biophysic course

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Chapter II : Phenomenon diffusion

1. Introduction

Diffusion Historically, diffusion has been studied about the movements of the solute, but in reality, it affects all molecules (solutes and solvents) similarly.

This chapter aims to:

• Explain why and how passive transport occurs.

• Understand the process of diffusion.

2. diffusion of solute liquid phase

diffusion is the passive process of transport. Diffusive transfers are related to the concentration gradient (grad c). It constantly involves the diffusion of metabolites, and macromolecules from one fluid compartment (intra or extracellular) to another, from one cell to another.

Experience shows that the distribution of a solute, introduced into a solvent, tends to become homogeneous. There is therefore transport of solute from the region where it was deposited to the regions where it was not distributed, therefore from the most concentrated regions to the least concentrated regions, to achieve equality of Concentrations. This development is irreversible. **https://www.youtube.com/watch?v=-ZwXUrZolD0**[1]

3. experimental demonstration of the phenomenon

For example, think about someone opening a bottle of perfume in a room filled with people. The perfume is at its highest concentration in the bottle and is at its lowest at the edges of the room. The perfume vapor will diffuse, or spread away, from the bottle, and gradually, more and more people will smell the perfume as it spreads.

3.1. Plasma membranes

Like prokaryotes, eukaryotic cells have a plasma membrane made up of a phospholipid bilayer with embedded proteins that separate the internal contents of the cell from its surrounding environment. A phospholipid is a lipid molecule composed of two fatty acid chains, a glycerol backbone, and a phosphate group.

Plasma membranes must allow certain substances to enter and leave a cell, while preventing harmful material from entering and essential material from leaving. In other words, plasma membranes are selectively permeable they allow some substances through but not others. If they were to lose this selectivity, the cell would no longer be able to sustain itself, and it would be destroyed.

[1] https://www.youtube.com/watch?v=-ZwXUrZolD0

3.2. Passive Transport

Passive transport is a naturally occurring phenomenon and does not require the cell to expend energy to accomplish the movement. In passive transport, substances move from an area of higher concentration to an area of lower concentration in a process called diffusion. A physical space in which there is a different concentration of a single substance is said to have a concentration gradient.

3.3. Selective Permeability

Plasma membranes are asymmetric, meaning that despite the mirror image formed by the phospholipids, the interior of the membrane is not identical to the exterior of the membrane. Integral proteins that act as channels or pumps work in one direction. Carbohydrates, attached to lipids or proteins, are also found on the exterior surface of the plasma membrane. These carbohydrate complexes help the cell bind substances that the cell needs in the extracellular fluid. This adds considerably to the selective nature of plasma membranes.

3.4. Diffusion with a permeable membrane

Materials move within the cell's cytosol by diffusion, and certain materials move through the plasma membrane by diffusion (Figure 3). Diffusion expends no energy. Rather the different concentrations of materials in different areas are a form of potential energy, and diffusion is the dissipation of that potential energy as materials move down their concentration gradients, from high to low.

4. Fick's first law

4.1. Quantitative Aspect of Liquid Phase Diffusion

$$\frac{n_1}{dt} = \frac{1}{2} \times \frac{S.dx}{dt} \times C_1$$

$$\frac{n_2}{dt} = \frac{1}{2} \times \frac{S.dx}{dt} \times C_2$$

We put :

