}$, $A_0 = 71,93 \cdot 10^{-3} \text{ N m}^{-1}$). For benzene, we find $h = 42,4 \text{ mm}$. Deduce the surface tension constant of benzene, knowing that its density ρ is $0,8840 \text{ Kg m}^{-3}$.

Exercise 3

Two vertical capillaries, with internal diameters $d_1 = 0,10 \text{ mm}$ and $d_2 = 0,30 \text{ mm}$ are immersed in a container containing water at 20°C .

- What is the difference in liquid levels between the two tubes?
- What happens to these levels and their difference when the temperature is raised to 70°C ?

Given: $\sigma = 0,073 \text{ N/m}$ (20°C), $\sigma = 0,064 \text{ N/m}$ (70°C).

Exercise 4

A capillary tube of radius $r = 50 \mu\text{m}$ is immersed in a container filled with water. Capillary phenomena cause the water to rise inside the capillary to a height h relative to the free surface of the water.

- Draw a diagram showing the capillary rise and the meniscus. Indicate where r , h , and θ are used in Jurin's law.
- Calculate the value of h .

Given: $A = 0,075 \text{ N m}^{-1}$, $\theta = 30^\circ$; $g = 10 \text{ m s}^{-2}$.

Exercise 5

A cylindrical capillary tube, open at both ends, is immersed in a liquid of density ρ contained in a beaker.

In the case of water, for a capillary tube of radius $r=0.75$ mm the liquid rises to a height $h=19$ mm with a contact angle $\theta=0^\circ$. Calculate the surface tension σ of water. Given

$$\rho_{\text{water}} = 1000 \text{ Kg m}^{-3}; g = 9,8 \text{ m. s}^{-2}.$$

Now, place this capillary tube in a beaker containing mercury; mercury is 13.6 times denser than water. Calculate the height h knowing that $\theta = 130^\circ$ et $A = 0,480 \text{ N/m}$. Draw a diagram to describe the phenomenon..

Exercise 6

Calculate the total average exchange surface of the pulmonary alveoli in a person whose two lungs have a total volume of 8 liters and an average of 8×10^7 alveoli per liter of lung, assuming that all alveoli are spherical with an average diameter of 0.2 mm.

When we breathe, our alveoli are in direct contact with the outside air through the respiratory tract. If the physiological liquid (surfactant) covering our alveolar membranes were purely aqueous (pure water)

- What is the pressure difference across each alveolar membrane?
- What would be the work required for each inspiration if the total alveolar surface varies by 5%?

Grâce aux surfactants, l'énergie de surface n'est plus que de 35 mJ/m^2 . The surface energy is reduced to 35 mJ/m^2 .

What happens to this work? Explain the role of surfactants. On donne : $\sigma_{\text{water}} = 73 \text{ mJ/m}^2$.

Exercise 7

A liquid has a surface tension $\sigma = 25 \times 10^{-3} \text{ N/m}$. With this liquid, a soap bubble of radius 3 cm is blown.

- Calculate the overpressure inside this bubble.
- What is the work required to blow the bubble?.
- Calculate the total pressure experienced by an air bubble located at 6.5 m depth in a lake.

Given:

$$P_{\text{atm}} = 1,01.105 \text{ N/m}^2 \quad \sigma_{\text{eau}} = 74,6. 10^{-3} \text{ N/m}$$

Exercise solutions of tutorial N°3

Exercise 1

1) Capillary rise formula

For a perfectly wetting liquid ($\cos\theta = 1$):

$$h = \frac{2\gamma}{\rho g r}$$

Therefore :

$$\gamma = \frac{h\rho g r}{2}$$

2) Data Conversion

$$h = 1.5 \text{ cm} = 1.5 \times 10^{-2} \text{ m}$$

$$d = 1.0 \text{ mm} \Rightarrow r = 0.5 \text{ mm} = 5.0 \times 10^{-4} \text{ m}$$

$$\rho = 1.05 \times 10^3 \text{ kg.m}^{-3}$$

$$g = 10 \text{ m.s}^{-2}$$

3) Calcul

$$\gamma = \frac{(1.5 \cdot 10^{-2})(1.05 \cdot 10^3)(10)(5 \cdot 10^{-4})}{2}$$

$$\gamma = \frac{10500 \cdot 7.5 \cdot 10^{-6}}{2}$$

$$\gamma = \frac{0.078}{2} = 0.0379 \text{ N/m}^{-1}$$

Interpretation

- This value is close to that of water ($\approx 0.072 \text{ N}\cdot\text{m}^{-1}$)
- The liquid is therefore moderately surface-active

Exercise 2

$$h = \frac{2\gamma}{\rho g r}$$

For the **same tube**, r and g are constant, so:

$$\frac{h}{h_0} = \frac{\gamma \rho_0}{\gamma_0 \rho}$$

Thus:

$$\gamma = \gamma_0 * \frac{h}{h_0} * \frac{\rho}{\rho_0}$$

Data

- $h_0=92.3 \text{ mm}$ (water)
- $h=42.4 \text{ mm}$ (benzene)
- $\rho_0=0.9973 \times 10^3 \text{ kg}\cdot\text{m}^{-3}$
- $\rho=0.8840 \times 10^3 \text{ kg}\cdot\text{m}^{-3}$
- $\gamma_0=71.93 \times 10^{-3} \text{ N}\cdot\text{m}^{-1}$

Calculation

$$\gamma = 71.93 * 10^{-3} * \frac{42.4}{92.3} * \frac{0.884}{0.997}$$

$$\gamma = 71.93 \times 10^{-3} \times 0.459 \times 0.886$$

$$\gamma = 0.0293 \text{ N}\cdot\text{m}^{-1}$$

Exercise 3

We use the **capillary rise formula** (perfect wetting, $\cos\theta=1$):

$$h = \frac{4\sigma}{\rho g d}$$

1) Data

- $d_1=0.10 \text{ mm}=1.0\times 10^{-4} \text{ m}$
- $d_2=0.30 \text{ mm}=3.0\times 10^{-4} \text{ m}$
- $\sigma_{20}=0.073 \text{ N.m}^{-1}$
- $\sigma_{70}=0.064 \text{ N.m}^{-1}$
- $\rho\approx 1000 \text{ kg.m}^{-3}$
- $g=10 \text{ m.s}^{-2}$

2) Heights at 20°C

Tube 1:

$$h_1 = \frac{4 * 0.073}{1000 * 10 * 1 * 10^{-4}}$$

$$h_1 = \frac{0.292}{1} = 0.292m$$

Tube 2:

$$h_2 = \frac{4 * 0.064}{1000 * 10 * 3 * 10^{-4}}$$

$$h_2 = \frac{0.292}{3} = 0.097m$$

Difference:

$$\Delta h = h_1 - h_2 = 0.292 - 0.097 = 0.195 \text{ m}$$

3) Heights at 70°C

Same formula, only σ changes.

Tube 1:

$$h_1' = \frac{4 * 0.064}{1000 * 10 * 1 * 10^{-4}} = 0.256m$$

Tube 2:

$$h_1' = \frac{0.256}{3} = 0.085m$$

New difference:

$$\Delta h' = 0.256 - 0.085 = 0.171m$$

- At 20°C $\Rightarrow$ Difference: **19.5 cm**
- At 70°C $\Rightarrow$ Difference: **17.1 cm**

Interpretation

When temperature increases:

- Surface tension **decreases**
- Capillary rise **decreases**
- Difference between levels **also decreases**

Exercise 4

1) Formula (Jurin's law)

$$h = \frac{2A \cos \theta}{\rho g r}$$

2) Data conversion

- $r = 50 \mu\text{m} = 5.0 \times 10^{-5} \text{ m}$
- $A = 0.075 \text{ N.m}^{-1}$
- $\theta = 30^\circ \Rightarrow \cos \theta = 0.866$
- $\rho \approx 1000 \text{ kg.m}^{-3}$
- $g = 10 \text{ m.s}^{-2}$

Calculation

$$h = \frac{2 * 0.075 * 0.86}{1000 * 10 * 5 * 10^{-5}}$$

$$h = \frac{0.129}{0.5} = 0.259 \text{ m}$$

Smaller tube $\Rightarrow$ higher rise (inverse relation with r)

Exercise 5

1) Case of water

a) Formula (Jurin's law)

$$h = \frac{2\sigma \cos \theta}{\rho g r}$$

$$\sigma = \frac{h \rho g r}{2 \cos \theta}$$

Data (water)

- $r = 0.75 \text{ mm} = 7.5 \times 10^{-4} \text{ m}$
- $\theta = 0^\circ \Rightarrow \cos \theta = 1$
- $\rho = 1000 \text{ kg.m}^{-3}$
- $g = 9.8 \text{ m.s}^{-2}$

Calculation

$$\sigma = \frac{(1.9 * 10^{-2})(1000)(9.8)(7.5 * 10^{-4})}{2}$$

$$\sigma = \frac{9800 * 1.4 * 10^{-5}}{2} = \frac{0.13}{2}$$

$$\sigma = 0.068 \text{ N.m}^{-1}$$

Result (water)

$$\sigma = 7 * 10^{-2} \text{ N.m}^{-1}$$

- Correct value (close to real ≈ 0.073)

