Open Access
Journal of Human Thermodynamics
ISSN 1559-386X
HumanThermodynamics.com/Journal.html

Article

On the Thermodynamics of the Evolution and Aging of Biological Matter

Georgi P. Gladyshev

International Academy of Creative Endeavors (science-culture); Russian Academy of Sciences, N.N. Semenov Institute of Chemical Physics, 117997, Moscow, Kosygin str. 4; E-mail: academy@creatacad.org (or gpgladyshev@gmail.com).

Received: 21 Mar 2010; Published: 28 Apr 2010

Abstract

The evolution of matter into that of animated biological matter and the aging of organisms is considered as a result of spontaneous and nonspontaneous thermodynamic processes, viewed as changes of different parts of the universe and its components of studied systems and their subsystems structured into time-defined hierarchies.

Introduction

The goal of the present work will be to show that thermodynamics can be applied to all stages of evolution of the matter, including all stages of biological evolution, particularly via using a 'hierarchical thermodynamics', a systems-within-systems type of thermodynamics, which is based generally on the principle of substance stability, a postulate conceived by the author in 1978, which states that: 'during the formation or self-assembly of the most thermodynamically stable structures at the highest hierarchical level (j), e.g., the supramolecular level, nature, in accordance with the second law, spontaneously uses predominantly the least thermodynamically stable structures available from a given local part of the biological system, belonging to a lower level, i.e. molecular level (j-1), and incorporates these unstable structures into next higher level, i.e. supramolecular level (j)'.

Article

Besides a limited number of citations of literary sources are given, which are relevant to the examined issues, thermodynamic methods start taking a due place in theoretical and applied biology.[1] This contributes to the slow transformation of biology as a 'science in pictures' into an 'equation-based science' able to explain numerous biological phenomena from the position of physics, chemistry, thermodynamics, and other exact sciences.

The starting point for this development is the premise, stated originally in 1865 by German physicist Rudolf Clausius, that everything in the universe is governed by thermodynamics. Thermodynamics, subsequently, acquires overwhelming character if it is reasonably applied to different structural and temporal hierarchies of material world. Thus, all possible types of work realized inside or over singled out complex thermodynamics systems should be taken into consideration.[2] These systems can be transformed or changed under the action of expansion work or any other types of work such as chemical, electromagnetic, gravitation, osmotic and others.[3] Such understanding of modern thermodynamics is generally admitted.[4] In origins, to note, most of thermodynamics revolved around equations applied to simple ideal systems, i.e. to the systems where only expansion work is done. When applied to more complex systems, more effort is needed on the part of the scientist.

On the premise that the principle of substance stability is found applicable to all systems of the universe, we can postulate that all natural processes can be explained via hierarchical thermodynamics. This postulate is based, in the general sense, on the agreed upon knowledge that everything in the universe happens under the action of energies of the systems themselves, and of the energy of the medium surrounding the systems, that systems are found in nature layered in a hierarchies, and that systems are coupled to each other energetically. This conclusion implies existence or distinction of spontaneous and non-spontaneous processes, as captured well by German-born American biochemist Fritz Lipmann's 1941 free energy coupling theory, whose set of complex dynamics determines evolution and development of the all systems in the earth.[5]

Gerontological thermodynamics

All of the presented reasoning is directly related to gerontology, since knowledge of general thermodynamic mechanisms of aging, has made possible the extension of healthy life of human beings, in applied medicine, e.g. drug receptor thermodynamics or protein thermodynamics. It is the contention herein, that while studying the evolution of quasi-equilibrium quasi-closed systems of different hierarchies Gibbs's specific function of the formation of complex system (ΔG) should be used. Variation of this value in the similar complex natural system characterizes changing of the relative stability of structures of studied hierarchies and identifies level of

development or extent of real processes in the system.[6] It is relevant for the study of the evolution as a whole as well as phylogenies and ontogenesis of biological systems.