$$n_1 - n_2 = dn\,;\,(C_1 - C_2) = dC$$

$$\frac{dn}{dt} = \frac{1}{2} \times \frac{S.dx}{dt} \times dC$$

Fick's first law

$$D = -D_0 \times S \times \frac{dC}{dx}$$

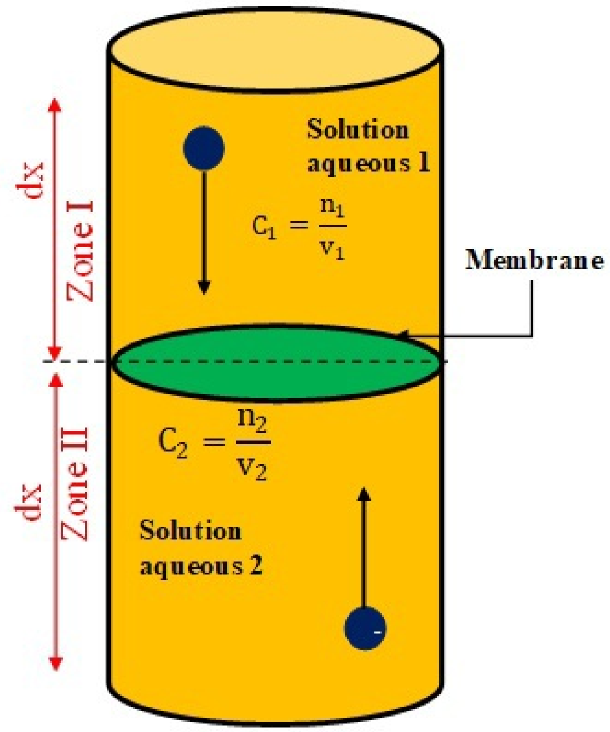

Figure 4: Diffusion shows the liquid phase

4.2. Units of the Fick equation

The tables 1 and 2 show the units for Fick's first law

	In the system MKS	In the system CGS
Molar debit	$D_{molar} = -D \times \left(\frac{dC}{dx}\right)$ D_{molar}: mole/s.m²; D: m²/s; dC: mol/m³; dx: m	$D_{molar} = -D \times \left(\frac{dC}{dx}\right)$ D_{molar}: mole/s.cm²; D: cm²/s; dC: mol/cm³; dx: cm
Mass debit	$D_{mass} = -D \times \left(\frac{dCp}{dx}\right)$ D_{mass}: kg/s.m²; D: m²/s; dCp: Kg/m³; dx: m	$D_{mass} = -D \times \left(\frac{dCp}{dx}\right)$ D_{mass}: g/s.cm²; D: cm²/s; dCp: g/cm³; dx: cm

Table 1: represents a molar and mass debit unit.

	In the system MKS	In the system CGS
Molar flow	$\emptyset_{molar} = \frac{dn}{dt} = -D \times S \times \left(\frac{dC}{dx}\right)$ $\emptyset_{molar}$: mol/s; D: m²/s; S: m²; dC: mol/m³; dx: m	$\emptyset_{molar} = \frac{dn}{dt} = -D \times S \times \left(\frac{dC}{dx}\right)$ $\emptyset_{molar}$: mol/s; D: Cm²/s; S: Cm²; dC: mol/cm³
Mass flow	$\emptyset_{mass} = \frac{dm}{dt} = -D \times S \times \left(\frac{dCp}{dx}\right)$ $\emptyset_{mass}$: Kg/s; D: m²/s; S: m²; dCp: Kg/m³; dx: m	$\emptyset_{mass} = \frac{dm}{dt} = -D \times S \times \left(\frac{dCp}{dx}\right)$ $\emptyset_{mass}$: g/s; D: cm²/s; S: cm²; dCp: g/cm³; dx: cm

Table 2: represents a molar and mass flow unit.

5. Exercice : Exercise series II

[solution n°2 p. 11]

Exercise 01

Two compartments A and B are separated by a membrane permeable to glucose molecules with a dx= 0.1 mm. Compartments A and B contain glucose solutions at concentrations of 36 g/l and 18 g/l, respectively. It is supposed that glucose molecules are spherical with a radius r=3 Å. The viscosity coefficient of glucose is η=10-3 poiseuille, and its molar mass is 180 g/mol.

1. Calculate the initial mass and molar flux of glucose diffusion at 25 and 0 °C.

Exercise 02

Consider two compartments (I and II) of equal volume separated by a membrane permeable to hemoglobin molecules with a surface area S=5 cm2 and a dx=3 cm. Compartment I contains a hemoglobin solution with a concentration of 2×10-4 mol/l, while compartment II contains pure water. After 5 minutes of diffusion, the concentration of hemoglobin in compartment I becomes 1.2×10-4 mol/L. the diffusion coefficient of hemoglobin as D=6.9×10-7 cm2/s and its molar mass as M= 68×103 g/mol.

1. Calculate the mass of hemoglobin that has moved to compartment II in mg.

Exercise 03

A container is divided into two compartments A and B by a membrane permeable to glucose molecules. The thickness of the membrane is dx=0.5 mm. Compartment A contains 1 l of an aqueous solution of glucose at 1 mol/L, and compartment B contains 1 l of pure water.

If it is considered that after one minute the mass of glucose that has moved to compartment B is m= 0.2 g, calculate the glucose flux at that moment. dx=0.5 mm, Dglucose=8.58×10-6 cm2/s.

6. Interrogation of chapter II

[cf. Inter 2]

Solutions des exercices

Solution n°1

[exercice p. 5]

Questions

1. Define the solutions?
2. What is the definition of quantity of matter?
3. What is the definition of Concentration?
4. Define the filtration process?
5. Define the dilution process?