2) Case of mercury

Important: mercury does NOT wet glass

$$\theta = 130^\circ \quad \cos\theta < 0$$

- **Capillary depression (liquid goes down)**

Data

- $\rho_{\text{Hg}} = 13.6 \times 1000 = 13600 \text{ kg.m}^{-3}$
- $\sigma = 0.480 \text{ N.m}^{-1}$
- $r = 7.5 \times 10^{-4} \text{ m}$
- $\cos(130^\circ) \approx -0.643$

Calculation

$$h = \frac{2 * 0.48 * (-0.643)}{13600 * 9.8 * 7.5 * 10^{-4}}$$

$$h = \frac{-0.617}{100} = -6.17 * 10^{-3}m$$

$$h = -6.2mm$$

- Negative $\Rightarrow$ **liquid goes down (depression)**

Water:

- Concave meniscus
- Liquid rises
- $\theta=0^\circ$

Mercury:

- Convex meniscus
- Liquid goes down
- $\theta=130^\circ$

Exercise 6

1) Total alveolar surface

Data

- Lung volume: 8 L
- Alveoli per liter: 8×10^7
- $N=8 \times 8 \times 10^7 = 6.4 \times 10^8$ alveoli
- Diameter: $d=0.2 \text{ mm} = 2 \times 10^{-4} \text{ m}$
- $r=1 \times 10^{-4} \text{ m}$

Surface of one alveolus

$$S_1 = 4 * \pi * r^2$$

$$S_1 = 4 * \pi * (10^{-4})^2$$

$$S_1 = 4 * \pi * 10^{-8} = 1.26 * 10^{-7} m^2$$

Total surface

$$S_{tot} = N * S_1 = 6.4 \times 10^8 \times 1.26 \times 10^{-7}$$

$$S_{tot} = 80.4 m^2$$

Very realistic physiological value

2) Pressure difference (Laplace law)

$$\sigma = 73 \text{ mJ/m}^2 = 0.073 \text{ N/m}$$

$$\Delta P = \frac{2 * 0.073}{10^{-4}} = 1460 \text{ Pa}$$

3) Work of inspiration (pure water)

Work due to surface variation:

$$W = \sigma * \Delta S$$

Surface variation

$$\Delta S = 0.05 * 80 = 4 m^2$$

Work

$$W = 0.073 \times 4 = 0.292 \text{ J}$$

4) With surfactant

$$\sigma = 35 \text{ mJ/m}^2$$

New work

$$W = 0.035 * 4 = 0.14 \text{ J}$$

Interpretation

- Without surfactant → high surface tension → high pressure + high work
- With surfactant:
 - Surface tension ↓
 - Pressure ↓
 - Work of breathing ↓ (almost divided by 2)

Role of surfactants

- Prevent alveoli collapse
- Reduce breathing effort
- Stabilize alveoli size
- Essential for normal respiration

Exercise 7

1) Overpressure inside a soap bubble

For a **soap bubble** (two interfaces):

$$\Delta P = \frac{4\sigma}{r}$$

Data

- $\sigma = 25 \times 10^{-3} = 0.025 \text{ N/m}$
- $r = 3 \text{ cm} = 0.03 \text{ m}$

Calculation

$$\Delta P = \frac{4 * 0.025}{0.03} = \frac{0.1}{0.03} = 3.33 \text{ Pa}$$

2) Work required to blow the bubble

Work = surface energy:

$$W = 2\sigma S$$

(for soap bubble $\rightarrow$ 2 surfaces)

Surface of sphere:

$$S = 4\pi r^2$$

Calculation

$$W = 2\sigma \cdot 4\pi r^2 = 8\pi\sigma r^2$$

$$W = 8\pi \times 0.025 \times (0.03)^2$$

$$W = 5.65 \times 10^{-4} J$$

3) Pressure at 6.5 m depth in water

Total pressure:

$$P = P_{atm} + \rho gh$$

Data

- $P_{atm} = 1.01 \times 10^5 \text{ Pa}$
- $\rho = 1000 \text{ kg/m}^3$
- $g = 10 \text{ m/s}^2$
- $h = 6.5 \text{ m}$

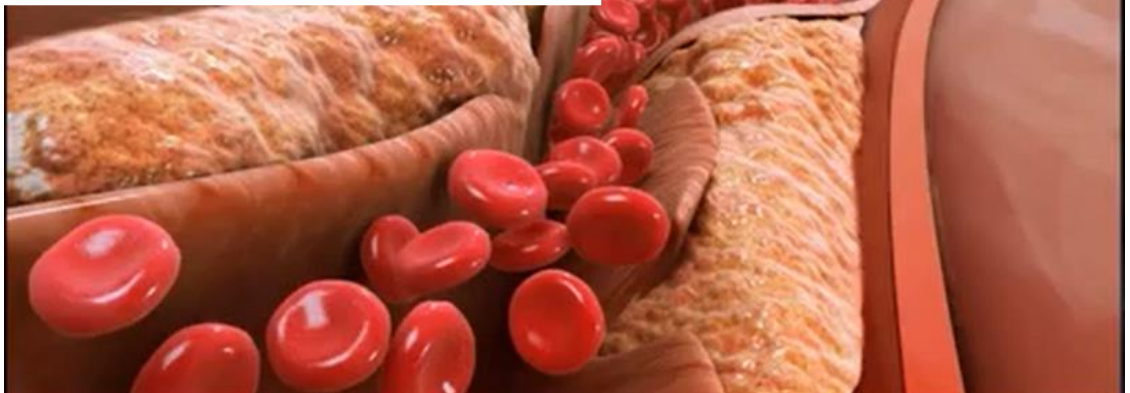
Calculation

$$\rho gh = 1000 \times 10 \times 6.5 = 65000 \text{ Pa}$$

$$P = 1.01 \times 10^5 + 65000 = 1.66 \times 10^5 \text{ Pa}$$

- Overpressure: **3.3 Pa**
- Work: **$5.6 \times 10^{-45} \text{ J}$**

CHAPTER 4



Chapter 4 : Fluid Dynamics and Properties of Fluids

1 Definition of fluid

If we want to define what a fluid is from a macroscopic point of view, we can say that it is a material medium that deforms under the action of a very small external force. Therefore, a fluid has no definite shape and adapts to the shape of its container.

From a microscopic point of view, a fluid can also be defined as a collection of molecules in a disordered, agitated state. These molecules are spaced apart and constantly interact with each other. It should be noted that the intermolecular forces between the molecules are very weak, unlike in a solid, where these forces are significant

The microscopic difference between the solid, liquid, and gaseous states is illustrated in **Figure 21** :

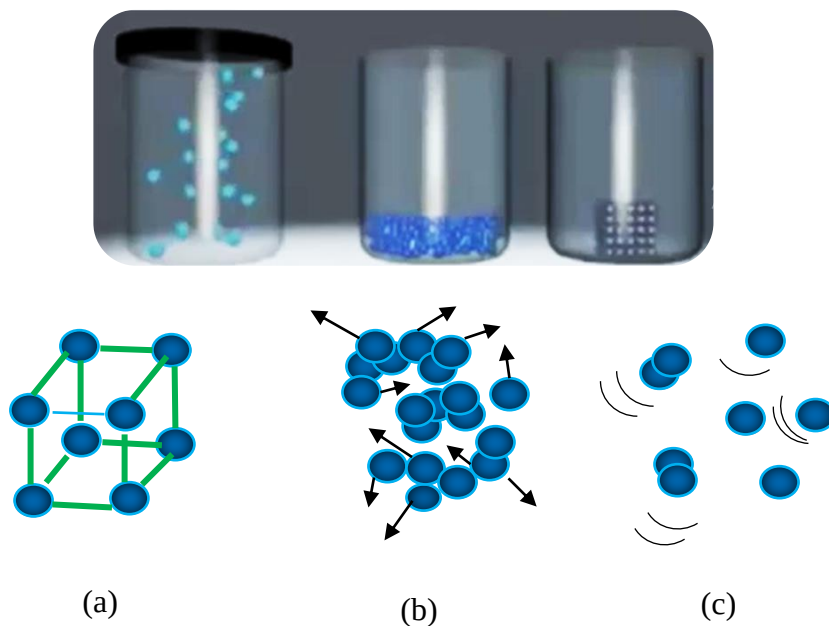


Figure 21 : Molecular structure: (a) solid, (b) liquid, (c) gas.

Fluids are divided into two classes: compressible (gas) and incompressible (liquid). As an example, we consider water and air. The difference between these two classes of fluids is striking. Liquids are viscous and occupy a well-defined volume when placed in a container, and they have a free surface. In contrast, gases have no free surface and expand to fill the entire volume of the container. Moreover, the volume of a compressible fluid depends on the external pressure, unlike an incompressible fluid, whose volume is independent of the external pressure.

Fluids are present everywhere and are essential to daily life. An ideal example to illustrate the important role of fluids is the human body, where inhaled air, being a fluid, is transported through the airways. Then, this air is indirectly transported by another fluid, the blood, to the various organs of the human body. Fluids are also essential for technological applications and the development of medical science. For example, in designing dialysis systems, transfusion devices, and so on.

