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The biophysical modelling of the diffusion in the living systems

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Abstract

The transport phenomena mean the variation in time and space of generalized forces when they generate flows for which conservation laws apply. According to the general definition, the diffusion is a mass transportation under the action of a generalising force, which can be the concentration gradient, the pressure gradient, etc. The diffusion is explained on the basis of the spontaneous movement of the molecules which have the tendency to spread in equal numbers in each subspace tendency which arises from the concentration gradient. The diffusion is a frequently found phenomenon: with diffusion, the respiratory gas exchange takes place between the air in the alveoli, blood and cellular cytoplasm, the nutritive substances diffuse from the thin intestine into blood and further away in the tissues, the diffusion lays at the basis of the white cells' chemotactism, the olfaction happens when the molecules of the smelling substances spread in the air reach the cells of the olfactory mucosa. A particular case of diffusion is dialysis, which consists in the diffusion thought semipermeable membranes of the substances with a molecule smaller than the membranes pores. The dialysis takes place up to the equalising of the concentration in the two parts of the membrane.

Keywords: Transportation Phenomena, Diffusion, Fick's First Law, Fick's Second Law

Introduction

The three dimensional model of the sciences has the following five main layers: inorganic, organic, societal, mental, and spiritual. The marginal sciences are vertically and horizontally connected with the classical ones. The boundaries of different scientific branches could be considered as starting points of many facets of new initiatives for collaboration. This also could be serve as a pretext for presently unanswered problems. The nature of the meeting points of heterogeneous sciences, the so called „border sciences" is that the appearance and rules are not based upon any of known classical scientific norms.

The biophysics is the result of the interaction at the borders of biology and physics. It is a result of a physical process which is connected directly to the biological and even to the spiritual manifestation of it. In addition to it the biophysics as science also study the methodology and its utilized instruments (1).

At the beginning the biophysicist made its research according to the rules of physics without leaving the ground of biology. The goal of the modern biophysical research is to follow the rules of physics to recognize the progression and its regularity in the formation of living organism. Furthermore, observe the inner development in light of its total symptoms, including the spiritual ones, in order to fit these observations into the larger image of the scientific world.

Most of the physicists feel, that one can find nowadays more exciting questions in the area of biology than that of the pure physics. To approach these questions in our time is different for a physicist than a biologist.

In order to be able to understand the substantial differences in a biological stratum, only, if we considering the psychological side of the biological order. This became more evident in pathological cases. In fact it could be unsuccessful, to cure then by physical tools only without consideration of the psychological aid (2).

The biophysics in mentality and technique is a synthesis of physics, psychology, and biology. In reaching a right result, the biophysics is employing the investigation methods of the mathematics.

The main goal of the biophysical cognition as that of a borderland science is to reveal and cautiously draw up the laws guiding the motion and development of phenomena. The phenomena investigated by the biophysics are in steady fluctuation, nothing of the sort unambiguous causal relations can be determined because their origin and manifestations are based on non-linear causal connection (3).

A causal connection characteristic in a given biopsychological case is not necessarily valid also for other singular cases, for this reason by discovering generally valid peculiarities and dependencies one must turn to statistical estimations. It can, therefore, occur that the average statistical parameter will not coincide with any individual value of the given variable (4).

In biophysics, the objectivity of a theory will be esteemed according to the followings: the measure of the effect and intervention to the phenomenon under study, the measure of drafting and expressivity; the level of usefulness. Every biophysical experiment bears the personal intuition of the researcher and especially in the interpretation the mark of the individual prejudice (one-sidedness), inventiveness. The reason stated by the biophysicist must mean an advance somewhere to answer of one scientific question otherwise the statement won't disclose any information.

Definition of the Transport Phenomena

The transport phenomena mean the variation in time and space of generalized forces when they generate flows for which conservation laws apply (J. Vincze 1967) (5,6).

This general and strongly scientific definition of the transportation phenomena has two major merits: 1) particular forms of transportation can be deducted from it (mass transport-diffusion; energy transport-thermal conductibility; impulse transport-viscosity; task/load transport-electric conductibility, crossed effects and other); 2.) it allows a quantitative characterization of the product exchange, which was impossible based on the previous definitions.