Gibbs fundamental equation

Hierarchical thermodynamics is based on the combined works of German physicist Rudolf Clausius and Willard Gibbs and for the first time considers average values of interaction on macrolevel inside any volume of any hierarchy of structure.[7] While studying all evolutionary transformations in real system it is convenient to use the well known now equation for the full differential of Gibbs's function, generally known as the Gibbs fundamental equation, which states that, because free energy is an extensive state variable, the total change in the Gibbs free energy of the system is equal to the sum of the component changes of Gibbs free energy if each reaction or process in the system:

$$dG^* = \sum_{i=1}^{N} dG^*$$

In expanded version, which is simply Clausius' 1865 ten fundamental equations with conjugate variable pairs added on so as to account for factors in complex systems:[8]

$$dG^* = -\sum_{i=1}^{N} S_i dT_i + \sum_{i=1}^{N} V_i \, dP_i - \sum_{i=1}^{N} \sum_{k=1}^{N} x_{k_i} dX_{k_i} + \sum_{i=1}^{N} \sum_{k=1}^{N} \mu_{k_i} dm_{k_i}$$

where: T-temperature; S-entropy: U- internal energy; V-volume; p-pressure; X-any generalized force except pressure; x-any generalized coordinate except volume; μ - chemical (evolutionary) potential; m – mass of k-substance; work realized by the system is negative. Index i pertains to the specific evolution, k – to the component i evolution. The upper asterisk '*' is used here to mean that free energies are being calculated under consideration that the behavior of the system is complex.

This presented equation is a generalized equation since in principle all interactions inside and outside of all structures of every hierarchical level are taken into consideration independently of the scale of these interactions. It is logical to consider this equation as one with considerably divided parameters, symbolic, or speculative, that can be efficiently used only in relation to every one or adjacent hierarchies of structures.[9] In this case, the Gibbs equation is considerably simplified in connection with negligibly small values of the majority of its isolated or individual members. In other words symbolism or speculative character of the equation consists in the fact that it is difficult, in one impulse of the thought, to take into consideration simultaneously all multi-scale effects determining the behavior of complex heterogeneous poly-hierarchical system at once as a whole.

Mathematics teaches us that, it enables to combine like with alike and prefers simplicity and alliance (unity) at describing physical picture of the real world.[10] The Gibbs equation is characterized by a certain community connected with unique thermodynamic approach to the study of all individual mono-hierarchical systems, forming a poly-hierarchical system.

Entropy

For each hierarchy structure, there are relevant different forces and factors. In every hierarchy, there are relevant and different interactions. In considering the transformation of the structures of a certain population, for instance, it is our contention, that the value of the entropy component is reduced practically to zero. To speak about influence of entropy factor characterizing interaction of a few sparse organisms as elementary structures in this case is devoid of any meaning.

Nevertheless, it should be borne in mind that transformation of interior structure of the organisms themselves as a result of their interaction among themselves inside the population can lead to a considerable change of entropy of molecular and supramolecular structures inside the organisms. At the same time, influence of the gravitation field, of hydrodynamic and other forces can be rather notable at the interaction-level of the organisms themselves inside the population. The bulk action of all factors, in all hierarchical structures, act to shape the aspect, form, composition, and structure of living organisms. Emergence and existence of a biological diversity is due to this fact.

Gibbs energy minimization

Biological diversity is formed by adapting living organisms to the conditions of the surrounding medium in the process of long-timescale evolution. Nature, at all hierarchical levels, seeks to minimize the value of specific Gibbs function of the formation of supramolecular structures and suprastructures of higher hierarchies up to ecological systems and unique global structure of the earth, as a whole.

Human thermodynamics

Hierarchical thermodynamics identifies the most stable forms of living structures of all hierarchies of the relevant conditions of the surrounding medium. With the changing of these conditions, forms of living organisms, their interrelation, and relation with surrounding medium is changed as well. Human thermodynamics, sociological thermodynamics, thermodynamics of populations deal with interactions of elementary structures, i.e. organisms corresponding to the given hierarchy. Human thermodynamics, subsequently, can study the interaction of two or more organisms.