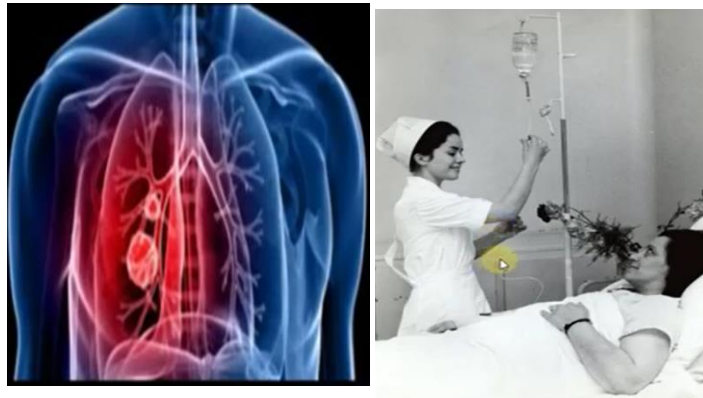


Figure 22: Medical field.



Figure 23: Automotive field.

2 Physical characteristics of fluids

All fluids (e.g., blood, an aqueous solution, serum, etc.) are characterized by physical quantities such as:

2.1 Density (mass density)

The mass density of a fluid is the mass per unit volume, as shown by the following relation:

$$\rho = \left[\frac{m}{V} \right] = \left[\frac{Kg}{m^3} \right]$$

It should be noted that the mass density varies slightly with temperature for liquids, and varies with both temperature and pressure for gases. The density of water is equal to 1000 kg/m³ at room temperature.

2.2 Density (Relative density)

The density (relative density) of a fluid is the ratio of its mass density to the mass density of a reference fluid at 4 °C. The reference fluid is generally water for liquids and air for gases. Density is dimensionless (it has no unit).

$$d = \frac{\rho}{\rho_{water}} \quad \text{Ou} \quad d = \frac{\rho}{\rho_{air}}$$

2.3 Viscosity

What is viscosity ?

It can be defined as the resistance to flow that occurs within a fluid. For example, if we move an object through air, we observe that it moves easily. However, we encounter more resistance if we move it through water. This resistance increases even more if the medium is oil.

To illustrate the definition of viscosity, consider a fluid moving between two parallel flat plates (Figure 24), one fixed and the other moving with a velocity U under the effect of a force F . The fluid resists the motion and reacts with a friction force equal in magnitude to the applied force but in the opposite direction.

The particles in contact with the moving plate move with the same velocity U , while the particles in contact with the fixed plate have zero velocity. Therefore, the layers of fluid slide over one another.

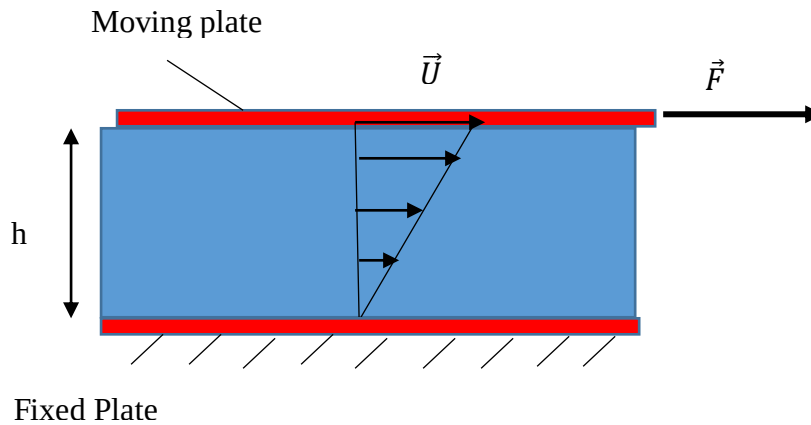


Figure 24: Velocity of a fluid confined between two parallel flat plates.

The velocity of each layer depends on the distance h . This sliding is expressed as a fluid friction force F , which depends on the velocity that varies along the height h . The proportionality coefficient is called the dynamic viscosity η , and it is given by the following relation:

$$F = \eta S \frac{u}{h}$$

The above expression can be used to derive the equation for dynamic viscosity:

$$[\eta] = \frac{[F][h]}{[S][U]} = \frac{[N][m]}{[m^2][m/s]} = Pa \cdot s$$

The unit of dynamic viscosity is $Pa \cdot s$ (Pascal-second).

The Poiseuille symbol, PI , is also used

The viscosity of liquids decreases with increasing temperature, as shown in **Figure 25** below

:

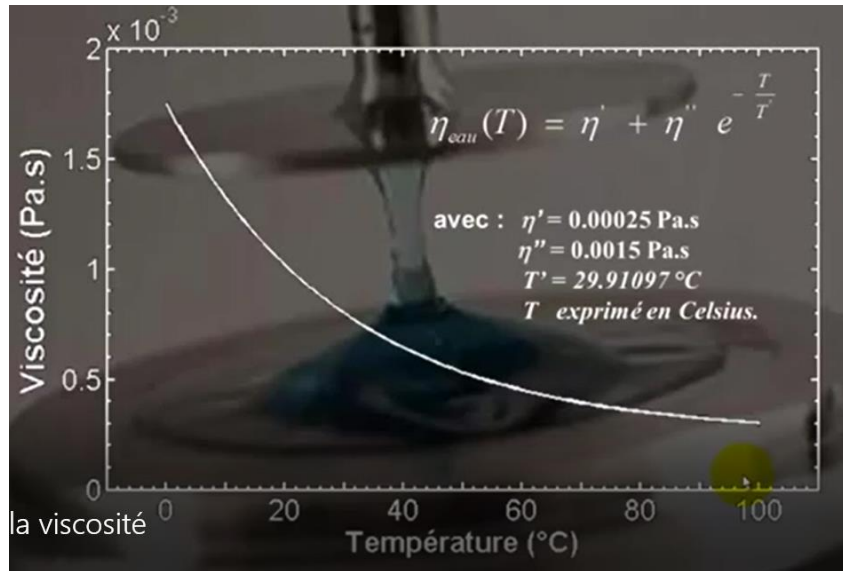


Figure 25: Variation of viscosity as a function of temperature.

Viscosity is also associated with another quantity, namely kinematic viscosity. Sometimes, instead of dynamic viscosity, kinematic viscosity is used. The expression for kinematic viscosity is given by the following formula:

$$[v] = \frac{[\eta]}{[\rho]} = \frac{[MLT^{-2}]}{[L^2][T^{-1}]} * \frac{L^3}{M} = m^2/s$$

The unit of kinematic viscosity m^2/s , The stokes, symbolized as st or stokes, can also be used, where stokes = $1 \text{ cm}^2/s$.

3 Different Types of Flow

Experiments conducted by Reynolds in 1883 on the flow of a fluid in a straight cylindrical pipe showed the existence of two flow regimes: laminar flow and turbulent flow.

For the laminar regime (**Figure 26**), the experiment shows that the streamlines (lines of fluid) inside a pipe move relative to each other without mixing, and the energy exchanges between them are minimal (small friction forces). In contrast, in turbulent flow (**Figure 27**), the fluid layers inside the pipe do not remain separate and mix with each other. As a result, energy exchanges between them are significant, which increases friction forces.

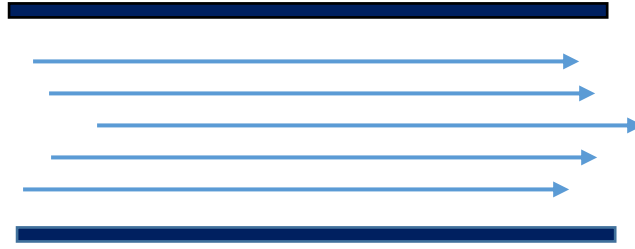


Figure 26: Laminar flow regime of a fluid in a tube.

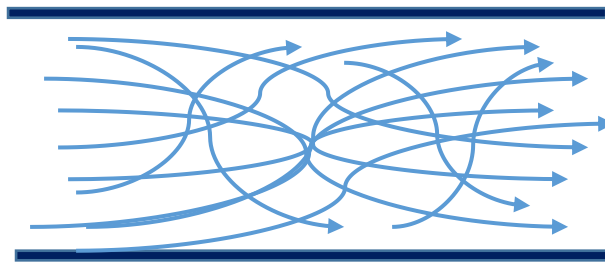


Figure 27: Turbulent flow regime of a fluid in a tube.

Schematically, the velocity profile of laminar flow forms a parabolic shape (**Figure 28**) for the first regime. In contrast, for the second regime (turbulent flow), the profile is flattened. It can be observed that the velocity varies according to the position along the axis in laminar flow. This observation helps differentiate between the average velocity and the maximum velocity along the axis, as shown in the figure.