1. Solutions are homogeneous mixtures usually classified based on their physical state, including solid solutions.
2. Quantity of matter refers to the quantity or mass present in a given object. It represents the total amount of atoms or molecules that make up a substance. it is exprissed in mol/l.
3. Concentration is the measure of the amount of solute dissolved in a given quantity of solvent or solution.
4. Filtration is a separation process used to separate solid particles from a liquid or gas by passing the mixture through a filter medium. The filter medium allows the liquid or gas to pass through while retaining the solid particles.
5. Dilution is the process of reducing the concentration of a solution by adding a solvent to it. This is typically done by adding more of the solvent (usually water) to a concentrated solution.

Solution n°2

[exercice p. 9]

Exercise 01

Two compartments A and B are separated by a membrane permeable to glucose molecules with a dx= 0.1 mm. Compartments A and B contain glucose solutions at concentrations of 36 g/l and 18 g/l, respectively. It is supposed that glucose molecules are spherical with a radius r=3 Å. The viscosity coefficient of glucose is η=10-3 poiseuille, and its molar mass is 180 g/mol.

1. Calculate the initial mass and molar flux of glucose diffusion at 25 and 0 °C.

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1. Calculation of mass flow

$$flow\ mass = \frac{1}{S} \times \frac{dm}{dt} = -D_0 \times \frac{dCp}{dx}$$

A diffusion is from C_pt^A to C_pt^B therefore

$$\frac{\Delta C_p}{\Delta x} = \frac{(C_t^B(t=0) - C_t^A(t=0))}{\Delta x}$$

$$D=(K_B T)/r6\pi\eta$$

For (T=0 °C):

$$flow\ mass=-(K_B T/6\pi\eta r)(\frac{C_t^B(t=0)-C_t^A(t=0)}{\Delta x})=0.1199\,g/s$$

For (T=25 °C):

$$flow\ mass=-(K_B T/6\pi\eta r)(\frac{C_t^B(t=0)-C_t^A(t=0)}{\Delta x})=0.1309\,g/s$$

3. Calculation of molar flow

$$flow\ molar=\frac{1}{S}\times\frac{dn}{dt}=-D_0\times\frac{dC}{dx}$$

For (T=0°C)

$$flow\ molar=-(K_B T/6\pi\eta r)(\frac{C_t^B(t=0)-C_t^A(t=0)}{\Delta x})=6.66\times10^{-4}\,mol/s$$

For (T=25°C)

$$flow\ molar=-(K_B T/6\pi\eta r)(\frac{C_t^B(t=0)-C_t^A(t=0)}{\Delta x})=7.27\times10^{-4}\,mol/s$$

Exercise 02

Consider two compartments (I and II) of equal volume separated by a membrane permeable to hemoglobin molecules with a surface area S=5 cm2 and a dx=3 cm. Compartment I contains a hemoglobin solution with a concentration of 2×10-4 mol/l, while compartment II contains pure water. After 5 minutes of diffusion, the concentration of hemoglobin in compartment I becomes 1.2×10-4 mol/L. the diffusion coefficient of hemoglobin as D=6.9×10-7 cm2/s and its molar mass as M= 68×103 g/mol.

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Calculation of mass flow

$$flow\ molar=\frac{dn}{dt}=-D_0\times S\times\frac{dC}{dx}$$

$$After\ 5\ min\ diffusion\ C_{pt}^{I}=1.2\times10^{-4}\,mol/l\ and C_{pt}^{II}=2\times10^{-4}\,mol/l\ therefore$$

$$\Delta m=-D_0\times S\times\frac{dCp}{dx}$$

$$The\ direction\ of\ diffusion\ C_{pt}^{I}\ and C_{pt}^{II},\ So:\Delta m=-D_0\times S\times\frac{dCp}{dx}=0.93\,\mu g$$

Exercise 03

A container is divided into two compartments A and B by a membrane permeable to glucose molecules. The thickness of the membrane is dx=0.5 mm. Compartment A contains 1 l of an aqueous solution of glucose at 1 mol/L, and compartment B contains 1 l of pure water.

If it is considered that after one minute the mass of glucose that has moved to compartment B is m= 0.2 g, calculate the glucose flux at that moment. dx=0.5 mm, Dglucose=8.58×10-6 cm2/s.

calculate the glucose flux at that moment.

calculate the glucose flux

$$\Delta m=-D_0\times\frac{\Delta C}{\Delta x}$$

$$C(t)=C_0\exp(DS/(V_0\Delta x))t$$

$$t=\ln(c(t)/c_0)/-(DS/(V_0\Delta x))=\ln(0.3/3)/(-((10^{-9}\times 3)/(50\times 10^{-3}\times 0.12\times 10^{-3})))=4.6\times 10^{3}\,s=1.27\,h=1\,h\,16\,min$$