It should be borne in mind, from the position of thermodynamics, that in these cases one should take into consideration first of all interactions which are determined by micro-particles (supra-molecular and molecular particles) contained in the above mentioned macro-particles: organisms.[11] Naturally, the organisms themselves should be considered as particles (fragments) of complex phases of biomass formed by molecular and supra-molecular structures. There is a full analogy to the particles and the ensembles of interacting colloidal, emulsion or suspension particles.

While studying human feelings, such as love, one can be used Le Chatelier-Brown principle and Weber-Fechner law which, as was shown for the first time by the author and fellow-researchers in 1980, are of thermodynamics origin.[12] The Weber-Fechner law enables one to measure the strength of the feelings appeared under action of one or simultaneously several factors. The law, for instance, acts well in case of action of light, electromagnetic fields, sound, smell, and nutritious substances on organs of relevant human senses and of other living organisms.

Complex of factors or stimulators determine manifestation of various types of love, hate, and mixings of feelings. There is a wide space for experimental research in future in this area. The above said, justifies completely study, from the position of thermodynamics, of the interaction of men and women, allowing the scientist to speak about feelings like love, friendship, hate and others, in the language of pure physics.[13]

On an aside, it is our contention that from the position of thermodynamics, one can consider gravitation and electromagnetic interactions of any macro bodies, since these interactions are in the final analysis determined by big complexes of micro-particles in the volumes and on the surfaces of these bodies. Let us consider the process of the transfer of chemical evolution into biological evolution in the conditions of the earth or similar celestial bodies.[14]

Selected studied quasi-closed physico-chemical (originally inanimate) systems under action of energy from outside are subjected to non-spontaneous transformations. Sources of energy are: energy of the sun, electrical discharges in the atmosphere, inner heat of the Earth, gravitation and magnetic fields, other energy sources. This leads, firstly, to non-spontaneous physical and chemical processes and increase of Gibbs specific function of the formation of studied systems from elements ($\Delta\bar{G}_m^*>0$,) as well as from molecules ($\Delta\bar{G}_{im}^*>0$). Where index *m* shows that chemical (molecular) processes are involved, and index *im* is related to intermolecular (supra-molecular) transformations. It should be noted that $\Delta\bar{G}_m^* >> \Delta\bar{G}_{im}^*$.

Moreover, in these dynamic, open (for considerable time), systems, one observes spontaneous physical, chemical, and molecular-condensation processes, characterized by decrease of Gibbs specific function of the formation of new chemical substance and supra-molecular structures ($\Delta\bar{G}_m^*<0$, $\Delta\bar{G}_{im}^*<0$). Supra-molecular structures of the systems become more stable, but these

systems are due to the action of principle of stability of the substance are enriched by emerging of energy-intensive chemical substance.[15] It should be noted that similar conclusions, due again to the action of the principle of stability of the substance, refer as well to the interaction of structures of all adjacent hierarchies. This is obvious in the social structures such as family and public associations.[16] All conclusions agree with numerous well known facts and experimental data.[17]