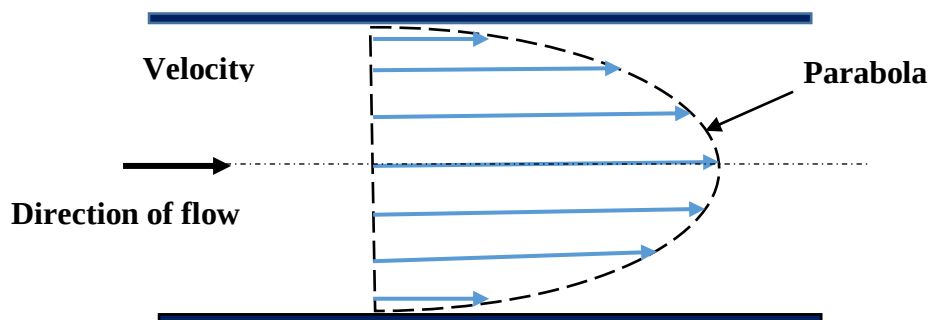


Figure 28 Velocity profile in the case of laminar flow.

$$V_{max} = V_{axe} = 2V_{moy}$$

One can visualize laminar and turbulent behavior, for example, when air flows over an obstacle (**Figure 29**):

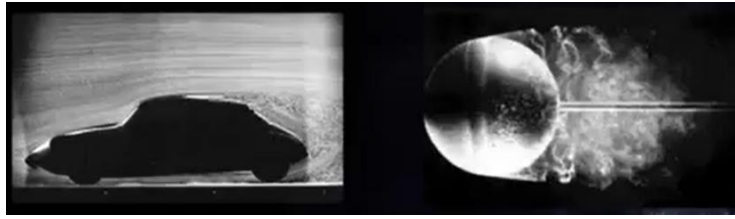


Figure 29: Laminar and turbulent behavior of a ball (a) and a car (b)

The laminar behavior is clearly visible in front of the sphere, where the layers of air do not mix and remain uniform. In contrast, behind the sphere, the air layers are no longer preserved, which indicates a turbulent flow regime.

In nature, there are streamlined shapes that reduce the turbulence generated by an object moving through a fluid. For example, the shape of a shark is highly aerodynamic. A shark has a body shape that minimizes friction and drag.



Figure 30: Streamlined shape reducing turbulence.

3.1 Reversibility

Another important property of laminar flow is that it is reversible. What does this notion of If we pour three drops of different colors into a container filled with water (Figure 31(a)), and then rotate the setup (Figure 31(b)), for example making six turns, at the end we see that the three colors have mixed (Figure 31(c)). Now, if we make six turns in the opposite direction, we observe that the fluid returns to its initial state. In summary, laminar flow is reversible. In the turbulent regime, due to the various exchanges between the fluid layers, this reversibility is lost. As a result, it is not possible to return to the initial state by reversing the motion.

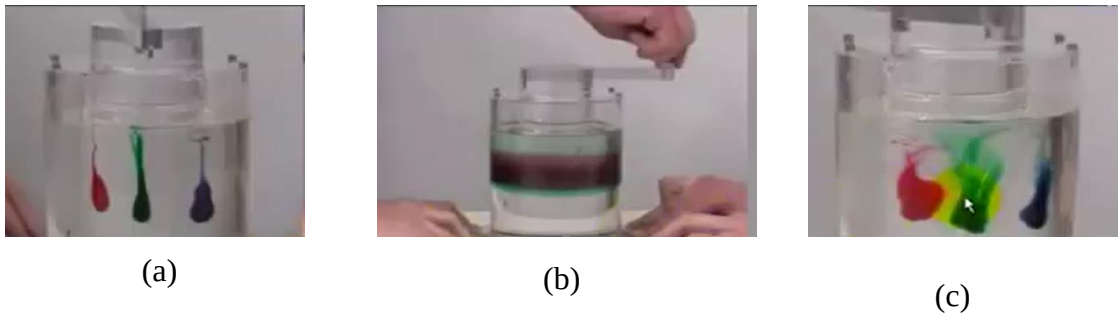


Figure 31: Reversibility of a flow.

3.2 Reynolds Number (Re)

According to Reynolds' experimental study, the nature of the flow (laminar or turbulent) of a fluid in a pipe is influenced by its velocity, density, viscosity, and the pipe diameter. Therefore, the Reynolds number (Re) is defined by the following expression:

$$Re = \frac{\rho v_m D}{\eta} = \frac{v_m}{\nu}$$

Where :

ρ : Density of the fluid, **v** = Average velocity.

D : Pipe diameter.

η : Dynamic viscosity of the fluid **ν** = Kinematic viscosity

If :

$R_e < 2000$ Laminar Flow.

$R_e > 3000$ Turbulent Flow.

4 Stokes' Law

In this experiment, we will study the fall of a spherical bead in a viscous liquid, such as glycerin. This phenomenon illustrates the sedimentation process, where a solid particle slowly moves through a fluid until it reaches a constant velocity, called the terminal velocity. This motion is governed by Stokes' law, which describes the drag force exerted on a sphere moving through a viscous fluid. As the bead falls, it experiences several forces, as shown in **Figure 32**. Studying this phenomenon allows us not only to understand the fundamental principles of fluid dynamics but also to measure the viscosity of a liquid by observing the sedimentation velocity of a bead. This approach is used in devices such as falling-ball viscometers, which are commonly employed to determine the dynamic viscosity of various fluids.

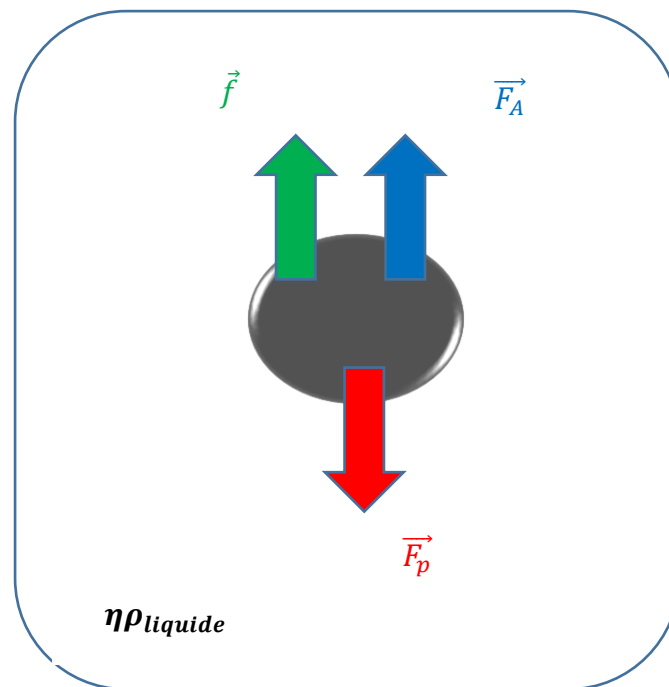


Figure 32: Fall of a spherical bead in a viscous fluid.

$\vec{f} = -6\pi\eta R\vec{v}$ is the friction force due to viscosity.

$\vec{F}_A = -\rho_{liquide}V\vec{g}$ is the Archimedes' buoyant force.

$\vec{F}_p = -\rho_{bille}V\vec{g}$ is the weight of the bead.

Where : $\vec{v}$ is the velocity of the bead.

V is the volume of the bead.

The resultant force is:

$$\begin{aligned}\vec{F}_{total} &= \vec{F}_p + \vec{F}_A + \vec{f} \\ &= (\rho_{bille}V - \rho_{liquide}V)\vec{g} - 6\pi\eta R\vec{v} \\ &= (\rho_{bille}V - \rho_{liquide}V)\vec{g} - K\vec{v}\end{aligned}$$

According to Newton's second law:

$$\begin{aligned}\vec{F}_p + \vec{F}_A + \vec{f} &= M\vec{a}_{cc} \\ (\rho_{bille}V - \rho_{liquide}V)\vec{g} - K\vec{v} &= M\vec{a}_{cc}\end{aligned}$$

Thus, the acceleration is expressed as:

$$\vec{a}_{cc} = \frac{\rho_{bille} - \rho_{liquide}}{\rho_{bille}}\vec{g} - \frac{K}{\rho_{bille}V}\vec{v}$$

$$\frac{d\vec{v}}{dt} = \frac{\rho_{bille} - \rho_{liquide}}{\rho_{bille}}\vec{g} - \frac{K}{\rho_{bille}V}\vec{v}$$

$$\frac{d\vec{v}}{dt} + \frac{K}{\rho_{bille}V}\vec{v} = \frac{\rho_{bille} - \rho_{liquide}}{\rho_{bille}}\vec{g}$$

The analytical solution is given by the following equation:

$$\vec{v} = \frac{\rho_{liquide} - \rho_{bille}}{K}Vg \left[1 - \exp\left(\frac{-Kt}{\rho_{bille}V}\right) \right]$$

At infinity : $\lim_{\infty} \vec{v} = v_{\text{limite}} = \frac{\rho_{\text{liquide}} - \rho_{\text{bille}}}{6\pi\eta r} Vg$

Since the volume of the bead is : $V = \frac{4}{3}\pi r^3$

Replacing in the previous equation gives:

$$v_{\text{limite}} = \frac{2}{9} \frac{\rho_{\text{bille}} - \rho_{\text{liquide}}}{\eta} r^2 g$$

Remark : This terminal velocity is widely used for blood analysis, in a test commonly called the **sedimentation rate** or **Biernacki's velocity**, because Biernacki was among the first to propose this test. He observed that during inflammation, this velocity could change significantly. Therefore, it is a routine laboratory test to determine the sedimentation rate.

4.1 Blood Sedimentation Rate

How can this velocity be calculated theoretically?

A common example to illustrate sedimentation velocity is blood. When blood is placed in a test tube, it initially appears as a homogeneous medium, but after several hours, a separation occurs between the different constituents of blood. This indicates that the different components of blood have settled to the bottom of the tube. Therefore, blood is not a homogeneous medium. The main constituents of blood are:

- Plasma (55%)
- Leukocytes (white blood cells) + Thrombocytes (platelets): 2%
- Erythrocytes (43%,
hématie, globules rouges).

