Evolution of Optimal Vitality during a Lifespan

SVETLA E. TEODOROVA

Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences,
72 Tzarigradsko chaussee, 1784 Sofia, Bulgaria
seteodor@tea.bg

Abstract: - Until to now, the biological processes have been studied using theoretical concepts borrowed from the field of physics. The present paper suggests that it will be advantageous for biology to deal with its own theoretical basis regarding the description of several dynamic processes related to recovery from unfavorable influences as well as changes of life quality during the lifespan. It is impossible to deduce the macro-characteristics of a living system from the processes on molecular level because of overwhelming mathematical difficulties. There will be a great advantage if the state of a living system could be assessed via prompt and simple measurement. Here new variables: vitality, optimal vitality, biological energy, and synergy are introduced as integral phenomenological characteristics, which could uniquely determine the status of biological objects. An idea for new science field, biodynamics, is proposed. Vitality could be measured via new device. Such one does not exist for the present but in principle, it could be constructed in the future. A simple mathematical model for the decrease of the value of optimal vitality during the lifespan is proposed. A procedure for determination of the kinetic parameters aging factor (q) and aging correction (α) is suggested. It is shown that the increase of α (due to healthy lifestyle and training) retards the senescence process and ensures longevity. This paper is heuristic at this stage but it could stimulate the scientific thought.

Key-words: - Vitality, Optimal vitality, Sinergy, Biodynamics, Lifespan, Aging, Aging correction, Longevity, Mathematical model

1 Introduction

In last decades, biology reached great success both in molecular approach and mathematical models. The concepts of dynamic systems were used and non-linear and other models for different biological processes were developed [1, 2, 3, 4, 5, 6, 7]. The understanding of the exceptional role that information exchange plays in the very existence of life was firmly established. Eigen explained the selforganization of macromolecular structures [8]. Volkenstein presented the life evolution in its informational aspect [9]. Yockey showed that only because the genetic message is segregated, linear, and digital, it can be transmitted from the origin of life to all present organisms and will be transmitted to all future life [10]. Smith considered that the biological information is inherently a chemical property, but is equally an aspect of control flow and a result of processes equivalent to computation [11]. Velazquez claimed that the emergence of coordination in the complex systems is a result, derived from the tendencies to maximize information exchange [12].

All these considerations are valuable. They elucidate different aspects of life activity. No conception is pronounced, however, to perceive the biological object in its functional entirety in its overall response to some influences or stimuli. Based on system theory and information theory an organism could be considered as a cybernetic system. However, our idea here is to describe the living object as a biophysical system. This statement implies an extension of the theoretical basis of physics. The selfregulation and integrity of biological objects provide a new quality of matter and it is quite reasonable to think about a new field of science. The organism reaction represents a dynamic behaviour. Thus, by analogy with other physical fields, describing dynamic processes, this new field could be denoted as biodynamics.

Each fundamental field has its own theoretical basis with respective concepts and laws. So, a basic measurable characteristic in classic dynamics is mass; in electrodynamics – charge; in hydrodynamics – fluxes; in thermodynamics – temperature, pressure etc.; in chemical kinetics - concentrations of reagents and reaction rate. In biology, there are no own proper quantities.
The most significant attempts to outline the specific of life are based on in being physical theories and mainly on thermodynamics. Shrödinger considered the living organisms as systems consuming negative entropy [13]. Goodwin created a statistical mechanics and thermodynamics based on kinetics of synchronized biochemical oscillators [14]. Nicolis and Prigogine developed theory of dissipative structures, as an extended irreversible thermodynamics, to explain the self-organization processes in nonequilibrium systems [15]. Mathews et al. modeled RNA secondary structure applying thermodynamics [16]. Haynie maintained that thermodynamic concepts are of considerable importance for biochemical research [17]. Really, several biological processes and trends are well described based on thermodynamic concepts. However, all attempts to construct an extended thermodynamics of living matter remained artificial and not adequate. Blümenfeld noted that the true way to a general life theory is not a biological thermodynamics [18]. The animate systems are thermodynamic systems (as each material system) but not thermodynamic laws determine the essence of life!