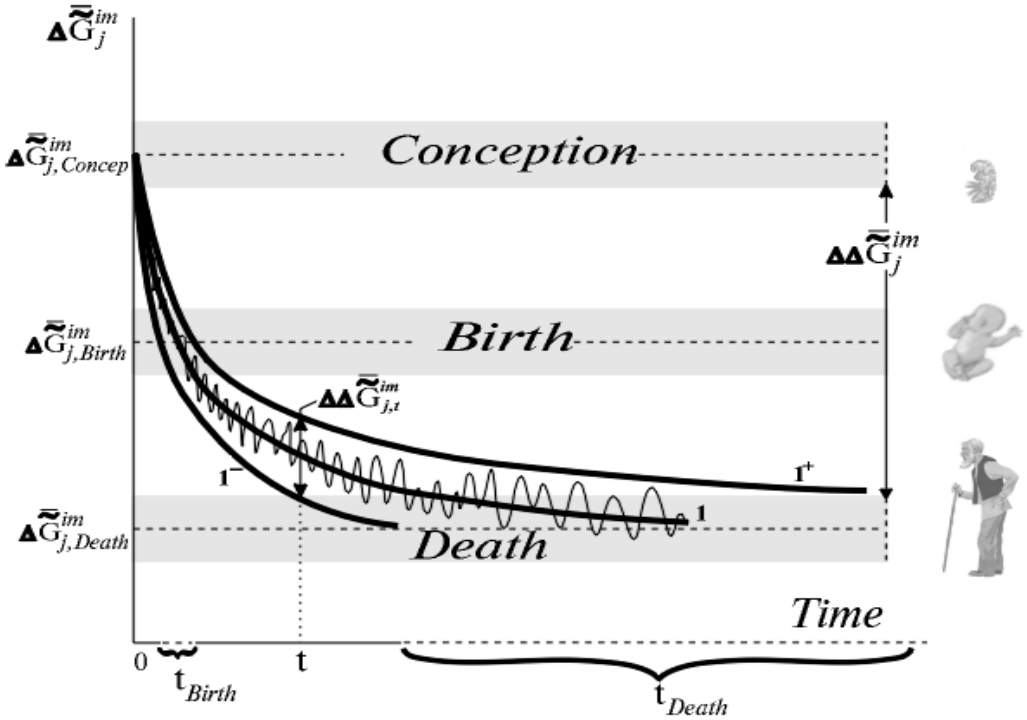
Nutrition thermodynamics

From the point of view of supramolecular stability, systems tend firstly to the inner supramolecular equilibrium ($\Delta\bar{G}_{im}^{*}<0$), though from the point of view of chemical molecular stability the systems are leaving from the state of chemical equilibrium with the surrounding medium ($\Delta\bar{G}_{m}^{*}>0$). Energy-intensive, slightly stable chemical structures, e.g. sugars and lipids, accumulated in the evolving systems comparatively quickly disintegrate (decompose).

Despite the fact that these systems tend to the inner supra-molecular stability, they fill themselves with new slightly stable chemical substance. Otherwise in the systems the exchange of chemical substance is observed. The process reminds functioning of laboratory or natural chemically active chromatographic columns as quasi-closed quasi-equilibrium system. Generation of minerals and their deposits in the earth crust is a vivid example of action of the similar dividing columns.[18]

The chromatographic column example as well as a living organism accumulates, like a burning candlewick, comparatively stable chemical substance.[19] The organism like an upper part of the candlewick 'burns' comparatively slowly. Otherwise in the final analysis the organism dies. At the same time like emergence of new 'fresh fragments' of the candlewick from the conserved solid part of the candle at its burning during the life of the organism appear a new generation of living creatures. Aging sorbents of chromatographic columns, catalyzers of chemical processes, etc., are similar to the burning candlewick. This analogy enables one, from the position of hierarchical thermodynamics, to understand the tendency of genetic material, or conserved nucleic acid, of living organisms, to aid in the process of reproduction.

To graphically explain the logic of this paper, the following diagram shows the changes of Gibbs specific function of the formation of supramolecular structures in its phases of evolution and ageing in ontogenesis. Graphs 1, 1^{+} and 1^{-} correspond to normal, improved, and bad life conditions of the organism, respectively, saw-edged line reflects oscillations of the above mentioned value of Gibbs specific function related to the changes of conditions of the surrounding medium.[20]



The birth of a new organism, in the reproduction process, reminds one of the emergence of a crystalline matter at the introduction of crystals in oversaturated solution in laboratory and geochemical systems. The lifespan of an organism, as shown in the diagram, depends substantially on the conditions of the surrounding medium, nutrition and other known factors.[21]

It is our position, that thermodynamics can suggest to us what we should eat and what way of life we should lead in order to increase time of healthy life and thus general lifetime. By determining thermodynamic-based gerontological (anti-aging) value of food products on the basis of quantity indexes, for instance, one calculate, scientifically (and not empirically) recommendations for a long healthy life.[22] It is easy to determine one of these parameters using what the author has referred to as the GPG (Georgi P. Gladyshev).[23] The easiest method employed to do his is by using measurement of temperatures of solidification (melting) of natural fats and oils contained in natural food products.

