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Research Article

A new theoretical basis for description of living matter

Abstract

In the context of environmental pollution, it is of prime importance to study the organism's overall response to harmful environments. This could be carried out if there were suitable dynamic variables, describing the state of a living system. In this respect, a new approach to life phenomena is needed because in phenomenological aspect, the biological objects in their entirety could be not adequately described in the terms of other science fields. The main features of the living system are its integrity and selfregulation. Energy dissipation runs in the living systems but there the more substantial property is the increase of the energy worth. Here a new theoretical basis and new science field, *biodynamics*, is suggested. A new state variable *vitality* as integral characteristic of a biological object is stated. It is impossible to deduce the macro-characteristics of a living system based on the processes on molecular level. Vitality could be a phenomenological characteristic uniquely determining the status of the living object. Quantities *biological energy* and *synergy* are introduced. The synergy is assumed as a measure of selfregulation quality. Biological principle for maximum synergy is stated. The conception proposed is illustrated on the case of recovery process of some biological object after some transitory disturbance. Based on variational principle of Hamilton type an equation describing the recovery process is obtained. If a quantity as vitality could be measured this could provide a great benefit for biology, medicine, and ecology.

Introduction

The problem of the environmental pollution has three main aspects: 1) study of the changes in the abiogenic factors (such as soil, water, and air); 2) study of the degrees of contamination in the living objects; and 3) organization of new technologies, diminishing hazard.

The scope of our work is related to possibility of a more rational exploration of the organism's reactions to different disturbances (particularly contaminations) via an effective assessment of the organism's overall response. The pollution load in an organism could be estimated through investigation of genetic, hematological and physiological parameters. No method exists, however, to assess the overall response of the organism to whatever factor.

The intrinsic phenomena for all biological objects (BOs): selfsaving, adaptation and reproduction exist due to the integrity, selfregulation, and maintenance of the energy worth in BO. These are characteristics for living matter only.

Each fundamental science field has own theoretical basis, including respective quantities and laws. So, the basic quantity in classic dynamics is *mass*; in electrodynamics – *charge*, *field intensity*; in chromodynamics – *colour charge*; in thermodynamics – *temperature*; in chemistry – *chemical affinity*. In biology there is no intrinsic quantity for a quantitative description.

The eminent physicist Niels Bohr perceived that the biological laws are nature laws complementary to those describing the inanimate bodies [1,2].

Some authors [3-8], have discussed interesting phenomena.

Really, particular processes in the living systems have been satisfactorily presented in the terms of mechanics, hydrodynamics, electrodynamics. As far as the life is based on biochemical reactions, many attempts have been made to describe the cell metabolism in the terms of thermodynamics. However, the metabolism is a highly organized complex of biochemical and biophysical processes, running much far from thermodynamic equilibrium. Shrödinger [9], pronounced the idea that the living organisms consume negative entropy (negentropy). Goodwin [10], created a biological statistical mechanics and thermodynamics based on kinetics of synchronized biochemical oscillators. Rosen [11], formulated optimal principles in biology. Szent-Györgyi [12], elucidated some mechanisms of cell regulation in the terms of bioelectronics. Nicolis and Prigogine [13], developed theory of dissipative structures, as an extended irreversible thermodynamics, to explain the self-organization processes in nonequilibrium systems. Davidov [14], gave a quantum-mechanical interpretation of some biological phenomena. Thermodynamic approach was applied to the structure and functions of macromolecules [15]. Thermodynamics combined with description of molecular machines was proposed [16]. Also interesting investigations about the molecular machines were made [17].

The importance of these studies, however, does not abolish the need of general phenomenological approach to living systems on an adequate theoretical basis, considering BO in its entirety. Phenomena as thermal conductivity, diffusion, electric current etc. were not describable in the terms of mechanics, and thus thermodynamics and electrodynamics were found. In the framework of thermodynamics, it is not possible to underline the most specific features of life. All attempts to construct an extended thermodynamics of irreversible processes, including living matter, remain artificial and not adequate. Blümenfeld [18], noted that the true way to a general life theory is not a biological thermodynamics.