If W-the amount of the transported parameter, for which the conservation law is valid; **K**-a constant dependent on the type of transportation and the nature of the transported parameter; **grad a**-the generalized force, then the amount of the parameter (flow) transported through the surface **dS** in the **dt** time frame will be given by the relation:

$$W = K\int_{t_1}^{t_2} \iiint_{S(x,y,z)} grad\ \ a\, dS\, dt$$

If the transportation takes place only after a direction x, then we obtain the formula:

$$W = K \int_{t_1}^{t_2}\int_{x_1}^{x_2} \text{grad } a_x \, dx \, dt$$

The differential form is the following:

$$\partial W = K \cdot \frac{\partial a}{\partial x} \cdot \Delta S \cdot \Delta t$$

Making the proper replacements in the relation above, we obtain the classical laws which describe particular, simple transportation phenomena.

With non stationary transportation we understand those transportations where the value of the flow is modified in time from one point to the other. ... Making the right replacements in the relationship above we obtain the classical laws which describe the simple non stationary transportation phenomena.

Diffusion

According to the general definition, the diffusion is a mass transportation under the action of a generalising force, which can be the concentration gradient, the pressure gradient, etc. It is about a mass flow, so that the parameter transported complies with the mass preservation law [7]. By replacing in the general relation the generalized force with the **dc/dx** concentration gradient the **K** constant with–**D**, where **D** is the diffusion coefficient through differentiation, we obtain Fick's first law:

$$\Delta m = - D \ \frac{dc}{dx}\ \Delta S \ \Delta t$$

The diffusion is explained on the basis of the spontaneous movement of the molecules which have the tendency to spread in equal numbers in each subspace tendency which arises from the concentration gradient. The minus sign in Fick's first law indicates the sense of development of the diffusion from the higher concentration towards the lower concentration. The value of the diffusion concentration can also be calculated based on the gas kinetic theory

$$D = 1{,}12\ \frac{2kT}{(N_1 + N_2)\cdot d^2}\sqrt{\frac{m_1 + m_2}{m_1 \cdot m_2}}$$

where: $\mathbf{N_1}$ şi $\mathbf{N_2}$-number of molecules of each type in the volume unit; $\mathbf{m_1}$ and $\mathbf{m_2}$ the mass of the two molecular species; **d**-average diameter of the molecules; **k**-Boltzmann's constant; **T**-absolute temperature. From this relation it results that the diffusion coefficient **D** depends on the nature of gas and it is directly proportional with the temperature and when the temperature is constant, it is reversely proportional with pressure [8].

If the diffusion must produce through a small orifice, then the diffusion speeds $\mathbf{v_1}$ and $\mathbf{v_2}$ of the two gases will be reversely proportional with the radical of the molecular masses $\mathbf{m_1}$ and $\mathbf{m_2}$:

$$\frac{v_2}{v_1} = \sqrt{\frac{m_1}{m_2}}$$

Which is the mathematical expression of the Graham law.

Einstein established that for the dispersed systems in which the molecules of the dissolved substance are higher in comparison with the molecules of the solvent, then between the ray **r** of the molecules of the diffusible substances (considered to be spherical), viscosity of the solution (**η**) and the diffusion constant (**D**) there is the relation:

$$D = \frac{R \cdot T}{6 \cdot \pi \cdot N \cdot \eta \cdot \cdot r}$$

Where: **N**-Avogadro's number; **R**-universal gas constant; **T**-absolute temperature. Knowing the diffusion coefficient **D** we can reach the often used formula for the calculation of the molecular weight (**M**) of the colloidal substances:

$$M = \frac{R^2}{162 \cdot \pi^2 \cdot N^2} \left(\frac{T^3}{D \cdot \eta} \right)$$

The diffusion is a frequently found phenomenon: with diffusion, the respiratory gas exchange takes place between the air in the alveoli, blood and cellular cytoplasm, the nutritive substances diffuse from the thin intestine into blood and further away in the tissues, the diffusion lays at the basis of the white cells' chemotactism, the olfaction happens when the molecules of the smelling substances spread in the air reach the cells of the olfactory mucosa.

Starting from Fick's first law, we can study the time variation of the concentration at the level of a given section [9]. If the gradient is constant, then through the layer of dx thickness of the section considered each number of molecules equal to the number of molecules which leave the layer towards the less concentrated area enters each second from the more concentrated area, hence the concentration in that layer remains constant. But if the concentration varies closer and closer on the direction x, then in time the concentration in the various layers will also change. For the calculation of this variation in time, we must take into account the fact that the entry speed **dn/dt** of the substance in the analysed layer in the t moment will be equal to:

$$\frac{dn}{dt} = -\text{D.S} \left(\frac{\partial c}{\partial x} \right)_t . \; dx$$