These constituents have different properties:

- Plasma : $\rho_p = 1.03 \cdot 10^3 \text{ Kg/m}^3$; $\eta = 1.030 \text{ Pa.s}$
- Erythrocytes : $\rho = 1.30 \cdot 10^3 \text{ Kg/m}^3$.

To study theoretically the fall of these constituents, we make some assumptions about the red blood cells (RBCs):

- Anticoagulated (independent of each other)
- Spherical shape (Stokes' law applicable)

- Radius $r=3 \mu\text{m}$
- Laminar regime.
- Stationary regime reached (motion considered uniform).

We focus on the second hour, i.e., when the stationary regime is reached. Finally, we can easily calculate the sedimentation velocity of red blood cells using the Stokes model previously studied:

$$v_{\text{limite-Erythrocyte}} = \frac{2}{9} \frac{\rho_{\text{globule rouge}} - \rho_{\text{plasma}}}{\eta} r^2 g$$

Numerical Application :

$$v_{\text{limite-Erythrocyte}} = \frac{2}{9} * \frac{1.30 \cdot 10^3 - 1.03 \cdot 10^3}{1.30 \cdot 10^{-3}} (3 * 10^{-6})^2 * 10$$

$$v_{\text{limite-Erythrocyte}} = \frac{2}{9} * \frac{270}{0.0013} * 9 * 10^{-12} * 10$$

$$v_{\text{limite-Erythrocyte}} = \frac{2}{9} * 207692.31 * 9 * 10^{-12} * 10$$

$$v_{\text{limite-Erythrocyte}} = 4.15 * 10^{-6} \frac{\text{m}}{\text{s}}$$

5 Poiseuille's Law

This law was proposed by Jean-Léonard-Marie Poiseuille (1797–1869), a French physicist and physician of the 19th century. His work was primarily focused on the heart and the circulation of blood in vessels. This naturally led him to study what happens in very small-diameter tubes.

If we consider a cylindrical pipe (of small diameter) (**Figure 33**) through which a fluid of flow rate Q and viscosity η passes, as shown in the figure:

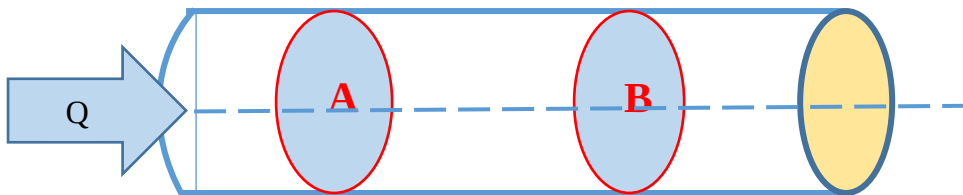


Figure 33: Fluid flow in a capillary pipe between two points A and B

The pressure drop, or the difference in pressure between points A and B, is given by:

$$\Pi = R_p Q$$

Where :

$$R_p = \frac{8\eta L}{\pi r^4}$$

If we substitute (1) into (2), we get :

$$\Pi = \frac{8\eta L}{\pi r^4} Q$$

This expression shows that R_p is proportional to the length L of the tube and the viscosity η of the fluid flowing through the cylindrical pipe. This means that the more viscous the fluid, the greater the pressure drop. We also note that Poiseuille's resistance is highly sensitive to the radius of the cylinder. For example, if the radius of the cylinder is halved, the resistance increases by a factor of 16. Consequently, the pressure drop becomes significant. This result highlights the risk factors and potential complications in humans with blood vessels clogged by cholesterol.

R_p : is called Poiseuille's resistance.

Q : is the volumetric rate.

η : is the fluid viscosity.

r : is the radius of the cylinder.

L : is the length of the pipe between points A and B.

Remark This applies only to laminar flows.

6 Connection of Capillary Tubes:

6.1 Series connection

We consider two segments of different diameters through which a fluid of flow rate Q passes. We assign a resistance to each segment as shown in **Figure 34**:



Figure 34: Series arrangement of two pipes.

The flow rate Q is the same in both segments. Therefore, the pressure drops add up to give the total pressure drop:

$$\Pi_{Total} = \Pi_{p1} + \Pi_{p2}$$

Thus, the total Poiseuille resistance of the two segments is equal to:

$$R_{pTotal} = R_{p1} + R_{p2}$$

6.2 Parallel connection

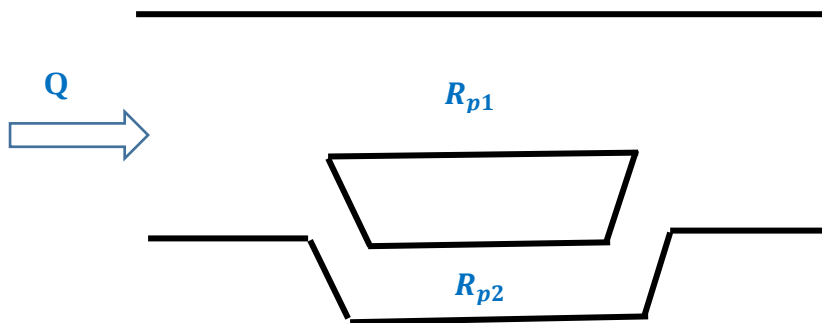


Figure 35: Parallel arrangement of two pipes.

The flow rate is divided between the two segments. Consequently, the pressure drops are equal:

$$\Pi_{Total} = \Pi_{p1} = \Pi_{p2}$$

For a parallel arrangement, the total Poiseuille resistance is given by the sum of the inverses:

$$\frac{1}{R_{pTotal}} = \frac{1}{R_{p1}} + \frac{1}{R_{p2}}$$

7 Area of Application: Fluid Dynamics and Properties of Fluids

Fluid dynamics is widely used in biological and life sciences to understand how liquids and gases behave in living systems.

7.1 Human physiology: blood circulation

Fluid dynamics explains the flow of blood in the cardiovascular system:

- blood flow through arteries and veins
- pressure variations in the circulatory system
- resistance due to vessel diameter

Essential for understanding hypertension and cardiovascular diseases.

7.2 Respiratory system: airflow in lungs

The movement of air in the respiratory tract follows fluid dynamic principles:

- airflow in bronchi and bronchioles
- pressure differences during breathing
- resistance in narrowed airways (asthma)

Helps explain breathing mechanics and respiratory disorders.

7.3 Biopharmaceuticals: drug transport in fluids

Fluid flow is important in:

- distribution of drugs in the bloodstream
- infusion systems and IV therapy
- controlled drug delivery systems

Ensures proper dosage and efficiency of treatments.

7.4 Biotechnology and laboratory systems

Fluid dynamics is used in:

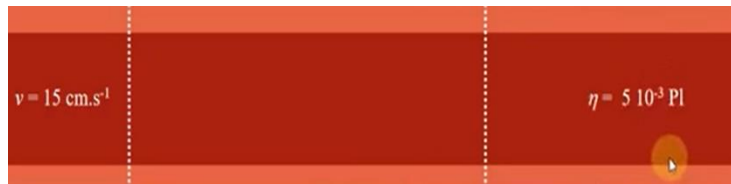
- microfluidic devices (lab-on-a-chip)
- mixing of biological solutions
- cell culture bioreactors

Very important in modern biomedical engineering.

Tutorial N°4

Exercise 1

We consider a blood vessel of radius $r=2$ mm and length $L=15$ mm through which blood flows with a viscosity $\eta = 6 \cdot 10^{-3} \text{ P.s}$. The blood flows with a velocity of $v = 15 \text{ cm.s}^{-1}$.



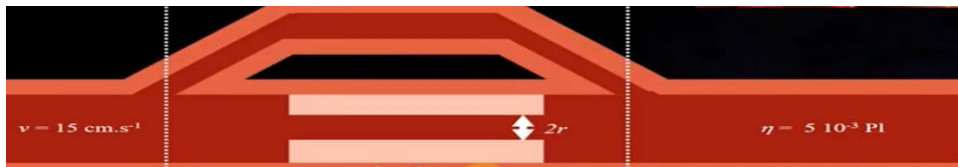
- Determine the Poiseuille resistance as well as the blood flow rate.
- Calculate the pressure drop within the blood vessel.

Now, consider an atheroma plaque that creates a narrowing inside this blood vessel. The narrowing is localized on a segment of length $l=6$ cm. The atheroma plaque reduces the radius of the vessel by half ($2r$). which leads to a new flow rate $Q' = KQ$, and a pressure drop equal to 5000 P.s.



- Calculate the new Poiseuille resistance.
- Determine the radius of the narrowed segment (r).

To remedy this atherosclerosis (pressure drop), a bypass or shunt can be performed to divert the flow around the obstructed section.



- What should be the Poiseuille resistance R_{p3} , corresponding to the resistance of the bypass.
- Calculate the flow rate that will pass through the bypass.