Many authors have tried to explain some life phenomena using the concept for decisive role of information in living systems. Quastler [19], represented the problems of the emergence of biological organization based on biological aspect of information. Eigen [20], explained the evolution of macromolecular structures taking into account the laws of information exchange. Volkenstein [21], considered life evolution in its informational aspect. Sheldrake developing the morphogenetic field theory claimed that the standard information theory is appropriate for quantitative study of the transmission of nerve impulses and patrimonial DNA transmissions, but is not relevant to biological morphogenesis.

The processes of control and biological selfregulation are regarded in details in cybernetic aspect. Our point of view is, however, that the biological selfregulation should be an object also of biophysics. It is of importance to found a theory of life extending the theoretical basis of physics. Up to now no dynamic theory is created, considering the living organism as a whole system with specific laws on system level.

Waterman [22,23], noted that several biological processes could be explained on the basis of physical and chemical laws.

However, the living organisms have peculiarities non-known in the inanimate nature and the definitive scientific explanation of life required a new scientific basis – with new variables and new laws; a theoretical basis specific for the biology. The biological phenomena are based on the principles of adaptation, development, heredity, evolution.

The quantity "temperature" was introduced to describe the state of a many-particles system, non-describable in mechanics. The living system is really a thermodynamic system but the thermodynamic laws are not determining for the essence of life. To describe adequately BO, specific quantities are needed. Therefore, we need a phenomenological, macroscopic theory of living systems dealing with their overall behavior under different environmental and other influences, and diseases.

The novelty of this manuscript is the suggestion of a new view and new possible apparatus for the description of living matter. Here the principal idea is that the living organism should be described *in its entirety*. Naturally, the study of separate processes has its significance. But it is also important to study the overall response of an intact organism to different influences. Thus, we are considering here such a problem. We could name a new science field in biology: biodynamics.

Theoretical basis

For simplicity, here we introduce only one quantity as integral characteristics of BO on macroscopic level. We call it "vitality". Thus, the basic quantity in biodynamics is *vitality* (V). The quantity V determines uniquely the state of a given BO. The respective measurement unit of the vitality in SI system we call *bion* (b).

Of course new type of measurements is needed. The quantity "temperature" in thermodynamics is measured via the device "thermometer". In biodynamics "vitalimeter" should be constructed, which could measure, for instance, the length of some electromagnetic BO emission, appearing integral characteristic of BO status. Electromagnetic waves of different frequencies, generated by human, animal and plant organisms in their metabolic activity and selfregulation were measured yet many years ago [24]. The explorations in this way were continued [25]. The advanced technologies today promise success in a searching of a new device and the author is optimist in this respect. Such apparatus could be calibrated in a manner to show V in bions. For instance, one bion may be defined so that the excellent health standard in human would correspond to vitality of 100 bions. Further on we are going to present the matter under the presumption that the quantity vitality V could be measured.

We introduce also the quantity *optimal vitality* (W). That is the value of the vitality, corresponding to state of excellent health of BO. Obviously W depends on the homeostasis characteristics, evolutionarily established for a given species. The value W is assumed as genetically determined. During the life W decreases due to aging processes increasing the entropy of BO. However, in time intervals much shorter compared to lifespan W may be considered as a constant.

Here we illustrate our conception on the particular case of BO recovery process after some disturbance (for instance: environmental influence, intoxication, acute disease, trauma etc.) within a time interval much shorter than BO lifespan. After such transitory disturbance the vitality V of BO temporarily deflects from W. The BO information potential switches the feedback control to restore the physiological homeostasis and a transient process $V \rightarrow W$ starts. That is *recovery process*.

We introduce the concept *biological energy* (B). This is the energy involved in the processes of selfregulation (on the basis of enzyme synthesis, resonance energy transfer between biological macromolecules, electric charge transfer, immune

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cell and antibodies production, DNA repair etc.) and in the maintenance of biological structures in the living system. What is the place of such kind of energy in the global energy balance in a given BO?

