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Characterization of Transport Phenomena in Living Systems

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Abstract

Metabolism, as the most important physiological process or transport phenomenom in its reality. During dissimilation the living systems liberate energy, which is then used for the maintenance of different functions; assimilation, contraction, maintenance of the electric potential. The simple transportation phenomena were discussed from different points of view according to the classical physics and this hindered somewhat formation of a unified viewpoint. Let us consider the transport phenomena and let us try to define them, scientifically well grounded and embraces all those phenomena, which has been discussed in this group in biophysics. This general definition of the transport processes makes possible quantitative characterization of the effected changes, which had been an impossible requirement before. However, in biological systems there are essential differences between the course of the simplest transport processes and those of the theoretical models described by physic-chemical equations. Many physiological phenomena are based on these inverse effect-pairs

Keywords: Transport Phenomena, Definition, Inverse Effect-Pairs

Introduction

When investigating the concept of structure, we may not abstract of its functional character, as they are mutually dependent of each other, and the living matter presents itself through its functions. The existence of the living matter may manifest itself within only such structure-possibilities, which functionally support the survival of a biological movement-form. The two basic functions, which make possible the survival of living matter i.e. the life-functions are; the energy release processes and the biosynthesis i.e. the metabolism. Use of the concept of metabolisms covers that mass-energy – and impulse transports take place between the organisms and the environment [1].

Metabolism, as the most important physiological process or transport phenomenom in its reality. Metabolism as such consists of simultaneous and parallel and mutually strictly interdependent and opposing direction processes; processes of building character (assimilation or anabolism as well as of destruction character (dissimilation or catabolism).

Assimilation is a comprehensive concept of all these metabolic processes in the living organism during which the substances taken up by the organism (CO_2, minerals, H_2O, floral- and fauna food staffs) and after corresponding transformations they are incorporated into the living matter. As a result of these processes partly the destroyed components of the living matter are substituted following the destruction processes and partly the living matter stock is increasing [2].

The large molecules built up during assimilation serve as energy reserves. Dissimilation, however, is the sum of the destructive processes of the living organism. The food substances getting into the organism, will be gradually decomposed by the help of enzymes and the intermediately liberated energy will be stored in chemical bonds from which it can be easily mobilized or in the moment of the liberation of the energy it will be transduced into others compounds with suitable enzyme systems. During catabolism or oxidation of the food substances the free energy is decreased within the organism, i.e. energy producing processes take place [3].

During dissimilation the living systems liberate energy, which is then used for the maintenance of different functions; assimilation, contraction, maintenance of the electric potential. Transportation is the process, which is made in every system and it consumes 80% of its energy available. The system takes up food from its environment, it conveys to its cells after conversion and what it needs not any more it excretes into its surrounding. The so many transport functions are examples of the magic circle of the life processes (Kedem-Essig 1965).

During the past few years that branch of biophysics has developed speedily, which deals with the transport phenomena. This is evident also from the fact that in the last times symposia were sacrificed solely for this topic. The revelation of the mechanism of transport processes is not an easy task, it is multilateral and it is seemingly endless. The transport phenomenon is complex;

therefore, it is difficult to elucidate corresponding theory because it requires serious knowledge in physics, biology, chemistry, medicine and mathematics.

The simple transport processes had already been described with mathematical formula but their use in relation to the living organisms became possible only at the beginning of the 20th century with the scientific foundation of physiology. From the data of the first four decades it became clear that transport phenomena in the living organisms essentially may deviate from the simple physical processes, therefore, additional conditions became necessary for the concrete solutions. The mathematical apparatus although it increased steadily, the results remained behind the requirements. The simple transportation phenomena were discussed from different points of view according to the classical physics and this hindered somewhat formation of a unified viewpoint.

In the years fifteen, by the biological membrane's researches, the importance of the transport-processes also increased by leaps and bounds predominantly according to biophysical and bioenergetical aspects. Application of the thermodynamics of the irreversible processes to describe transport processes acting in living organisms brought significant results: it made possible introduction of the phenomenological discussion and unification of the simple transport phenomena into a unified theory (Vincze 1978). This was the level that was reached by the transport researches around 1970.

The results of the last decade may be characterized rather by a mark no headway as well as the boarder lines of recognition of the formally successful researches. Today it is already clear that the phenomenological mode of discussion bring no new essentials (Bass et al. 1986). The more and more exact determination of the fluxes of the transport phenomena just increased the differences between the theoretical and the experimental values. In the clarification of the mechanisms of the transportations it was necessary to obligatory return to the pores (ionic channels) at a higher-level definition [4-6].

General Definition

Let us consider the transport phenomena and let us try to define them, scientifically well grounded and embraces all those phenomena, which has been discussed in this group in biophysics.

Transport phenomena are time and space changes of the „general forces" when they produce such fluxes to which the conservation laws remain valid [7].

