Review Article

Open Access

The Biophysical Modeling of Crossing-Effects in Living Organisms

Janos Vincze* and Gabriella Vincze-Tiszay

Health Human International Enviroment Foundation, Budapest, Hungary

ABSTRACT

The transport phenomena mean the variation in time and space of generalized forces when they generate flows for which conservation laws apply. After we describes: mass-, impulse-, energy- and electric-charge-transport and their mathematical characteristic equations. In the living organisms, flows are not generated only by the conjugated generalized forces, but also by the simultaneous action of other forces, so frequencies of the crossing-effects in the human organism. The biophysical modeling offer a „language" of quantitative and qua¬litative process¬sing of expe¬rimental data, being compatible and adequate to the laws of biology.

*Corresponding author

Janos Vincze, Health Human International Enviroment Foundation, Budapest, Hungary. E-mail: ndp@t-online.hu

Introduction

Homeostasis is the ability to maintain the structure and functions of the living organism within optimal limits, on the basis of the adaptive requirements imposed by the surrounding environment [1]. This implies complex control and anticipation mechanisms through which the organism and its constitutive systems autoadjustmets the equilibrium level for the given situation, dynamic equilibrium between the disturbing and compensating factors. Homeostasis is a dynamic process of permanent adaptation (by the transport phenomena), each of its sequences representing a new equilibrium which, in the following sequence, will be at a different level, in accordance with the requirement, between the permissive limits of the systems reactivity.

The modelling method in biophysics consists of the creation of certain devices (models), with which processes analogue with those happening in living organism are studied. The biophysical model though abstract reasoning leads to models of the phenomena which by simpli¬fying and isolating some aspects of the phenomena discover laws and relationships which describe with a certain approximation the behaviour or functioning of bodies or biological ensembles. The biophysical models offer a „language" of quantitative and qua¬litative processing of experimental data, being compatible and adequate to the laws of biology.

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 [2]. This general and strongly scientific definition of the transportation phenomena has two major merits:
- particular forms of transportation can be deducted from

it (mass transport – diffusion; energy transport – thermal conductibility; impulse transport – viscosity; electric charge transport – electric conductibility, crossed effects and other).
- it allows a quantitative characterization of the product exchange, which was impossible based on the previous definitions [3].

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:

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

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 [4]. 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 relation¬ship above we obtain the classical laws which

describe the simple non stationary transportation phenomena.

Transports simple
Diffusion = mass transport
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.

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

These is Fick's first law, the minus sign in Fick's first law indicates the sense of development of the diffusion from the higher concentration towards the lower concentration. 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.
These is Fick's second law.

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

Osmosis = volum transport
The various compartments of the living organisms are separated from one another through membranes with selective permeability. Between two solutions of various concentrations of the same solvent, separated through a membrane impermeable for the solvent, the migration of the solvent takes place from the diluted solution in the concentrated one. This phenomenon is called osmosis. We observe that osmosis is a particular case of diffusion. The necessary pressure for preventing osmosis is called osmotic pressure, whose value is calculated on the van't Hoff's law:

$$\pi = R \cdot T \cdot \frac{c}{M}$$

where: **c/M** – number of solvate molls; **R** – universal gas constant, **T** – absolute temperature [5]. In the case of osmosis, the generalized force is the pressure gradient, which generates a volume flow. The characteristic parameter of the process is the osmotic pressure (π). By making the necessary replacements in the general equation of the transport processes, we obtain the relation:

$$\pi = \frac{R.T}{M} \cdot c + \frac{R.T}{V_1 \cdot \rho^2}(0,5 - \tau) \cdot c^2 + \frac{R.T}{V \cdot \rho^3_1} \cdot c^3 + \cdots$$

