# THERMODYNAMICS OPTIMIZES THE PHYSIOLOGY OF LIFE

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*Thermodynamics serves as a basis for optimal solutions of the tasks of physiology, which are solved by organisms in the characteristic process of life: evolution, development, homeostasis, and adaptation. It is stated that the quasiequilibrium thermodynamics of quasiclosed complex systems serves as an impetus of evolution, functions, and activities of all levels of biological systems' organization. This fact predetermines the use of Gibbs' methods and leads to a hierarchical thermodynamics in all spheres of physiology. The interaction of structurally related levels and sub-levels of biological systems is determined by the thermodynamic principle of substance stability. Thus, life is accompanied by a thermodynamic optimization of physiological functions of biological systems. Living matter, while functioning and evolving, seeks the minimum of specific Gibbs free energy of structure formation at all levels. The spontaneous search of this minimum takes place with participation of not only spontaneous, but also non-spontaneous processes, initiated by the surrounding environment. The hormone optimization of the treatment of various pathologies, presented by Dr. Sergey A. Dzugan et al. demonstrates the effectiveness of their innovative medical approach.*

*Key Words: Gibbs energy, living matter, physiology, thermodynamics.*

# ТЕРМОДИНАМИКА ОПТИМИЗИРУЕТ ФИЗИОЛОГИЮ ЖИЗНИ

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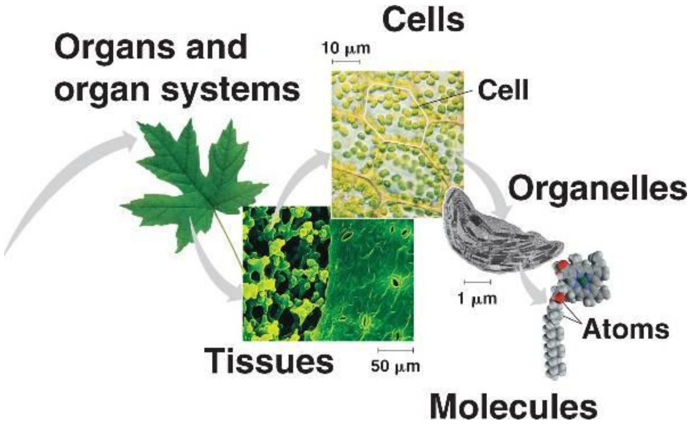
*Термодинамика находит оптимальные решения физиологических задач, решаемых живыми системами при эволюции, развитии, гомеостазе, адаптации, поведении и других процессах, характеризующих жизнь. Утверждается, что квазиравновесная термодинамика квазизакрытых сложных систем является движущей силой эволюции, функционирования и регуляции всех уровней организации биологических систем. Это фактически предопределяет использование Гиббсовских методов иерархической термодинамики во всех сферах физиологии. Взаимодействие структурных смежных уровней и подуровней биологических систем определяется принципом стабильности вещества, справедливым для всех структур живой материи. Таким образом, жизнь сопровождается термодинамической оптимизацией физиологических функций биологических систем. Живая материя, эволюционируя и функционируя, ищет минимумы «удельной свободной энергии Гиббса образования» структур всех иерархических уровней. Самопроизвольный поиск этого минимума протекает с участием не только самопроизвольных, но и несамопроизвольных процессов, инициируемых окружающей средой. Явление термодинамической оптимизации физиологии живых систем может быть распространено на физиологическую оптимизацию медицины. Так, гормональная оптимизация лечения различных патологий, представленная методами академика С. Дзюгана и коллег, демонстрирует эффективность их новаторского медицинского подхода.*

*Ключевые слова: живая материя, термодинамика, физиология, энергия Гиббса.*

*"One of the principal objects of theoretical research in any department of knowledge is to find the point of view from which the subject appears in its greatest simplicity".*
*J. Willard Gibbs*

*"The aim of science is not things in themselves but the relations between things; outside these relations there is no reality knowable".*
*Henri Poincaré*

*"Hierarchical thermodynamics in accordance with the laws of nature creates and optimizes forms and functions of living systems in their habitat. This optimization is connected with the search of minimums of specific Gibbs free energy formation of dynamic structures of all hierarchies".*
*Author*




## 1. Thermodynamics and physiology

**Thermodynamics** is the science of energy conversion involving heat and other forms of energy. Thus thermodynamics provides a universal set of laws governing all processes. Thermodynamics uses the apparatus of full differentials and examines changes of state functions. Thermodynamics is the driving force of evolution and development [http://endeav.net/news/39-thermodynamics-evolution-life.html; http://www.thefullwiki.org/Energy].