The total energy E of a natural system is sum of the mechanical energy E_M, and internal energy E_I [26]:

$$E = E_M + E_I$$

The balance of the internal energy may be present in the form: [27,28]:

$$dE_I = TdS - pd\upsilon - \sum_r A_r d\xi_r + \sum_k \mu_k dn_k^e$$

The internal energy E_I reflects the energy of a large number of particles (atoms, molecule etc.). The temperature T is the measure of the particles' kinetic energy. The sense of this expression is that the internal energy E_I increases at the expense of the heat quantity $Q = TdS$ and external substances n_k^e, going into the system, and decreases at the expense of the work (mechanical $pd\upsilon$, chemical $\sum_r A_r d\xi_r$ etc.) performed by the system. In the living systems, however, many chemical reactions lead to building of macromolecules with important structural and physiological functions, to adenosine-3-phosphate (ATP) synthesis. ATP is the energy "power-station" of the living cell. These syntheses are ensured by the biochemical energy of the catabolic processes. The first law of thermodynamics presents the energy balance in the system. The second law of thermodynamics indicates the irreversibility of all real processes because of energy dissipation and entropy increase. The living systems obey to the thermodynamics laws; nevertheless, their most essential feature is not the entropy increase. It is the organization increase. In the growth, development, recovery and training process the inner organization in BO increases. In BOs not only energy devaluation is realized but also an increasing of the energy worth, involved in biological structures and ATP, takes place. An introducing of concept as "negentropy" is not the most suitable way to describe adequately the life. This concept presumes to stay in the terms of thermodynamics.

The biological energy B should be a part of the internal energy of a BO:

$$dE_I = TdS - pd\upsilon - \sum_r A_r d\xi_r + \sum_k \mu_k dn_k^e + dB$$

B is an energy related to the information program encoded in the living system. In some sense it could be determined as structural energy. Naturally, B is ensured by the biochemical energy stored in the form of macroergic chemical bonds of ATP. B should be a function of $V(t)$ and $\dot{V}(t)$, where $\dot{V}$ is the rate of vitality change in time:

$$B = B(V, \dot{V}) \quad (1)$$

We introduce also the function *synergy* $G(V)$, uniquely determining the state of a given BO:

$$dG(V) = \frac{dB(V)}{V} \quad (2)$$

G reflects the degree of coordination and synchronization of the regulatory links, and the structural and functional order in BO, i. e. G reflects the BO integrity. It could be an indicator of BO health and youth. G increases, i. e. $dG > 0$, in organism growth as well as in recovery and training processes. In aging processes, in severe and chronic diseases G decreases, i. e. $dG < 0$. In mature, healthy BO the synergy G is almost constant i. e. $dG = 0$.

The following equation for the balance of biological energy B could be written:

$$dB = dU + dZ - dR \quad (3)$$

Here

$$U = U_W + U_V \quad (4)$$

is the *genome energy*; U_W is *potential genome energy* and U_V is *recovery energy*.

U_W = const is characteristic for a given species. The recovery energy U_V, should be proportional to the difference $W - V(t)$, i. e. $U_V = K(W - V)$. U_V should be positive function and the simplest such expression is the positive determined quadratic form:

$$U_V = \frac{1}{2} K (W - V)^2 \quad (5)$$

K ($[K] = [\mathrm{kg\,m^2 b^{-2} s^{-2}}]$) is the *genome inductivity*, representing the feedback control strength. U has minimum at $V(t) = W$, when $U = U_W$.

We assume that the *power of immune response* P, expressed on phenomenological level, should be proportional to the rate of change of the vitality, i. e. $P = M\dot{V}$, where M ($[M] = [\mathrm{kg\,m^2 b^{-2} s^{-1}}]$) is *immune memory impulse*. To be a positive function P should be constructed as follows:

$$P = M\dot{V}^2 \quad (6)$$

The immune response has a cumulative effect. The state of a BO at a given moment depends not on the immune synthesis at that moment but on the summary effect of immune response in all prior moments. Therefore the *immune reaction energy* Z in recovery process should have the form:

$$Z(t) = \int_{t_0}^{t} P(\tau) d\tau = \int_{t_0}^{t} M\dot{V}(\tau)^2 d\tau \quad (7)$$

Because BO behavior is considered on phenomenological level, we are interested in the total effect of immune response and do not differentiate cell and humoral immunity.