It will be a great benefit if a new quantity could be put in correspondence to the state of whole organism, a quantity indicating the global health degree of the organism. Such a quantity should be measured. There is no adequate device at present. Notwithstanding, the author is optimist regarding a quick development of the experimental sciences and technologies and proposes, in heuristic aspect, a possible theoretical basis. Here our attention is focused on the evolution of the quantity “optimal vitality”, here introduced, in lifespan scale.

2 Basic concepts

It is assumed that the total physiological status of a biological object could be presented by a state variable, named vitality \((V)\). Thus, \(V\) is presumed as integral characteristics of the biological object, on macroscopic level. The metrical unit of the vitality was named bion \((b)\). The respective device, which will be constructed, could be called “vitalimeter”. One bion could be defined so that the excellent health standard in human corresponds to vitality of 100 bions. Vitalimeter should be gauge to direct measurement of bions.

The following analogy could help to comprehend the indispensability of specific state variables for living systems. Phenomena as thermal conductivity, diffusion etc. are not describable in the terms of classical mechanics and thus thermodynamics was created, where quantity “temperature” was introduced and a specific device “thermometer” was contrived. In the same manner, the essential features of life could not be described by thermodynamics.

The important question arises: what of nature should be the quantity \(V\)? Let us assume that it is possible to measure a dominant tone in human’s (respectively animal’s or plant’s) “aura”. This could be, for instance, the length (frequency) of some electromagnetic emission from the biological object. Electromagnetic waves of different frequencies, generated by human, animal and plant organisms in their metabolic activity and selfregulation were measured yet many years ago [19]. The explorations in this way were continued [20, 21, 22, 23, 24]. The advanced technologies today promise success in the searching of a principally new method, which will ensure an integral evaluation of organism’s health status via measurement of an appropriate wavelength. As dominant, respectively, integral characteristic of the organism’s status should be considered that wave, which has maximum brilliance.

A new field, biodynamics could be stated, in which vitality should be a basic measurable quantity. Here “biodynamics” is understand not as a field indicating a multitude of different non-linear and others mathematical models describing dynamical systems, including biological ones, but as a separate field of science like thermodynamics, electrodynamics etc.

In addition, quantity optimal vitality \((W)\) is introduced. \(W\) corresponds to the state of excellent health. 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 organism entropy. However, in time intervals much shorter compared to lifespan, \(W\) may be considered as a constant.

Each field of physics operates with specific concept for “energy”. It is quite reasonable to consider a specific energy form regarding the living matter, biological energy \(B\).

In thermodynamics, the balance of internal energy \(E_i\) is present in the form [25, 26]:

\[
dE_i = dQ - pdV + \sum_r A_r d\xi_r + \sum_k \mu_k dn_k
\]  

(1)
The biological energy $B$ should be a part of the internal energy of a biological object and then, the energy balance could be present as follows:

$$dE_i = dQ - pdV - \sum_i A_i d\xi_i + \sum_k \mu_k dn_k^i + dB \quad (2)$$

$B$ should be an energy associated with the interactions of cell and organism components on information level. $B$ ensures the processes of selforganization (on the basis of enzyme synthesis, resonance energy transfer between biological macromolecules, electric charge transfer, immune cell and antibodies production, DNA repair etc.) and thus is related to the information program encoded in the living system. $B$ is involved in the biological structures and their harmonized action. Really, the selfregulation energy is provided by the catabolic reactions of metabolism and ATP hydrolyzes. However, when we would like to deal with the information aspect of life processes, we should consider $B$ as a quantity of biodynamics and present it as a function of new variables. Further, we do not use the thermodynamics relations. Biological systems represent a new quality of matter, where the global pattern of the wholeness forms the rules of the interaction of the system’s components.

$B$ is a function of vitality $V(t)$ and rate of vitality change in time $\dot{V}(t)$:

$$B = B(V, \dot{V}) \quad (3)$$

A function synergy $G(V, \dot{V})$ is also introduced, defined by the following differential equation:

$$dG(V, \dot{V}) = WdB(V, \dot{V}) \quad (4)$$

### 3 Evolution of optimal vitality

The simplest quantitative assumption about the change of $W$ with the life course is that the rate of $W$ decrease is proportional to the time:

$$\frac{dW}{dt} = -qt \quad (5)$$

where $q ([q] = [b \text{ year}^{-2}])$, aging factor, is a parameter of the reduction of optimal vitality.