**Physiology** is the study of the function of living systems. This includes how organisms, organ systems, organs, cells, supramolecular structures and biological molecules carry out the chemical or physical functions that exist in a living system. Physiology as a scientific discipline is very extensive; it includes various aspects of related sciences. Thermodynamics investigates the motive forces of physiological processes and their functions.

**Human physiology** is the science of the mechanical, physical, bioelectrical, and biochemical functions of humans with respect to their health, their organs, and the cells of which they are composed. Physiology focuses principally at the level of organs and systems [http://en.wikipedia.org/wiki/Human_physiology].

## 2. On life and thermodynamics

Life in the universe continues to emerge and develop under certain conditions in accordance with the general laws of nature, in particular in accordance with the law of temporal hierarchies, with the second law of thermodynamics and the principle of substance stability [http://gladyshevevolution.wordpress.com/article/science-evolution-and-reality-169m15f5ytneq-12/].

Biological evolution is accompanied by a change in the chemical and supramolecular compositions of living bodies, and it is accompanied by a change the compositions of all higher hierarchies of living matter too. As shown by author in 1977 these well-known changes are of a thermodynamic nature (origin). Phenomenological thermodynamics of near-equilibrium quasi-closed systems allows us to explain and predict the evolutionary transformation in the living world. From a viewpoint of power-consuming substance of biological objects, the phenomenon of life is the struggle for power-consuming chemicals. The accumulation of this substance in biological systems is associated with the aspiration of the specific Gibbs function of formation of supramolecular structures of living organisms to a minimum [*Gladyshev*, 1997; *Gladyshev*, 1999; *Gladyshev*, 2002*c*; *Gladyshev*, 2003*b*; *Gladyshev*, 2004*b*; *Gladyshev*, 2005; *Gladyshev*, 2007*a*; *Gladyshev*, 2009].

I believe abiotic development and primary life evolved on the young Earth (or on the celestial bodies). These processes are still produced today. However, the existing life protects itself and prevents the development of own primary forms. This is the self-defending property of life. Origin, development and the preservation of life is controlled by the hierarchical thermodynamics of complex systems [http://endeav.net/news/49-life-origin-of-life.html; http://gladyshevevolution.wordpress.com/].

## 3. The physiological principle “thermodynamic optimization of life” – a special case of the principle of substance stability

“Nature seeks to minimize the Gibbs free energy of a subsystem formation”. The principle of substance stability describes the tendency or trend of natural systems to seek local and general equilibria (quasi-equilibria) at all temporal and structural levels of the organization of matter [*Gladyshev*, 1978; *Gladyshev*, 2002*a*; *Gladyshev*, 2002*b*; *Gladyshev*, 2002*c*; *Gladyshev*, 2003*a*; *Gladyshev*, 2003*b*; *Gladyshev*, 2004*b*; *Gladyshev*, 2006; *Gladyshev*, 2014*a*]. These tendencies derive from the second law of thermodynamics (the Clausius–Gibbs variation) in coordination with the Le Chatelier–Braun principle.

The principle of substance stability is connected with the limited power possibility, i.e. the limited change of Gibbs free energy, of jointly interacting elementary structures of neighboring (adjacent) hierarchies. This principle appears at all hierarchical levels, temporal and structural, of living matter. It is connected with the fact that we can observe stabilizing tendencies and actions at time scales corresponding to our capabilities.

This principle was formulated by the author whose focus is an understanding of the greatest simplicity for the creation of thermodynamic models of our world.

Such an approach was applied by classics of scientific thought, including J. Willard Gibbs and Henri Poincaré.

Earlier, the author proposed different formulations of the principle of substance stability, which are not contradictory.

The principle applied to molecular and supramolecular structures was named "the principle of the stability of a chemical substance". Subsequently this principle was applied by the author to various hierarchies as a part of the theory of the evolution of life. This principle is also known as: the principle of stability of matter, the principle of substance stability, the feedback principle, and Gladyshev's principle. The principle boils down to the following:

"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*)".

The justice of the principle is proven on a quantitative basis as applied to the molecular and supramolecular structural levels of biological tissues. Furthermore, the justice of the principle is proven up to the sociological level.

The higher are the relative stability of supramolecular structures, the lower are the relative chemical stability of molecules or theirs fragments which are incorporated into these supramolecular structures. Restating the principle in a condensed format:

**"The higher Δ√j-1 (Δ√j-1 >0) is, the higher is |Δ√j| (Δ√j <0).**

For the supramolecular (intermolecular) and chemical (molecular) hierarchies in evolution and aging:

**"The higher the supramolecular stability (Δ√ im <0), the lower the chemical stability ( Δ√m >0)" or "The higher is the chemical stability (Δ√ m <0), the lower is the supramolecular stability (Δ√ im >0)".**

These rules correspond to schemes: the article [*Gladyshev*, 1978] (fig. 1), the book [*Gladyshev*, 1997] (fig. 4), and the book [*Gladyshev*, 2003*a*] (fig. 11).