This general and scientifically exact definition of the transport phenomena comprises all those phenomena, which belong to this group. One may deduce from this mass transport (diffusion), energy transport (thermic conductivity), impulse transport (internal fiction), electric charge transport (electric conductivity) phenomena, the cross-effects and other transport phenomena as well [8].

This general definition of the transport processes makes possible quantitative characterization of the effected changes, which had been an impossible requirement before. If we consider **W** – as the amount of the transported parameter; **K** – a qualitatively dependent constant of the type of the transport and the parameter; **dS** – as the surface through which transport occurs; **dt** – as time duration of the transport process; **grad a** – as the generalized force, then the following function gives the amount of the transported parameter (flux):

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

Obviously, the law of conservation is valid for W flux. If the transport process takes place only unidirectional, toward one distinct direction of the space, then we receive:

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

The differential form is the following:

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

and from this equation one may receive the classical laws of the particular transport phenomena [9].

However, in biological systems there are essential differences between the course of the simplest transport processes and those of the theoretical models described by physic-chemical equations. The connection between the viscosity of the plasma and the hyperlipemic state is regulated by a very complex physiological mechanism. But in a first approach the process occurring in the living organism can be a characterized fairly well with the simple types of the transport processes.

The pinpoints of the transport processes are liquid mobilization, water transport, formation of the action potential and its propagation. The experimental researcher of this field emphasized the role of the cross-effect within the living organism. Vincze (1974) results are very interesting in relation of thermoosmosis. Cross-effects are well known from physics; e.g. electricity is generated from thermal differences, but biological applications were not taken into consideration. Study of a flux-change as a consequence of the effect of a non-adherent generalized force raised many questions to which adequate theoretical logical explanation is missing (Eisinger-Halperin 1986) [10].

Inverse Effect-Pairs

In most biological systems, in general not only one but many gradients are effective. E.g. in electrolytes electric and concentration gradients are in function. In different systems many streaming may exist simultaneously. A single flux-type, in theory, not only a gradient belonging to it, but any kind of „force" may influence it. In such simple case when two fluxes and the related gradients exist, then besides the simple transport processes the non-related fluxes may develop together with connections between the forces, the so called cross-effects. Those cross-effects at which the gradients influence the mutually related fluxes we denominate inverse effect-pairs [11].

Many physiological phenomena are based on these inverse effect-pairs: action potential absorption, matter streaming from the blood to the interstitial medium and further on into the cells, respiration, excretion, i.e. most part of the metabolic processes. Frequency of the inverse effect-pairs is very much different.

Below we give some examples:

1. Seebeck effect ↔ Peltier effect (as an effect of the temperature difference charge current may develop a vice versa);
2. L.Soret effect ↔ Dufour effect (as a consequence of the temperature difference concentration difference may develop a vice versa);
3. Thermomechanical effect ↔ mechanocaloric effect (in a semi¬permeable membrane ozmometer water is streaming from the warmer place to the cooler one, and in this way hydrostatic pressure difference may be produced et vice versa).

At the present level of the researches in medicine and in biology the theories show about 90% agreement. This was the reason why we regarded a basic aim of ours the discussion of the cross effects. Their physiological models are not well elaborated and in these cases the disagreements are very striking [12]. In physics the inverse effect pairs are symmetric but at the same time one of the components of the pairs occurs more often. Taking into consideration of cross effects represents a second level of approach for better understanding of the details of the biological phenomena at the expense of larger differences between theory and experiments.

The physiological processes, better characterizing the biological systems, can be mostly approached by the linked transport processes. In such systems the fluxes are not indifferent of each other. Therefore, the fluxes in the organism may be created not only by their own conjugated "generalized forces" but also by other simultaneous driving forces. In general, as many generalized forces are present in a system so many fluxes come about, and every force takes part in every flux, therefore, the simple transport phenomena interfere with each other. It has a great importance that the connected transport phenomena can be reduced to the internetic system of the cross effects [13].

Research of the cross-effects received unexpected push – from theoretical point of view - from the possibilities of the solutions of the phenomenological equations characteristic for certain systems. The conductivity coefficients characterized by a determinant can be resolved to the sum of the mutual actions of cross-effects and simple transport phenomena. This means that the joint transport phenomena can be discussed internetically as cross-effects. This seems to be adequate driving force for the successful discussion of the transport phenomena in the near future [14].

Another possible way of analysis of the transport phenomena is the cybernetics. This makes possible interdisciplinary conception and it takes into account in a given system the input-output informations caused by the fluxes, as well as it tends to clarify the mechanisms of the fluxes generating forces [15]. This mode of view is widely accepted in the research of modeling physiological processes and many people use it successfully, so there is a scope for it in the future [16].

The molecular biophysical concept makes possible better association of the biophysical and the cybernetic modeling by cross-effects as opposed to the thermodynamic concept.

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