When the two solutions of various concentrations ($c_1 < c_2$) are separated through a membrane permeable only for the solvent, this will cross the membrane towards the most concentrated solution, until a difference of hydrostatic pressure equal to osmotic pressure $\pi = p$ appears. In this case the system itself performed an osmotic mechanical work (**L**), whose expression can be deduced in the following mode:

$$L = \int_{p_0}^{p_0 + \pi} p \, dV$$

Viscosity = impulsive transport
The viscosity is a fluid and gas property determined by the internal rub which starts in the fluid's mass as a consequence of the movement of the layers which move away from one another with different speeds. Due to the cohesion forces, the reciprocal sliding of the layers of liquids produces an internal resistance, at a rubbing force called viscosity. For the viscosity is valuable the Newton's law:

$$\mathbf{F} = - \boldsymbol{\eta} \, \frac{dv}{dx} \, \Delta S$$

where η is the viscosity coefficient.
Newton's 2nd law is obtained by making a similar deduction as in the case of Fick's 2nd law for the case of viscosity, from the general equation we obtain:

$$\left(\frac{\partial v}{\partial t} \right)_x = \eta \cdot \left(\frac{\partial^2 v}{\partial x^2} \right)_t$$

Which we will call Newton's 2nd and it also applies in the case of non stationary conditions on viscosity.

Thermal conductibility = energy transport
By replacing in the general relation the generalized force with the temperature gradient dT/dx, the constant K with $-\chi$, where χ is the thermal conductibility coefficient, through differentiations, we can deduct Fourier's law:

$$\Delta Q = - \chi \cdot \frac{dT}{dx} \cdot \mathbf{dS} \cdot \mathbf{dt}$$

where: ΔQ – the amount of energy to be transported; dS – the surface through which the transportation takes place; dt – transportation time [6].

Fourier's 2nd law is obtained by making a similar deduction as in the case of Fick's second law, for the thermal conductibility, from the general equation we obtain:

$$\left(\frac{\partial T}{\partial t} \right)_x = \chi \cdot \left(\frac{\partial^2 T}{\partial x^2} \right)_t$$

Which we will call Fourier's 2nd law and it applie in the case of non stationary conditions on the thermal conductibility.

Electric conductibility = electric charge transport
By replacing in the general force with the electric potential gradient dU/dx, the constant K is the electric conductibility coefficient and by subtraction we can deduce Ohm's law:

$$dQ = - K \cdot \frac{dU}{dx} \cdot dS \cdot dt$$

Where: dQ – electrical charge; K – electric conductibility coefficient; dU – is the electric potential; dx – the pathway difference; dS – the surface that the transportation takes place through; **dt** – time frame.

Ohm's second law is obtained by making a similar deduction as in the case of Fick's second law. For the case of electric conductibility, from the general equation we will obtain:

$$\left(\frac{\partial U}{\partial t} \right)_x = K \cdot \left(\frac{\partial^2 U}{\partial x^2} \right)_t$$

which we will call Ohm's 2nd law and it applies in the case of non stationary conditions on the electric conductibility.

Crossing-effects

The biophysical models of crossed effects have not been elaborated too rigorously (detailed), this being the cause for which in the description of the processes found in the living organisms, there are bigger discrepancies between models and reality [7].

The biophysical processes which actually characterize the biological systems can be better described by knowing the coupled transport processes. In these systems the flows are not independent from one another, but they influence one another. Hence, in the living organisms, flows are not generated only by the conjugated generalized forces, but also by the simultaneous action of other forces. Generally in the system there are as many flows as generalized forces and each force partially participated at the generation of each flow, so the simple types of the transport processes interfere with one another. It is extremely important the fact that the coupled transport systems can be reduced to the interconnected effect of the crossed effects [8].

In most of the biological systems, more gradients act in general. For examples, in the case of the electrolytes, the concentration and the potential gradient cam function all the same. Several flows can coexists simultaneously. A certain type of flow is determined not only by the corresponding gradient, but basically it can be influenced by any force. In a simpler case, when there are two flows and two corresponding gradients, then, except for simpler transport phenomena, there are interactions between the existing flows and forces, namely the so called crossed effects.

Thermo diffusion is the most typical crossed effect between the non equilibrium thermodynamic processes. Under the influence of a permanent temperature difference, in a gas mixture or solution, there is a separation of the components or a concentration difference. As a consequence of the temperature gradient a mass transport takes place, which is nothing else but the transfer of caloric energy through convection.