Evolving organisms in ontogenesis and phylogenies, within adaptation range or zone, are subjected to non-spontaneous action under influence of the surrounding medium including non-spontaneous processes connected with mutual reciprocal interaction of organisms themselves.[24]

It should be noted that from the point of view of the living organism in any objects of the surrounding medium, e.g. stars, thunderclouds, or living organisms, take place spontaneous processes of energy release which being absorbed by receptors of studied organism lead to the development of spontaneous processes. If a system emits energy to the surrounding medium this

emitted energy can lead to the development of spontaneous processes in the surrounding medium.

Energy of the sun and other sources of energy emitted as a result of spontaneous processes, stimulate non-spontaneous processes in animate and inanimate systems. In these types of allocated systems, it has been mentioned that they can be enriched by certain portions of energy at the expense of energy of the surrounding medium, what leads as a rule to the increase of Gibbs specific function of the formation of their chemical and supra-molecular structures ($\Delta\bar{G}_{m>}$*0, $\Delta\bar{G}_{im}$>0*). Further, these systems are subjected to the spontaneous transformations. Reiterated repetition of such non-spontaneous and spontaneous (periodical) cycles, transformation is accompanied by appearance of new higher structure hierarchies.

At the same time, structures of low hierarchies are embedded or inserted in structures of higher hierarchies. Poly-hierarchical structures or organisms are formed which exchange energy and matter among each others and surrounding medium. Emergence and existence of spontaneous poly-hierarchical structures, metabolism in these structures (systems), with influx of energy and matter from outside are inherent to substance of life as phenomenon.

In the process of phylogenies and ontogenesis, organisms and other living objects are interacting with each other and surrounding medium through physical fields, smells, other factors perceived by various receptors.[25] Thus, the signal as a spontaneous process sent by an organism stimulates receptors of other organisms. Derivative processes of this stimulation should be considered as non-spontaneous processes occurred at the expense of energy impulses from without. Further, energy of the stimulated receptors, for instance, through neurons as electric impulses, is spontaneously transferred in the brain. Certain areas of the brain, under the action of impulses (signals), are thus, resultantly, stimulated in a non-spontaneous manner. Received signals can stimulate muscle action thus provoking reaction of the organism. This alternation of non-spontaneous and spontaneous processes takes place at adjusting (adaptation) of organisms to the changes of the surrounding medium etc.

Boltzmann-Schrodinger-Prigogine analogies

From what was said above, as well as from other widely known ideas, it follows that it is hardly logical (reasonable) to use obviously wrong ideas of Austrian physicist Ludwig Boltzmann, Austrian physicist Erwin Schrödinger, and Belgian chemist Ilya Prigogine, and others, which reduce life phenomenon and its evolution only to the increase of entropy of our real universe (or negentropy of the living systems) as thermodynamics function of the state.[26]

There exists a great amount of misunderstanding in public and scientific circles related to the inadmissible confusion in terminology and incomprehension, or negligence by many authors of

basics of classical thermodynamics of real systems as well as of hierarchy thermodynamics applied to the description of evolution of the animate and inanimate matter.[27] Examples include conclusions of thermodynamics related to the ideal systems such as ideal gas are sometimes applied to the systems with interactions and everything is reduced to the changes of certain imaginative and undefined entropy devoid of physical sense.

Conclusion

In general, it is possible to claim that the appearance of the life is connected with the appearance of spontaneous poly-hierarchy systems. It is possible that this circumstance is important in distinction of animate and inanimate matter. It is clear that inanimate systems are smoothly transformed into animate objects (organisms) under influence of non-spontaneous and spontaneous processes directed by the driving force of thermodynamics, i.e. of thermodynamic exterior and interior influences.

Subsequently, it is our position that hierarchy thermodynamics, in connection with the influence of all forces and influences manifested in the conditions of our planet, allows one to ascertain that life can exist only on completely analogous celestial bodies. Though certainly, other forms of life should exist in different areas of our immense universe.

Regarding the evolution of earth-bound animate objects from the point of view of this position we can say that evolution is a process of expansion and development of the universe taking place as an effect of transformations of its numerous inanimate and animate objects under the guiding action, influence, or impact of hierarchy thermodynamics of complex systems. We can ascertain that in all local areas of the universe, these rules apply, within the framework of its applicability.