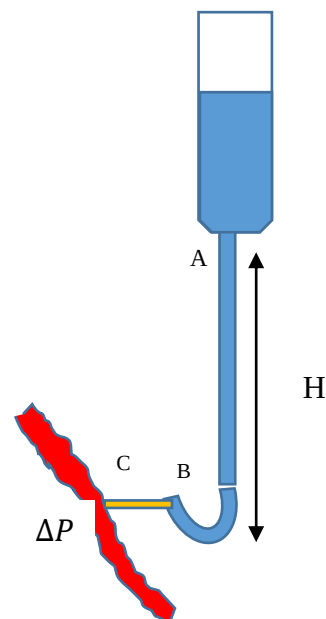
Exercise 2

We want to perform an infusion on a patient using a container suspended above, which is connected to the catheter by a tube. The catheter is then inserted into the patient's vein. The container holds an ionic solution with a volume $V=500 \text{ mL}$ and a density $\rho = 1.1 \text{ gcm}^{-3}$. Thus, the viscosity of the infused solution is 210^{-3} Pa.s . It should be noted that the diameter of the tube ($D=0.4 \text{ mm}$) is greater than that of the needle (d).

- What is the flow rate Q of the solution?
- What is the nature of the flow?
- What is the Poiseuille resistance of the needle?
- What is the resulting pressure drop?
- At what height should the container be placed to compensate for the overpressure?

Given:

- ΔP : venous overpressure = 6 cmHg
- ρ : density of mercury = 13.6 g/cm³
- T : infusion time = 4 h



Exercise 3

In a straight smooth pipe with an internal diameter $D=15$ mm, oil flows at a velocity $V=2,5$ m/s.

1. Calculate the Reynolds number and indicate the flow regime.
2. Calculate the pressure losses Δp per meter of pipe length.

Data: kinematic viscosity of the oil $\nu = 25 \cdot 10^{-6} \text{ m}^2 \cdot \text{s}^{-1}$; Density of oil : $\rho = 850 \text{ kg} \cdot \text{m}^{-3}$

Exercise 4

An iron sphere with a density $\rho_{bille} = 7800 \text{ Kg/m}^3$ and a diameter of 4 mm de diamètre falls under gravity in glycerin. The density of glycerin is: $\rho_{glycérine} = 1265 \text{ Kg/m}^3$. Calculate the dynamic viscosity of the fluid. We Assume terminal velocity $v=0.02$ m/s

Deduce the value of the kinematic viscosity

Exercise 5

Consider N small-diameter tubes with viscosity $\eta = 6 \cdot 10^{-3} \text{ P} \cdot \text{s}$ and radius $r = 4$ mm.

- Calculate the Poiseuille resistance and the equivalent pressure drop for a series and parallel arrangement.
- Compare the results obtained.

Exercise solutions of tutorial N°4

Exercise1

1) Flow rate Q

$$Q = v * S = v * \pi r^2$$

$$S = \pi * (2 \times 10^{-3})^2 = 1.26 \times 10^{-5} \text{m}^2$$

$$Q = 0.15 \times 1.26 \times 10^{-5} = 1.89 \times 10^{-6} \text{m}^3/\text{s}$$

2) Pressure drop (Poiseuille law)

$$Q = \frac{\pi r^4}{8\eta L} \Delta P$$

So :

$$\Delta P = \frac{8\eta L Q}{\pi r^4}$$

Calculate r^4

$$r^4 = (2 \times 10^{-3})^4 = 16 \times 10^{-12} = 1.6 \times 10^{-11}$$

Substitute

$$\Delta P = \frac{8 * 6 * 10^{-3} * 1.5 * 10^{-2} * 1.89 * 10^{-6}}{\pi * 1.6 * 10^{-11}}$$

$$\Delta P = \frac{1.36 * 10^{-9}}{5.03 * 10^{-11}} = 27 \text{ Pa}$$

Part 2

Poiseuille resistance

$$R = \frac{8\eta L}{\pi r^4}$$

Very important:

$$R \propto \frac{L}{r^4}$$

1) Effect of narrowing (radius halved)

The statement says the radius is reduced by half:

$$r' = \frac{r}{2}$$

New resistance on the narrowed segment:

$$R' = \frac{8\eta l}{\pi (r/2)^4}$$

$$\left(\frac{r}{2}\right)^4 = \frac{r^4}{16}$$

$$R' = \frac{8\eta l}{\pi \frac{r^4}{16}} = 16 \frac{8\eta l}{\pi r^4}$$

$$R' = 16R$$

Original vessel: $L=15 \text{ mm}=1.5 \text{ cm}$

Narrowed segment: $l=6 \text{ cm}$

Resistance ratio :

$$\frac{R'}{R} = 16 * \frac{l}{L}$$

$$\frac{R'}{R} = 16 * \frac{6}{1.5} = 64$$

$$R' = 64R$$

The resistance becomes **64 times larger**

2) New flow rate

$$Q = \frac{\Delta P}{R}$$

$$Q' = \frac{\Delta P}{R'}$$

$$Q' = \frac{Q}{64}$$

Flow is **divided by 64** → very severe reduction

3) Radius of narrowed segment

Given in the statement:

$$r' = \frac{r}{2}$$

Original radius

$$r = 2\text{mm}$$

Third part

Parallel resistances

When a bypass is added, we have **two parallel paths**:

- Path 1: narrowed vessel → resistance R'
- Path 2: bypass → resistance R_p

Equivalent resistance:

$$\frac{1}{R_{eq}} = \frac{1}{R\backslash} + \frac{1}{R_p}$$

Goal of the bypass

The purpose is to **restore the original flow Q**

So we want:

$$R_{eq} = R$$

(where R is the original healthy resistance)

1) Use previous result

From part 2:

$$R\backslash = 64R$$

2) Calculate bypass resistance

$$\frac{1}{R_{eq}} = \frac{1}{64R} + \frac{1}{R_p}$$

$$1 = \frac{1}{64} + \frac{R}{R_p}$$

$$\frac{R}{R_p} = 1 - \frac{1}{64} = \frac{63}{64}$$

$$R_p = \frac{64}{63} R$$

$$R_p = 1.02R$$

The bypass must have **almost the same resistance as the original vessel**

3) Flow rate in the bypass

In parallel:

$$Q_{Total} = Q_{nrraowed} + Q_{bypass}$$

Same pressure drop $\Rightarrow \text{flow} \propto \frac{1}{R}$

Ratio of flows :

$$\frac{Q_{bypass}}{Q_{nrraowed}} = \frac{R \setminus}{R_p}$$

$$= \frac{64R}{(64/63)R} = 64$$

Interpretation

$$Q_{bypass} = 63 * Q_{nrraowed}$$

Total flow = original Q, so:

$$Q_{Total} = Q_{nrraowed} + Q_{bypass}$$

$$Q_{Total} = 63x + x = 64x$$

$$x = \frac{Q_{Total}}{64}$$

Final flows

- Narrowed vessel:

$$Q_{nrraowed} = \frac{Q_{Total}}{64}$$

- Bypass:

$$Q_{bypass} = \frac{63}{64} Q_{Total}$$

Physical interpretation

- Almost **all the blood flows through the bypass**
- The narrowed artery carries **almost nothing**
- This explains why bypass surgery is effective

Exercise 2**1) Flow rate Q**

Total volume:

$$V = 500 \text{ mL} = 5.0 \times 10^{-4} \text{ m}^3$$

$$T = 4 \text{ h} = 14400 \text{ s}$$

$$Q = \frac{V}{T}$$

$$Q = \frac{5.0 \times 10^{-4}}{14400} = 3.47 \times 10^{-8} \text{ m}^3/\text{s}$$

2) Nature of the flow

Use Reynolds number:

$$R_e = \frac{\rho v d}{\eta}$$

First, velocity:

$$v = \frac{Q}{S} = \frac{Q}{\pi r^2}$$

Even without detailed calculation:

Very small diameter + low velocity + high viscosity $\Rightarrow$

Flow is: Laminar

3) Poiseuille resistance of the needle

Formula:

$$R = \frac{8\eta L}{\pi r^4}$$

Data

- $\eta = 2 \times 10^{-3} \text{ Pa.s}$
- $L = 3 \text{ cm} = 0.03 \text{ m}$
- $d = 0.4 \text{ mm} \Rightarrow r = 2 \times 10^{-4} \text{ m}$

Calculation

$$r^4 = (2 \times 10^{-4})^4 = 1.6 \times 10^{-15}$$

$$R = \frac{8 * 2 * 10^{-3} * 3 * 10^{-2}}{\pi * 1.6 * 10^{-15}}$$

$$R = \frac{4.8 * 10^{-4}}{5.03 * 10^{-15}} = 9.5 \times 10^{10} \text{ Pa.s}\backslash m^3$$

4) Pressure drop

$$\Delta P = R * Q$$

$$\Delta P = 9.5 \times 10^{10} \times 3.5 \times 10^{-8} = 3.3 \times 10^3 \text{ Pa}$$

5) Required height**Convert venous pressure**

$$6 \text{ cmHg}$$

$$\Delta P_{\text{vein}} = \rho_{\text{Hg}} g h$$

- $\rho_{\text{Hg}} = 13600 \text{ kg/m}^3$
- $h = 0.06 \text{ m}$

$$\Delta P_{\text{vein}} = 13600 \times 10 \times 0.06 = 8160 \text{ Pa}$$

Total pressure needed :

$$P_{\text{Total}} = 3300 + 8160 = 11460 \text{ Pa}$$

Height of container :

$$P = \rho g h$$

$$\rho = 1100 \text{ kg/m}^3$$

$$h = \frac{11460}{1100 * 10} = 1.04m$$

Exercise 3

$$R_e = \frac{VD}{\nu}$$

Data

- $V=2.5$ m/s
- $D=15$ mm= 0.015 m
- $\nu=25 \times 10^{-6}$ m²/s

Calculation

$$R_e = \frac{2.5 * 0.015}{25 * 10^{-6}}$$

$$R_e = \frac{0.037}{25 * 10^{-6}} = 1500$$

low regime

- Laminar: $Re < 2000$
- Turbulent: $Re > 4000$

Therefore:

Flow is laminar

2) Pressure loss per meter

For **laminar flow**, use:

$$\frac{\Delta P}{L} = \frac{32\mu V}{D^2}$$

First: dynamic viscosity

$$\mu = \rho v = 850 \times 25 \times 10^{-6}$$

$$\mu = 0.02125 \text{ Pa} \cdot \text{s}$$

Apply formula:

$$\frac{\Delta P}{L} = \frac{32 * 0.015 * 2.5}{(0.015)^2}$$

$$\frac{\Delta P}{L} = \frac{1.7}{2.25 * 10^{-4}} = 7555 \text{ Pa/m}$$

$$\frac{\Delta P}{L} = 7.6 * 10^3 \text{ Pa/m}$$

- Reynolds number: **1500** → **Laminar flow**
- Pressure loss: **≈ 7.6 kPa per meter**

Exercise 4

1) Dynamic viscosity η

Using Stokes' law:

$$\eta = \frac{2}{9} \frac{r^2 g (\rho_{\text{sphere}} - \rho_{\text{fluid}})}{\vartheta}$$

Calculation

$$r^2 = (2 \times 10^{-3})^2 = 4 \times 10^{-6}$$

$$\rho_{sphere} - \rho_{fluid} = 7800 - 1260 = 6540$$

$$\eta = \frac{2}{9} * \frac{4 \times 10^{-6} * 10 * 6540}{0.02}$$

$$\eta = 2.9 Pa.s$$

2) Kinematic viscosity ν

$$\nu = \frac{\eta}{\rho_{fluid}}$$

$$\nu = \frac{2.9}{1260} = 2.3 \times 10^{-3} m^2/s$$

- High viscosity $\Rightarrow$ slow motion (glycerin is very viscous)
- Stokes' law applies only for:
 - **laminar flow**
 - **small Reynolds number**

Exercise 5**1) Poiseuille resistance of ONE tube**

$$R = \frac{8\eta L}{\pi r^4}$$

Data:

- $\eta = 6 \times 10^{-3} \text{ Pa.s}$
- $r = 4 \text{ mm} = 4 \times 10^{-3} \text{ m}$

Compute r^4 :

$$r^4 = (4 \times 10^{-3})^4 = 256 \times 10^{-12} = 2.56 \times 10^{-10}$$

Resistance of one tube :

$$R = \frac{8 * 6 * 10^{-3} * L}{\pi * 2.56 * 10^{-10}}$$

$$R = \frac{4.8 * 10^{-2} * L}{8.04 * 10^{-10}} = 5.97 \times 10^7 L$$

2) Series arrangement

Resistances add:

$$R_{series} = NR$$

$$R_{series} = N * 6.07 * 10^7 L$$

Pressure drop

$$\Delta P = RQ$$

$$\Delta P_{series} = NRQ$$

Pressure drop **increases with N**

3) Parallel arrangement

Reciprocal addition:

$$\frac{1}{R_{parallel}} = \frac{N}{R}$$

$$R_{parallel} = \frac{R}{N}$$

$$R_{parallel} = \frac{6.0 * 10^7 L}{N}$$

Pressure drop

$$\Delta P_{parallel} = R_{parallel}Q = \frac{R}{N}Q$$

Pressure drop **decreases with N**

- **Series** → fluid faces more obstacles → harder to flow
- **Parallel** → more paths → easier flow

BIOPHYSICS EXAM – PROTOTYPE

Examination 1

Department of Biology

Module: Biophysics

Duration: 1 h 30 min

Exercise 1: Electrolytes (5 points)

A sodium chloride solution is prepared by dissolving **5.85 g of NaCl** in water to obtain a final volume of **500 mL**.

Given:

- Molar mass of NaCl = 58.5 g/mol
- NaCl dissociates completely into Na^+ and Cl^-

Questions

1. Calculate the number of moles of NaCl. (1 pt)
2. Calculate the molar concentration of the solution. (1 pt)
3. Determine the concentration of Na^+ ions and Cl^- ions. (2 pts)
4. State one biological role of sodium ions in the human body. (1 pt)

Exercise 2: Diffusion (5 points)

A molecule diffuses across a membrane surface of area **2 cm²**.

The diffusion coefficient is **$1.5 \times 10^{-5} \text{ cm}^2/\text{s}$** .

The concentration gradient is **0.4 mol/cm³**.

The membrane thickness is **0.02 cm**.

Using Fick's law:

Questions

1. Calculate the diffusion flux J . (2 pts)
2. Calculate the quantity of substance diffusing per second through the membrane:

Mention one factor that increases diffusion rate. (1 pt)

Exercise 3: Surface Tension (5 points)

A capillary tube of radius **0.5 mm** is placed in water. Water rises to a height of **3 cm**.

Given:

- Density of water $\rho=1000 \text{ kg/m}^3$
- Gravitational acceleration $g=9.81 \text{ m/s}^2$

Using Jurin's law :

Questions

1. Convert the radius into meters. (1 pt)
2. Calculate the surface tension γ of water. (3 pts)
3. Define surface tension. (1 pt)

Exercise 4: Fluids (5 points)

Blood flows through a vessel with:

- Radius $r=2 \text{ mm}$.
- Flow velocity $v=0.25 \text{ m/s}$.

Using the flow rate formula

Questions

1. Convert the radius into meters. (1 pt)
2. Calculate the cross-sectional area A . (2 pts)

3. Calculate the flow rate Q. (1 pt)
4. Cite one factor that can reduce blood flow in vessels. (1 pt)

Examination 2

Department of Biology

Module: Biophysics

Duration: 1 h 30 min

Part I: Multiple Choice Questions (10 points)

Question 1: Electrolytes (2.5 pts)

Choose the correct answer.

1. An electrolyte is:
 - a) A non-conductive substance
 - b) A substance that produces ions in solution
 - c) A gas dissolved in water
 - d) A neutral molecule
2. Which ion is mainly responsible for nerve impulse transmission?
 - a) Fe^{2+}
 - b) Na^+
 - c) Mg^{2+}
 - d) Zn^{2+}
3. The unit of molar concentration is:
 - a) kg
 - b) mol/L
 - c) Pa
 - d) N/m
4. NaCl dissociates into:
 - a) Na and Cl_2
 - b) Na^+ and Cl^-
 - c) Na^{2+} and Cl^{2-}
 - d) NaOH and HCl
5. A solution with high ion concentration generally has:
 - a) Low conductivity
 - b) No conductivity
 - c) High electrical conductivity
 - d) Zero osmotic pressure

Question 2: Diffusion (2.5 pts)

1. Diffusion is the movement of particles from:
 - a) Low concentration to high concentration
 - b) High concentration to low concentration
 - c) Equal concentration
 - d) Vacuum to liquid
2. Fick's law describes:
 - a) Fluid pressure
 - b) Surface tension
 - c) Diffusion
 - d) Viscosity
3. Increasing temperature generally:
 - a) Decreases diffusion
 - b) Stops diffusion
 - c) Increases diffusion
 - d) Has no effect
4. The diffusion rate increases when membrane thickness:
 - a) Increases
 - b) Becomes infinite
 - c) Decreases
 - d) Remains constant
5. The SI unit of diffusion coefficient is:
 - a) m^2/s
 - b) mol/L
 - c) Pa
 - d) N

Question 3: Surface Tension (2.5 pts)

1. Surface tension tends to:
 - a) Increase surface area
 - b) Reduce surface area
 - c) Eliminate gravity
 - d) Increase viscosity
2. Surface tension is caused by:
 - a) Nuclear forces
 - b) Magnetic forces
 - c) Cohesive intermolecular forces
 - d) Electrical resistance
3. Capillary rise is greater when tube radius is:
 - a) Large
 - b) Infinite
 - c) Small
 - d) Zero density
4. The SI unit of surface tension is:
 - a) Pa
 - b) mol/L

- c) N/m
- d) kg/m^3
- 5. Water droplets are spherical because of:
 - a) Osmosis
 - b) Surface tension
 - c) Diffusion
 - d) Gravity

Question 4: Fluids (2.5 pts)

- 1. Blood is considered:
 - a) An ideal gas
 - b) A biological fluid
 - c) A solid
 - d) A vacuum
- 2. The flow rate is:
 - a) Pressure divided by time
 - b) Volume flowing per unit time
 - c) Mass divided by density
 - d) Area divided by velocity
- 3. Poiseuille's law applies to:
 - a) Diffusion
 - b) Heat transfer
 - c) Laminar fluid flow
 - d) Surface tension
- 4. Increasing vessel radius generally:
 - a) Decreases flow
 - b) Increases flow
 - c) Stops flow
 - d) Has no effect
- 5. The SI unit of pressure is:
 - a) Pascal
 - b) Newton
 - c) Joule
 - d) Watt

Part II: Calculation Exercises (10 points)

Exercise 1: Electrolytes (2.5 pts)

A solution is prepared by dissolving **11.7 g of NaCl** in water to obtain **1 L** of solution.