During the recovery process the biological energy B decreases in some extent at the expense of the energy R, spent for surmounting of the *metabolic "resistance"* due to waste products of metabolism (non-fully oxidized substances, macromolecules damaged by free radicals etc.) and toxicants (heavy metals, bacterial and virus toxins etc.) occurring in the cell and decreasing the efficiency of the metabolic processes and hence of the selfregulation. It is reasonable to define R as follows:

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$$R = \frac{1}{2} A\dot{V}^2 \qquad (8)$$

where A ([A] = [kg m² b⁻²]) is *resistance coefficient*.

The time derivative of G in (2) taking into account (3) and (4) could be written in the form:

$$\dot{G} = \frac{\dot{B}}{V} = \frac{\dot{U}_V + \dot{Z} - \dot{R}}{V} \qquad (9)$$

Taking into account (5), (7) and (8) one obtains from (9):

$$V\dot{G} = [-K(W-V) + M\dot{V} - A\ddot{V}]\dot{V} = \Phi\dot{V} \qquad (10)$$

The quantity

$$\Phi_U = -K(W-V) \qquad (11)$$

is *biological force of feedback control*;

$$\Phi_Z = M\dot{V} \qquad (12)$$

is *biological force of immune reactivity*;

$$\Phi_R = A\ddot{V} \qquad (13)$$

is *biological force of metabolic resistance.*

$$\Phi = \Phi_U + \Phi_Z - \Phi_R \qquad (14)$$

is *biological recovery force.*

Their dimension is: $[\Phi_U] = [\Phi_Z] = [\Phi_R] = [\Phi] = [kg\ m^2 b^{-1} s^{-2}]$.

We postulate the following principle in biological systems:

$$G(W) = \max G(V) \qquad (15)$$

It means that the synergy of BO in its normal, undisturbed state has maximum. $G(W)$ corresponds to excellent health.

After disturbance BO goes to recovery, to irreversible damage, or to death:

1) Recovery: $dV > 0$, $V\uparrow$; then it follows from (15), (10) and (14) that

$$dG > 0, \quad G(V) \to G(W) \text{ and } \Phi_U + \Phi_Z - \Phi_R > 0$$

2) Destruction: $dV < 0$, $V\downarrow$; then we have:

$$dG < 0, \quad G(V) \to G(V_{unstable}) \text{ and}$$

$$\Phi_U + \Phi_Z - \Phi_R > 0 \text{ but } \Phi < \Phi_{crucial}$$

3) Death: $V = 0$; therefore $\dot{V} = 0$ and from (10) it follows:

$$G = 0 \text{ and } \Phi = 0$$

In training processes in the living organism with followed improvement of the vital parameters and health: $dW > 0$ and $W \to W^*$, where $W^* > W$; then:

$$dG > 0, \quad G(V) \to G(W^*)$$

This means that in a training process the optimal vitality increases due to the genetically in being reserve determined by the potential genome energy U_W. The synergy of such an organism increases respectively.

One of the most profound concepts in theoretical physics is that the equations of motion in different fields can be obtained based of integral variational principles. The variational principle of Hamilton allows a common treatment of dynamic problems in mechanics, electrodynamics, optics, thermodynamics, quantum mechanics etc. By means of appropriately chosen Lagrangeans the basic equations in physics can be introduced. This approach has a great heuristic concern. The presence of variational principles in all fields of physics clearly shows that a basic nature law exists. This promises validity of a variational principle of Hamilton type in fields, where there are no other approaches to some problems.

We propose the following integral principle:

$$\Gamma = \int_{t_0}^{T} (U + Z - R)dt = \max \qquad (16)$$

choosing the Lagrangean: $L = L(V(t), \dot{V}(t), t) = U + Z - R$,

where U, Z and R are determined by the equations (4), (5), (7) and (8).