Acknowledgements

The author heartily thanks professors V.P. Kazakov, Y.B. Monakov, and Libb Thims for their kind advice.

Reference notes

1. Refs: (1-33).
2. Refs: (2-8, 24-32).
3. Refs: (1-8, 27, 28, 32).
4. Refs: (3-6, 32).
5. Refs: (22).
6. Refs: (4-8).
7. Refs: (1, 2, 7-8, 29-32).
8. Refs: (3-8, 27-26).

9. Refs: (11, 21).
10. Refs: (21, 23).
11. Refs: (11,20).
12. Refs: (5,8, p.82-89).
13. Refs: (22, 29-32).
14. Refs: (2, 5-8, 11, 17, 22, 26).
15. Refs: (2, 7, 8, 12, 13, 16).
16. Refs: (20, 32).
17. Refs: (4-20, 29-32).
18. Refs: (10, 13, 17, 20).
19. Refs: (17, 26, 32).
20. Refs: (7, 8).
21. Refs: (13, 14,18,25).
22. Refs: (9, 18, 19, 24, 25).
23. Refs: (24).
24. Refs: (22).
25. Refs: (7, 9, 11).
26. Refs: (2-20).
27. Refs: (15, 20, 26).
28. Refs:

Reference list

1. 1. Gibbs, J.W. (1876). *On the Equilibrium of Heterogeneous Substances*, in *The Scientific Papers of J. Willard Gibbs: Vol. 1, Thermodynamics*. - Connecticut: Ox Bow Press.
2. (a) Gladyshev G.P. (1978). "On the Thermodynamics of Biological Evolution", *Journal of Theoretical Biology*. 75(4): 425-441.
(b) Preprint in Russian and English, p. 45. Institute of Chemical Physics, USSR Academy of Sciences. Chernogolovka
3. Гладышев Г.П. (1983). Иерархическая термодинамика сложных открытых систем. Препринт. Уфа: Башк. Фил. АНСССР. (Gladyshev G.P. 1983. Hierarchical thermodynamics of complex systems. Preprint. Ufa: Bash. Department of Academy of Science of USSR).
4. Гладышев Г.П. (1994). Движущая сила биологической эволюции. *Вестник РАН*, т. 64, N3, с. 221. (Gladyshev G.P. 1994. A Motive Force of Biological Evolution. *Herald of the Russian of Sci.*, v. 64, N 2, p. 118).
5. Гладышев Г.П. (1988). Термодинамика и макрокинетика природных иерархических процессов. М.: Наука, – 287 с. (Gladyshev G.P. Thermodynamics and Macrokinetics of Natural Hierarchical Processes. M.: Nauka Publ., 1988).