Given:

- Molar mass of NaCl = 58.5 g/mol

Questions

1. Calculate the number of moles of NaCl. (1 pt)
2. Calculate the molar concentration. (1 pt)
3. Calculate the concentration of Na⁺ ions. (0.5 pt)

Exercise 2: Diffusion (2.5 pts)

A substance diffuses through a membrane of thickness **0.01 cm**. The diffusion coefficient is:

$$D = 2 * 10^{-5} cm^2/s$$

The concentration difference is:

$$\Delta C = 0.5 mol/cm^3$$

Using Fick's law:

$$J = -D \frac{\Delta C}{\Delta X}$$

Questions

1. Calculate the diffusion flux J. (2 pts)
2. State one factor affecting diffusion rate. (0.5 pt)

Exercise 3: Surface Tension (2.5 pts)

A capillary tube has a radius:

$$r=0.4 mm$$

Water rises to a height:

$$h=2.5 \text{ cm}$$

Given:

$$\rho=1000 \text{ kg/m}^3$$

Questions

1. Convert the radius into meters. (0.5 pt)
2. Calculate the surface tension γ . (2 pts)

Exercise 4: Fluids (2.5 pts)

Blood flows in a vessel with radius:

$$r=1.5 \text{ mm}$$

Velocity:

$$v=0.20 \text{ m/s}$$

Questions

1. Calculate the cross-sectional area. (1.5 pts)
2. Calculate the flow rate. (1 pt)

Examination 3

Department of Biology

Module: Biophysics

Duration: 1h30

Part A: Multiple Choice Questions (MCQs) (5 points)

Circle the correct answer.

1. Electrolyte solutions mainly contain:

- A. Only neutral molecules
- B. Ions in solution
- C. Only gases
- D. Only solids

2. Diffusion is:

- A. Active transport requiring energy
- B. Movement from low to high concentration
- C. Movement from high to low concentration
- D. Movement only in solids

3. Surface tension is caused mainly by:

- A. Gravity
- B. Cohesive forces between liquid molecules
- C. Magnetic forces
- D. Electrical resistance

4. Blood circulation is mainly described using:

- A. Thermodynamics
- B. Fluid dynamics
- C. Quantum physics
- D. Optics

5.Osmosis is:

- A. Diffusion of water through a semi-permeable membrane
- B. Movement of ions using energy
- C. Gas exchange in lungs
- D. Heat transfer

Part B: Short Answer Questions (5 points)

1. Define electrolyte solution and give one biological example. (1 pts)
2. Explain the role of diffusion in respiration. (1 pts)
3. Give two biological applications of surface tension. (1 pts)
4. What is the importance of fluid viscosity in blood circulation? (1 pts)
5. Differentiate between diffusion and active transport. (1 pts)

Part C: Applied Biology Problems (10 points)

Exercise 1: Diffusion (4 pts)

A molecule moves from a region of 80% concentration to 20% concentration across a membrane.

1. What process is occurring?
2. Is energy required? Explain briefly.

Exercise 2: Electrolytes (3 pts)

A patient suffers from dehydration due to diarrhea.

1. Why are electrolyte solutions given in treatment?
2. Name one physiological role of Na^+ or K^+ in the body.

Exercise 3: Fluid Dynamics (3 pts)

Blood flows faster in large arteries than in small capillaries.

1. Explain this using fluid dynamics concepts.

CORRECTION / ANSWER KEY

Examination 1

Exercise 1 Solution

1. Number of moles

$$n = \frac{m}{M}$$

$$n = \frac{5.85}{58.5} = 0.05 \text{ mol}$$

2. Molar concentration

Volume:

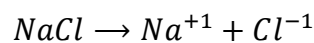
$$V = 500 \text{ mL} = 0.50 \text{ L}$$

$$C = \frac{n}{V}$$

$$C = \frac{0.1}{0.5} = 0.2 \text{ mol. L}^{-1}$$

3. Ion concentrations

NaCl dissociation:



Therefore

$$[Na^{+1}] = 0.2 \text{ mol. L}^{-1}$$

$$[Cl^{-1}] = 0.2 \text{ mol. L}^{-1}$$

4. Biological role

Sodium ions are involved in nerve impulse transmission.

Exercise 2 Solution

1. Diffusion flux

$$J = -D * \frac{\Delta C}{\Delta X}$$

$$J = -(1.5 \times 10^{-5}) \times \frac{0.4}{0.02}$$

$$J = -3.10^{-4} \text{ mol}\backslash\text{cm}^2.\text{s}$$

2. Quantity diffusing per second

$$Q = J * A$$

$$Q = (3 * 10^{-4}) * 2$$

$$Q = 6 * 10^{-4} \text{ mol/s}$$

3. One factor increasing diffusion

Increasing temperature increases diffusion rate.

Exercise 3 Solution

1. Radius conversion

$$r=0.5 \text{ mm}=0.0005 \text{ m}$$

2. Surface tension calculation

$$h = \frac{2\gamma}{\rho g r}$$

Rearranging

$$\gamma = \frac{h\rho g r}{2}$$

Heights :

$$h=0.3\text{cm}=0.03\text{m}$$

Substitution:

$$\gamma = \frac{0.03 * 1000 * 9.81 * 0.0005}{2}$$

$$\gamma = 0.0735 \text{ N/m}$$

3. Definition

Surface tension is the force acting at the surface of a liquid that tends to minimize its surface area.

Exercise 4 Solution**1. Radius conversion**

$$r=2\text{mm}=0.002\text{m}.$$

2. Cross-sectional area

$$S = \pi \cdot r^2$$

$$S = 3.14 * (0.002)^2$$

$$S = 1.25 \times 10^{-5} \text{ m}^2$$

3. Flow rate

$$Q = S * v$$

$$Q = 1.25 \times 10^{-5} * 0.25$$

$$Q = 3.14 \times 10^{-6} * 0.25 \text{ m}^3/\text{s}$$

4. Factor reducing blood flow

Narrowing of blood vessels reduces blood flow.

Examination 2

Part I: QCM Answers

Electrolytes

1. b
2. b
3. b
4. b
5. c

Diffusion

1. b
2. c
3. c
4. c
5. a

Surface Tension

1. b
2. c
3. c
4. c
5. b

Fluids

1. b
2. b
3. c
4. b
5. a

Part II: Solutions

Exercise 1 Solution

1. Number of moles

$$n = \frac{m}{M} = \frac{11.7}{58.4} = 0.2 \text{ mol}$$

2. Concentration

$$C = \frac{n}{V} = \frac{0.2}{1} = 0.2 \text{ mol. L}^{-1}$$

3. Sodium ion concentration

$$[Na^{+1}] = 0.2 \text{ mol. L}^{-1}$$

Exercise 2 Solution

$$J = -D \frac{\Delta C}{\Delta X}$$

$$J = -(2 \times 10^{-5}) \times \frac{0.5}{0.01}$$

$$J = -1 * 10^{-3} \text{ mol}\backslash\text{cm}^2.\text{s}$$

Exercise 3 Solution

1. Radius conversion

$$r=0.4 \text{ mm}$$

2. Surface tension

$$\gamma = \frac{h\rho gr}{2}$$

Convert height:

$$h=2.5 \text{ cm}=0.025 \text{ m}$$

Substitution:

$$\gamma = \frac{0.025 * 1000 * 9.81 * 0.0004}{2}$$

$$\gamma = 0.049 \text{ N.m}^{-1}$$

Exercise 4 Solution

1. Area

Convert radius:

$$r=1.5 \text{ mm}=0.0015 \text{ m}$$

$$S = \pi r^2$$

$$S = 3.14 * (0.0015)^2$$

$$S = \pi r^2$$

$$S = 7.07 \cdot 10^{-6} \text{ m}^2$$

2. Flow rate

$$Q = S * v$$

$$Q = (7.07 \cdot 10^{-6}) * 0.20$$

$$Q = 1.41 * 10^{-6} \text{ m}^3/\text{s}$$

Examination 3

Part A: MCQs

1. **B** – Ions in solution
2. **C** – Movement from high to low concentration
3. **B** – Cohesive forces between molecules
4. **B** – Fluid dynamics
5. **A** – Diffusion of water through a semi-permeable membrane

Part B: Short Answers

1.

An electrolyte solution is a solution that contains ions capable of conducting electricity.
Example: NaCl solution in blood plasma.

2.

Diffusion allows oxygen to move from alveoli into the blood and carbon dioxide from blood to alveoli, enabling gas exchange.

3.

- Stability of lung alveoli (via surfactant)
- Movement of water in plants
- Insects walking on water surface

(any two correct answers)

4.

Viscosity affects resistance to blood flow; higher viscosity increases resistance and reduces flow efficiency.

5.

- Diffusion: passive movement from high to low concentration
- Active transport: requires energy (ATP) to move substances against gradient

Part C: Problems

Exercise 1

1. Diffusion
2. No energy is required because it is passive transport driven by concentration gradient.

Exercise 2

1. Electrolyte solutions restore ion balance and hydration in the body.
2. Na^+ helps regulate osmotic balance and nerve function / K^+ is essential for nerve and muscle activity.

Exercise 3

Blood flows faster in large arteries because resistance is lower compared to small capillaries (based on fluid dynamics and vessel diameter)

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