And the exit speed through the opposite side will differ from the first one, due to the variation of the concentration gradient:

$$c - dc = c - \left(\frac{\partial c}{\partial x} \right)_t . \; dx$$

Hence the exit speed will be equal to:

$$\frac{dn'}{dt} = -\text{D.S} \left(\frac{\partial (c - dc)}{\partial x} \right)_t$$

$$\frac{dn'}{dt} = -\text{D.S} \left[\left(\frac{\partial c}{\partial x} \right)_t - \left(\frac{\partial^2 c}{\partial x^2} \right)_t \cdot dx \right]$$

It means that the variation per second of the amount of substance from the layer of **dx** thickness is **(dn-dn')/dt**, and by dividing these values at the **S.dx** volume of the layer gives us the sought concentration variation:

$$\frac{dn - dn'}{S \cdot dx \cdot dt} = \left(\frac{\partial c}{\partial t} \right)_x$$

By replacing the values of **dn/dt**, respectively **dn'/dt** we arrived to Fick's second law:

$$\left(\frac{\partial c}{\partial t} \right)_x = \text{D} . \left(\frac{\partial^2 c}{\partial x^2} \right)_t$$

Which establishes that the variation in time of the concentration in a space is proportional with the variation in space of the concentration gradient in that particular timeframe. This law lays at the basis of determination of the diffusion by measuring the distribution of the concentration in the system after a determined period of time [10].

A particular case of diffusion is dialysis, which consists in the diffusion thought semipermeable membranes of the substances with a molecule smaller than the membranes pores. The dialysis takes place up to the equalising of the concentration in the two parts of the membrane. It is also used in the modern therapy. An example is the artificial kidney whose functioning is based on achieving an extrarenal and extracorporal dialysis which allows the purification of the organism from catabolytes and exo-and endogenous toxins because the depuration could not be performed by the non functional kidney.

Some Observations

The diffusion is according to the general definition-a mass-transport which comes into existence as a consequence of the generalized force; this force can be a concentration gradient, pressure gradient, etc. It is, therefore, all about the flux of the mass for which the principle of the mass conservation is effective. For the description of the diffusion we use the laws of Fick.

The concentration and partial pressure, resp., of the oxygen in the lung is higher than that in the blood, so it arrives in the blood by diffusion. The CO_2-concentration and partial pressure, resp., is higher in the blood-also by diffusion-through the alveolar wall of the lung [11]. Blood up the CO_2. Both phenomena take place also by diffusion. On the basis of the partial pressure of the oxygen in the venous blood we distinguish four cases:

1. The normal physiological state, if $p(O_2)>4$kPa;
2. The pathological state of hypoxy, if 4 kPa>$p(O_2)>3{,}3$ kPa;
3. The threshold value of critical hypoxy (which leads to unconsciousness) if $p(O_2)\sim 2{,}2$ kPa;
4. The lethal threshold, if $p(O_2)<1{,}5$ kPa.

Membranes possess so-called selective permeability. The movement of dissolved mole¬cules across the membrane that it can be passed through by some molecules and by others not, is called permeability. Penetration is the peculiaritiy of the moving material, permeability-on the other hand-is that of the membrane. The active character of the environmental link thus comprises that across the membrane a continuous mas-transport is going on during the life.

In the case of such solutions where the different concentration phases are divided from each other by pellicles, we learn that the molecules of the solvent migrate from the site of lower concentration towards that of higher concentration. This phenomenon is called osmosis. Osmosis is that kind of diffusion when we insert a half permeable film between two sites of different concentration [12].

The total osmotic pressure of the blood plasma on normal body temperature corresponds to 0,77 MPa. The hydrostatic pressure of the blood of capillary level on the arterial site is 4,3 kPa and on the venous site 1,6 kPa, resp.; the colloidal osmotic pressure of the macromolecules is 3,3 kPa; the hydrostatic pressure of the interstitial space varies between 0,13-1,2 kPa; the osmotic pressure of the macromolecules from the interstitial space lies between 13-600 Pa.

In plants, the osmotic value changes according to the species, within one species also according to organs and tissues, even in the same cell according to parts of the day and humidity [13].

The water uptake of plants can be explained by passive mechanisms (swelling, diffusion, osmosis) and by active ones (evaporation, respiration). The water transport in the plants is assured by the root pressure, the suction effects of the leaves and by the cohesion force [14].

The osmotic equilibrium contributes to
✓ Keep pH around the normal value;
✓ Absorption of nutrients from the bowels-through the blood-to the tissues;
✓ Contractility of myocardium;
✓ Migration of ions.

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