We would like once more to underline that the present consideration is related to a lifespan scale. The course of the decrease of $W$ during the lifespan represents the time course of the senescence.

The parameter $q$ should be a time function. Experimental studies and actuary assessments showed that the rate of senescence remains not a constant during the lifespan. The aging rate is most intensive to the age of 25 years (in human) and then it decreases with time [30]. Targeted investigations on male and female populations in 13 age ranges (within the interval of 30-92 years) have established that the local aging rate value is not constant. Generally, it has been found that the male aging rate lowers monotonically with time, while the female aging rate has a minimum in the range of 45-60 years and a maximum within the range of 70-80 years [31].

A monotonous decrease of senescence rate could be represented quantitatively supposing that the rate of decrease of $q$ is proportional to $q$ value at a given moment of the lifespan. Thus, one can write the following differential equation:

$$G$$
\[ \frac{dq}{dt} = -\alpha q \]  
\[ q_0 = q(t_0), \quad t_0 = 25 \text{ years} \]

(\( q_0 \) (\( [q_0] = [\text{b year}^{-2}] \)) and \( \alpha \) (\( [\alpha] = [\text{year}^{-1}] \)). The constant \( \alpha \) can be named aging correction, because at higher values of \( \alpha \) the parameter \( q \) decreases faster with time and hence, as follows from (5), the rate of aging decreases. Respectively, when \( q \) decreases slowly the aging processes run at accelerated rate.

The analytical solution of (6) is

\[ q = q_0 e^{-\alpha(t-t_0)} \]  
(8)

Taking into account (8) the equation (5) can be written as

\[ \frac{dW}{dt} = -q_0 e^{-\alpha(t-t_0)} \]

(9)

The analytical solution of (9) is

\[ W = W_0 - \frac{q_0(\alpha t_0 + 1)}{\alpha^2} + \frac{q_0(\alpha t + 1)}{\alpha^2} e^{-\alpha(t-t_0)} \]

(10)

The constant \( \alpha \) may be determined from the solution (8) after taking a logarithm:

\[ \ln q = \ln q_0 - \alpha(t-t_0) \]

(11)

The equation (11) is an equation of a straight line with angular coefficient \( \alpha \). Using the values of \( q \), a plot could be constructed with X-axis: \( t - t_0 \) and Y-axis: \( \ln (q/q_0) \). Thus, the parameter \( \alpha \) could be found.

The \( q \)-values could be determined in the following way. Human individuals in perfect health could be selected in different age groups ranging by five years (25–30, 30–35, 35–40 etc.). Within these groups, \( q \) may be considered approximately constant. Then the analytical solution of equation (5) has the form:

\[ W = W_0 - \frac{1}{2} qt^2 \]

(12)

and respectively:

\[ q = \frac{2(W_0 - W)}{t^2} \]

Here we hypothesize that the device “vitalimeter” is available. Then the values of optimal vitality \( W \) for the different age groups could be empirically measured (of course under a reliable statistics) and bearing in mind equation (13) values of \( q \), specific for the respective age periods, could be calculated. Thus, the straight line (11) will be drawn and the parameter \( \alpha \) subsequently determined. The value of \( q_0 \) may be determined in healthy individuals of 24–26 years old. One could assume that \( W_0 = 100 \) bions. If the constants \( W_0, q_0 \), and \( \alpha \) were known the time course of \( W(t) \) would be calculated.

The above case presents a picture of a normal aging, i. e. aging in healthy individuals, who are not burdened with chronic diseases (because the empirical data are taken from healthy people). The same procedure could be applied in people with certain chronic diseases, in smokers, etc. It is seen from (13) that at a greater difference \( W_0 - W \) the parameter \( q \) will have a higher value. For instance, at age 60 years, the optimal vitality \( W \) of a sick man will be less than \( W \) of a healthy man (\( W_{\text{sick}} < W_{\text{healthy}} \)) and respectively \( W_0 - W_{\text{sick}} > W_0 - W_{\text{healthy}} \). Therefore, \( q_{\text{sick}} > q_{\text{healthy}} \). According to equation (5), this situation indicates a faster senescence in the sick compared to the healthy man. In illness at young age, the value of \( q_0 \) may be higher than in normal conditions and this will influence the further life and aging pace.