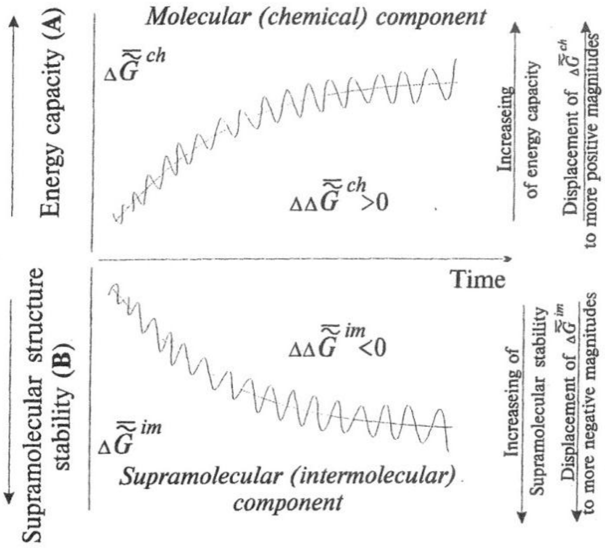



Fig. 1. Schematic plot (fig. 4, from the book [8]).

The validity of “the principle of substance stability" is a quantitative comparison of ΔG im (level j) and ΔG m (ch) (level j-1) for hydrocarbons and their derivatives, and nucleic acids. These data are presented in [*Gladyshev*, 2002*b*]. This statement for n-alkanols is shown in Fig. 2.

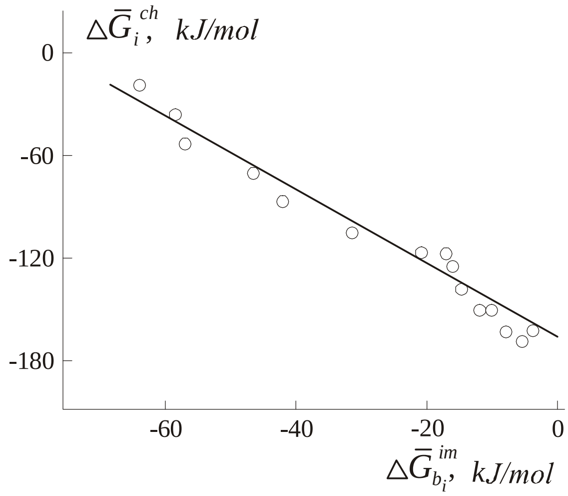



Fig. 2. Specific (per mole of substance) Gibbs’ function of formation (at 298K) of n-alkanols C1-C10, C12, C14, C16, C18, C20, $\Delta\overline{G}_i^{ch}$ ( $\Delta\overline{G}_f^{ch_0}$ ) as a function of specific (per mole of substance) Gibbs’ function of nonequilibrium phase transition of substances from the state of supercooled gas to the condensed state (at 298K) $\Delta\overline{G}_{b_i}^{im}$. The calculation was performed [*Gladyshev*, 2002*b*] using the published data from Stull et. Al., 1969; Handbook..., 1986).

The same situation applies to nucleic acids.

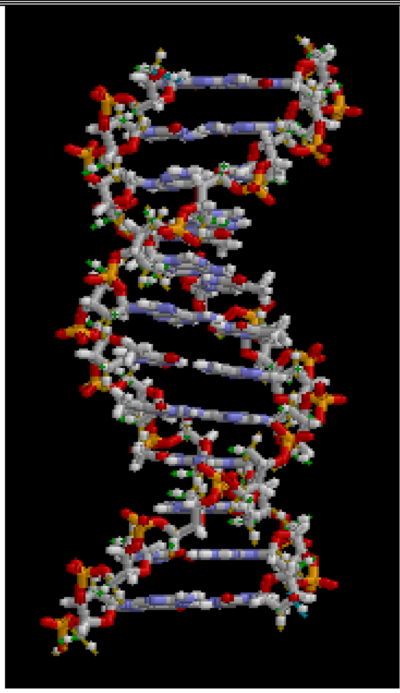


Fig. 3. The structure of a part of a DNA [http://en.wikipedia.org/wiki/DNA]

For example, purine (A, G) and pyrimidine (C, T, U) bases are relatively unstable or low stable from the viewpoint of thermodynamic chemical stability. At the same time, they form highly stable supramolecular structures between chains of nucleic acids. In other words, low chemical stability nucleobases accompanied by an increased stability of supramolecular structures formed mainly by hydrogen bonds. Now this is a known fact http://gladyshevevolution.wordpress.com/ . Some results are presented in Table "Properties of molecules" [*Gladyshev*, 2014*a*].