After variation of (16)

$$\Gamma'(\varepsilon)\big|_{\varepsilon=0} = 0 \qquad (17)$$

where ε is an arbitrary parameter, the biodynamic equation is obtained:

$$\ddot{V} + \frac{2M}{A - 2M(T-t)}\dot{V} + \frac{K}{A - 2M(T-t)}V = \frac{KM}{A - 2M(T-t)} \qquad (18)$$

under initial conditions:

$$V(t_0) = V_0 \quad \text{and} \quad \dot{V}(t_0) = \dot{V}_0 \qquad (19)$$

V_0 is the state of the disturbed BO from where the recovery process starts and $\dot{V}_0$ is the start rate of time change of V. T is the time period of the recovery process. Equation (18) has physical sense and aperiodic solution under the conditions:

$$A > 2MT \qquad (20)$$

$$M^2 > K(A - 2MT) \qquad (21)$$

It is clear from (20) that the recovery period T is so much longer as higher is the contamination of the organism expressed by the coefficient A. When the immune memory impulse M has a higher value, T is shorter. If (21) is not valid and $K > \frac{M^2}{A - 2MT}$ (that could be a situation most often in younger organisms) an over-shoot time course of the recovery process takes place. However, in such case the following condition should be satisfied:

$$\frac{M^2}{A - 2MT} < K < K_{crucial} \qquad (22)$$

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At $K > K_{crucial}$ an over-regulation takes place, an oscillatory regime is generated and BO fails in unstable regime.

Many targeted investigations and empirical data are needed to determine the real value of *W* for different species and different ages. If *T* and one of the parameters *K*, *M*, and *A* were known the areas of the two others parameters could be determined using (20) and (21). When all constants were known the BO state might be calculated at each moment and the recovery course would be predicted.

In Figure 1 two possible time courses of recovery processes are presented at different values of the parameters. The experimentally measurements of many biological characteristics (changes in metabolite concentrations, biopotentials etc.) often indicate very similar time courses. The curves displayed in Figure 1 are numerical solutions of equation (18).

Conclusion

The proposed theoretical approach presuming development of a new science field, biodynamics, is of great theoretical importance. The biological selfregulation and integrity provide a new quality of matter. It is quite reasonable to evaluate the state of living systems in terms of a specific energy form. It is impossible to deduce the macro-characteristics of a living system based on the processes on molecular level because of invincible mathematical difficulties. The health of BO essentially depends on selfregulation quality and BO status should be assessed via adequate quantities. Thus, biodynamics as a phenomenological field could be a substantial step to a more profound study of living matter.

Although the work is heuristic at this stage, a further development of the idea here proposed is quite realistic. Biodynamics will be also very important for practical purposes as a new step in exploration of living systems in the context of several disturbances and environmental changes, such as global change and environmental pollution. Designing of a new device that will measure quantity "vitality" would revolutionize biology and medicine. It could provide a quick and easy assessment of the health status of BO, particularly human, would allow the study of the organism's overall response to harmful environments and provide prognosis of the recovery processes. The optimal vitality *W* at respective age, and synergy *G* could be added as important integral biomarkers in patient's files alongside the other data.

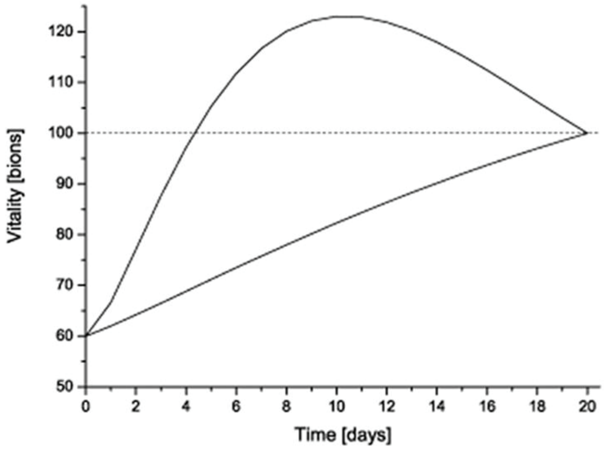

Figure 1: Time courses of the quantity vitality *V* during recovery processes. In exemplification a recovery period *T* = 20 days and a value of 100 bions for the optimal vitality *W* were chosen. The initial conditions were supposed V_0 = 60 b and $\dot{V}_0$ = 1.8 b/day. The displayed curves were calculated at two sets of different values of the characteristic constants: *A* = 9, *M* = 0.2, *K* = 0.03; *A* = 8, *M* = 0.19, *K* = 0.18 (the over-shoot curve).

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