In most cases, the life conditions and life mode can play a significant role for \( q \) modification. The healthful nutrition, going in for sports, natural regimen etc. could increase \( \alpha \)-constant in large extent. Consequently, the rate of \( q \) diminution increases. This process can ensure longevity (if no unexpected, unfavorable circumstances take place). Contrariwise, hard conditions, sedentary lifestyle, unhealthy diet and stress lead to a reduction of \( \alpha \)-constant, hence \( q \) remains at higher level, and the aging rate increases.

In Fig. 1, four analytical solutions (10) are presented. They were calculated under initial conditions \( W_0 = W(t_0) = 100 \) bions, \( t_0 = 25 \) years, and \( q_0 = 0.07 \) b year^{-2}. The values of the parameter \( \alpha \) were fitted according to some chosen lifespan maximums. For potential lifespan of 120, 100, 80, and 70 years, the values of \( \alpha \) are 0.034, 0.031, 0.0239, and 0.0163 year^{-1}, respectively. The points where the curves cross the X-axis correspond to absolute lifespan potential in the respective conditions. Usually (often due to different fortuitous factors, disturbances, or acute diseases), the concrete lifespan is (much) shorter than
potentially possible one. In such cases, life ceases at $W$-values greater than zero. In principle, the lifespan potential may be considered as genetically determined possible lifespan maximum for a given species.

Figure 1. Evolution of the optimal vitality $W$ during the lifespan.

Taking into account (4) one can present the time derivative of $G$ in the form:

$$\frac{dG}{dt} = W \frac{dB}{dt}$$ (14)

When we deal with recovery processes (after transient disturbances) much shorter compared to the lifespan, $W$ can be considered as a constant. After a disturbance, the synergy $G$ declines, in the recovery processes it increases, and at the end of the recovery, $G$ restores its optimal value. From (14) it is clear that in young organisms $G$ increases at greater rate compared to adults.

In lifespan scale, $W$ is a time function, i.e. $W = W(t)$ and the equation (14) becomes:

$$\frac{dG}{dt} = W(t) \frac{dB}{dt}$$ (15)

where $\frac{dG}{dt} < 0$ and $\frac{dB}{dt} < 0$, due to the general trend of decrease of biological energy $B$ and synergy $G$ during the lifespan.

Since $W(t)$ decreases during the life course, $\left| \frac{dG}{dt} \right|$ also decreases. It means that during the lifespan $G$ decreases at diminishing rate. This fact suggests that the loss of the selfregulation quality (expressed by the value of $G$) follows an exponential law.

4 Conclusion

It will be a great benefit if a measurable macro-characteristic (vitality $V$) exist, uniquely corresponding to the total physiological status of a biological object. Thus, the total health state of a given organism could be evaluated by simple measurement and the organism response to different influences could be explored and predicted.

Optimal vitality $W$ could be considered as a constant in time intervals much shorter compared to the lifespan. In lifespan scale, however, $W$ decreases with the time at a diminished rate. Synergy $G$ also decreases during the lifespan. The study of optimal vitality $W$ evolution shows that senescence process develops by exponential law. The aging rate could be established via measurements of $W$ in separate groups of different age ranges. The empirical investigations could provide reliable data for determining the characteristic lifespan for several species. Important quantitative correlations could be found between health status and longevity. Satisfactory values of the parameters introduced here (aging factor $q_0$ and aging correction $\alpha$) could be determined based on experimental data and by the model proposed. Further research could help to explain how these phenomenological constants depend on some molecular characteristics.

This work submits for the first time the idea of creating of a phenomenological theory for biological systems with its own conceptual basis (one that is not borrowed from the theoretical bases of other branches of physics). Biodynamics seems to be a suitable name of a field that deals with the organism’s overall response to particular influences, and the evolution of life parameters during life’s course. The presented concept is also of importance for practical purposes because it could stimulate the search of new diagnostic methods in biology and medicine. The work is heuristic at this stage, however the author hopes that the idea proposed here encourages further research efforts regarding a development of a phenomenological life theory.

References:

[1] Kitney R.I., A nonlinear model for studying oscillations in the blood pressure control system,