The crossed effects in which gradient act and reciprocally interconnect flows form pairs of reverse effects.
In the following paragraphs we briefly explain those above through the effect dealt with in the previous paragraphs.
1. Seebeck effect – Peltier effect (under the influence of a temperature difference there is an electric current and vice versa).
2. L. Soret effect – Dufour effect (the temperature difference produces the modification of the concentration and vice versa).
3. Thermal mechanical effect – mechanical caloric effect (in an osmometer containing a semi-permeable membrane a water current starts from the warmer area to the colder one, producing a difference of hydrostatic difference and the other way around).

The couples of crossed effects are included in table.
We must underline the fact that the flow produced through the difference of hydrostatic pressure is not considered a real transport phenomenon; this is why the crossed effects they participate in are not real crossed effects. The hydrostatic pressure difference produces a volume flow for which no conservation law is valid, hence it is not a real transport phenomenon.

Moreover, in the solution we cannot talk about their hydrostatic pressure and the gas, without a constant liquid volume, respects other laws. But since the liquids' hydrostatic pressure has a

remarkable importance, we considered it useful to include this phenomenon in the discussion of the transport phenomena.

The frequency with which we find different types of reverse effects shows great variations [9]. In table 1. we denoted with * the very frequent pairs which lie at the basis of a lot of physiological processes, the action potential, absorption, substance transport in blood from the interstitial liquid and from here in the cells, secretion, breath, hence they lie at the basis of most of the metabolic processes.

Table 1: Crossing-effects with their frequencies

Pairs	Crossing-effect	Fluxus	Gradients	Frequencies
$\Delta T \Leftrightarrow \Delta\varphi$	term.electric Peltier-effect	electric charge term.energy	ΔT $\Delta\varphi$	* * *
$\Delta T \Leftrightarrow \Delta c$	term.diffusion Dufour-effect	mass term.energy	ΔT Δc	* *
$\Delta T \Leftrightarrow \Delta P$	term. osmose mech.cal. effect	volume term.energy	ΔT ΔP	* *
$\Delta c \Leftrightarrow \Delta P$	osmose diffus. reversing-curr.	volume mass	Δc ΔP	*
$\Delta\varphi \Leftrightarrow \Delta P$	electric osmose inverse effect	volune electric. charge	$\Delta\varphi$ ΔP	* *
$\Delta\varphi \Leftrightarrow \Delta P$	electrophoresis diffusion potential	mass electric charge	$\Delta\varphi$ Δc	*
$\Delta v \Leftrightarrow \Delta c$	Einstein- elation Jones-Dole-law	mass impulse	Δv Δc	*
$\Delta T \Leftrightarrow \Delta v$	viscoz. from temp. inverse effect	impulse term. energy	ΔT Δv	* *
$\Delta\varphi \Leftrightarrow \Delta v$	viscoz. of electrolyte inverse effect	impulse electric charge	$\Delta\varphi$ Δv	* * *
$\Delta P \Leftrightarrow \Delta v$	viscoz. from pressure inverse effect	impulse volume	ΔP Δv	* *

References

1. Hoppe W, Lohmann W, Markl H, Ziegler H (1983) Biophysics. Springer-Verlag, Berlin.
2. Vincze J (2001) The Transport Phenomena and Cross-effects in the Living Systems. NDP P., Budapest.
3. Vincze J (2020) Biophysics of the Apparatuses. NDP P. Budapest.
4. Vincze J (2018) Medical Biophysics. NDP P., Budapest.
5. Kedem O, Katchalsky A (1963) Mechanism of Active Transport. Trans. Faraday Soc 59:1918–1930.
6. Adinarayana G, Sambasivarao G, Supriya K (2019) Numerical study of effective thermal condutivities. Inter. J. Current Advan. Res 10: 9518-9521.
7. Sarson E, Cobelli C (2014) Modelling Methodology for Physiology and Medicine. Elsevier.
8. Vincze J (2020) The Biophysical Modeling of the Apparatuses in the Human Organism. Lambert Academic Publishing, Berlin.
9. Vincze J (1984) The Cross-effect in the Living Systems. Med. P. Budapest.