6. (a) Гладышев Г.П. (1995). Термодинамика иерархических систем. М. : Химическая энциклопедия. т. 4, с. 1062. (Thermodynamics of hierarchical systems. 1995. Moscow: Chemical Encyclopedia. Vol. 4, p. 1062).
(b) URL: http://www.xumuk.ru/encyklopedia/2/4371.html
7. Гладышев Г.П. (1996). Термодинамическая теория эволюции живых существ. М.: Луч,. -86с. (Gladyshev G.P. Thermodynamics Theory of the Evolution of Living Beings. M: Luch, 1996. 86 p.)
8. Gladyshev, Georgi P. (1997). *Thermodynamics Theory of the Evolution of Living Beings*. Nova Science Publishers, Inc.
9. (a) Gladyshev, G.P. (1994). "Method for measuring the gerontological value of biologically active substances and compositions: Mainly food and cosmetic products." Canadian Patent 2,327,747, 2004/12/14 (RU: 2147370 C1, 29.06.1999).
(b) URL: http://www.wipo.int/pctdb/en/wo.jsp?wo=2001001128
10. Gladyshev, G.P. (2002). "The Hierarchical Equilibrium Thermodynamics of Living Systems in Action", *SEED Journal*. 3: 42-59. (Toborsky E., co-editor SEED. Editorial, № 3. P. 1-2).
11. Гладышев Г.П. (2003). Супрамолекулярная термодинамика – Ключ к осознанию явления жизни. Издание второе – М - Ижевск. (Gladyshev G.P. Supramolecular thermodynamics is a key to understanding phenomenon of life. Moscow- Izhevsk: ISBN: 59397-21982. 2003. 144 p.)
12. Gladyshev, G.P. (2003). "Thermodynamic self-organization as a mechanism of hierarchical structures formation of biological matter", *Progress in Reaction Kinetics and Mechanism* (An International Review Journal. UK, USA). 28: 157-188.
13. Gladyshev G.P. (2004). "Macrothermodynamics of Biological Evolution: Aging of Living Beings." *International Journal of Modern Physics B*, 18(6): 801- 825.
14. Gladyshev, G.P. (2005). "Life is inalienable component of matter evolution", *Adv. Gerontol*. 16: 21-29.
15. (a) Gladyshev, G.P. (2005). "The Second Law of Thermodynamics and the Evolution of Living Systems", *Journal of Human Thermodynamics*. 1(7): 68-81.
(b) URL: http://www.humanthermodynamics.com/JHT/Second-Law-Systems-Evolution.html
16. (a) Gladyshev, Georgi P. (2006). "The Principle of Substance Stability is Applicable to all Levels of Organization of Living Matter", *Int. J. Mol. Sci.* 7: 98-110.
(b) URL: http://www.mdpi.org/ijms/papers/i7030098.pdf
17. Gladyshev, G. P. (2007). "Leonhard Euler's methods and ideas live in the thermodynamic hierarchical theory of biological evolution." *International Journal of Applied Mathematics and Statistics*, No. 1.
18. Gladyshev, G. P. (2006). "Lecture", The 14th and 15th annual International Anti-Aging Congresses and Expositions, Chicago and Las Vegas, 2006, 2007.
19. Гладышев Г.П. (2008). "О механизме влияния продуктов питания на продолжительность здоровой жизни," *Успехи геронтологии*, 21(1): 34-36. (Gladyshev G. P.

On mechanism of food influence for prolongation of health life . *Advance of Gerontology*, 2008, Vol. 21, № 1, pp. 34-36).
20. Gladyshev, G. P. (2009). "Hierarchical thermodynamics – General theory of existence and living world development." Knol.google.com.
21. Gladyshev, Georgi. (2009). "Математическая физика и теория эволюции живой материи. История и современност." (Evolution: spontaneous and non-spontaneous processes). Knol.google.com.
22. Gladyshev, Georgi (2009). "Evolution: spontaneous and non-spontaneous processes", Knol.google.com.
23. Gladyshev, Georgi. (2009). "What is Thermodynamics?" Knol.google.com.
24. Гладышев Г.П. (2009). Способ измерения геронтологической ценности пищевых продуктов по шкале Гладышева. Патент № 2350948. Зарегистрировано в Государственном реестре изобретений Российской Федерации 27 марта 2009 г. (Gladyshev G. P. Method for measuring the gerontological value of biologically active foodstuffs by Gladyshev scale. Patent, № 2350948. 2009).
25. Gladyshev G.P. (2009). "Definition of anti-aging values of natural foodstuff." Knol.google.com.
27. Sychev V.V. (1986). *Thermodynamics of Complex Systems*. M.: Energoatomizdat, 208 p.
28. Sychev V.V. (1973). *Complex Thermodynamic Systems*, London: Consultants Bureau.
29. Thims, Libb. (2007). *Human Chemistry* (Volume One). LuLu.
30. Thims, Libb. (2007). *Human Chemistry* (Volume Two). LuLu.
31. Thims, Libb. (2008). *The Human Molecule.* LuLu.
32. Thims, Libb. (2010). *Encyclopedia of Human Thermodynamics.* EoHT.info.
33. Aging – EoHT.info.

Creative Commons Attribution License © 2010 by the Authors
(CreativeCommons.org/license/by/3.0/)