*Table 1.* Properties of molecules.

| | **Molecule** | **Formula** | **Mol. Mass** | $T_{melting}$ K**(dec.)** | $T_{boiling}$ K | **ΔGf°298 (kcal/mole) (s)** | **ΔGf°298 (kcal/g)** |
|---|---|---|---|---|---|---|---|
| 1 | **Adenine** (A) | $C_5H_5N_5$ | 135,13 | **633–638** (365 °C) | - | + 71.58 (s) | **+ 0.530** |
| 2 | **Guanine** (G) | $C_5H_5N_5O$ | 151,13 | **633** (360 °C) | - | + 11.33 (s) | **+ 0.075** |
| 3 | **Cytosine** (C) | $C_4H_5N_3O$ | 111,10 | **593–598** (325 °C) | - | Negative (s) | |
| 4 | **Thymine** (T) | $C_5H_6N_2O_2$ | 126,11 | **589–590** (317 °C) | - | - « - | |
| 5 | **Uracil** (U) | $C_4H_4N_2O_2$ | 112,09 | **608** (335 °C) | - | - « - | |

Table 2 presents nearest-neighbor parameters for DNA/DNA duplexes. It can be seen that all duplexes (excluding terminal base pair) have the stable supramolecular structures (**$\Delta G°37 < 0$**).

Table 2. Nearest-neighbor parameters for DNA/DNA duplexes (1 M NaCl)
[http://en.wikipedia.org/wiki/Nucleic_acid_thermodynamics]

| **Nearest-neighbor sequence (5'-3'/3'-5')** | **$\Delta H^{\circ}$ kJ/mol** | **$\Delta S^{\circ}$ J/(mol·K)** | **$\Delta G^{\circ}_{37}$ kJ/mol** |
|---|---|---|---|
| **AA/TT** | -33.1 | -92.9 | -4.26 |
| **AT/TA** | -30.1 | -85.4 | -3.67 |
| **TA/AT** | -30.1 | -89.1 | -2.50 |
| **CA/GT** | -35.6 | -95.0 | -6.12 |
| **GT/CA** | -35.1 | -93.7 | -6.09 |
| **CT/GA** | -32.6 | -87.9 | -5.40 |
| **GA/CT** | -34.3 | -92.9 | -5.51 |
| **CG/GC** | -44.4 | -113.8 | -9.07 |
| **GC/CG** | -41.0 | -102.1 | -9.36 |
| **GG/CC** | -33.5 | -83.3 | -7.66 |
| **Terminal A-T base pair** | 9.6 | 17.2 | 4.31 |
| **Terminal G-C base pair** | 0.4 | -11.7 | 4.05 |

The emergence of life on Earth in its current form, is associated with the emergence and functioning of biological hierarchies. Life is made possible primarily thanks to the commensurability of the specific Gibbs function of formation of chemical molecules - metabolites and supramolecular structures of living organisms [*Gladyshev*, 1997]. In other words, the thermodynamic stability of chemical and biological supramolecular structures is comparable.

At the same time, strong inequalities divide these values varying over time. Their difference depends of the types of compared molecules and supramolecular structures. Range of differences in these parameters contributes to a great variety of supramolecular structures. Biological diversity of cells, organs and living organisms of higher hierarchy is also associated with a broad spectrum of differences of thermodynamic stability of adjacent hierarchical levels. The existence of different commensurabilities (or the optimality) is connected with the diverse conditions of life on the planet and the presence of chemical elements which are present in the biosphere. Here the principle of substance stability manifests itself as the interaction of adjacent hierarchical levels and sublevels "according to an optimal way". This contributes to the efficient reproduction of hierarchical structures and their interaction. Applying to physiology and medicine, this principle can be called the principle of 'thermodynamic physiological commensurability" or the principle of "thermodynamic optimization of life." This latter physiological-medical principle is a special case of the general thermodynamic "principle of substance stability." Thus, the principle of substance stability is manifested in the Earth's biosphere as a principle of "thermodynamic optimization of life.” The principle of substance stability removes the question about the mysterious appearance and existence of life. Everything happens in accordance with the known laws of nature, which manifest themselves in the specific conditions prevailing on Earth. From this point of view, the definition of life can be presented [*Gladyshev*, 2014*a*]. We can now say:

**In the compressed general formulation, life can be defined as the phenomenon of existence of the energy-dependent dynamic hierarchic structures, as mandated by thermodynamics under certain conditions existing on celestial bodies.**

## 4. Life and its physiological optimization

Supramolecular (hierarchical) thermodynamics seeks a minimum specific Gibbs free energy (Gibbs function) of the formation of supramolecular structures. Supramolecular thermodynamics establishes the quasi-equilibriums in all local areas of the body. These quasi-equilibriums are characterized by the equality of chemical and supramolecular potentials of components interacting phases, which is achieved through electrochemical and other interactions. The organism is a unified structure, which supports the overall internal balance. This balance is ensured by the principle of substance stability. Function of the body are balanced by the actions of hierarchical thermodynamics. Environmental changes lead to a deviation from this equilibrium. If homeostasis is not able to compensate for the deviation of the specified changes, changes in nutrition, living conditions or use of therapeutic and other methods become necessary.

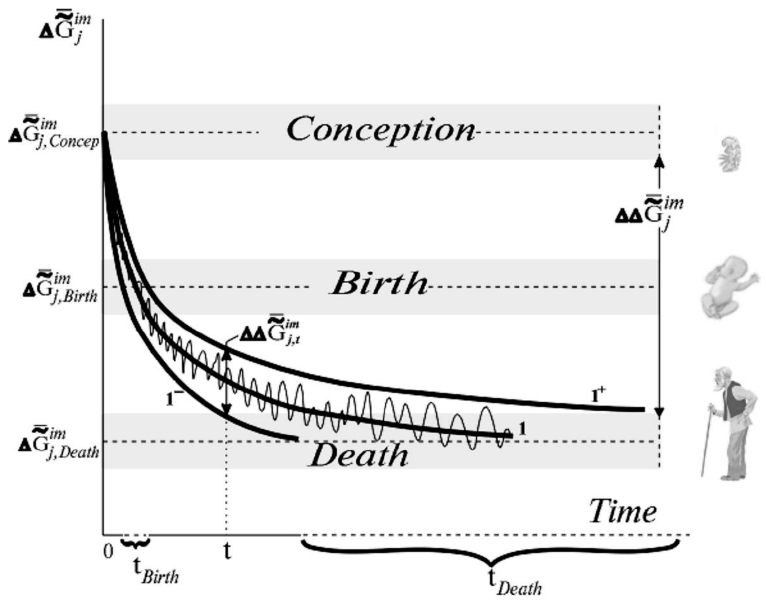



Fig. 4. The birth of a new organism, in the reproduction process, reminds one of the emergences of a crystalline matter at the introduction of crystals in oversaturated solution in laboratory and geochemical systems. The lifespan of an organism, as shown in the diagram, depends substantially on the conditions of the surrounding medium, nutrition and other known factors.

Well-known thermodynamic and experimental recommendations of the correction of food, supplements of vitamins, hormones and their imitators, as well as other drugs, can significantly improve the health of patients.

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 [*Gladyshev*, 1997]. It is easy to determine one of these parameters using what the author has referred to as the GPG (Georgi P. Gladyshev).

The easiest method employed to do this is by using measurement of the temperatures of the solidification (melting) of natural fats and oils contained in natural food products.

The usage for the food of various oils and fats alters the composition of body tissues due to changes in the composition of the lipid fraction. In addition this change is also slow (slightly) affects the composition of peptides and proteins of tissues. Function of many levels of the body, primarily dependent on low molecular weight components, such as water, lipids, amino acids, vitamins, hormones and others. All these components are involved in the functioning of the organism as a whole. **Despite the different nature of biological components of tissues, they combine with each other during the formation of local supramolecular structures "as like with like."** This circumstance allowed to justify and create a simplified quantitative method for the determination of anti-aging quality (gerontological valuable) of food, identifying only the thermodynamic characteristics of lipid fractions of products [*Gladyshev*, 1998; *Gladyshev*, 2003*b; Gladyshev*, 2004*a*; *Gladyshev*, 2004*c*; *Gladyshev*, 2007*b*; *Gladyshev*, 2011]. Scale for assessment of gerontological value of natural products based on measurement of the melting temperature Tm of individual lipid fractions [*Gladyshev*, 2004*a*; *Gladyshev*, 2014*a*].This scale is named "the Gladyshev's scale" [*Gladyshev*, 2014*a*].

Data presented on the scheme (fig. 5) and melting temperatures of seed's oils helps us to estimate anti-aging properties of natural seeds.

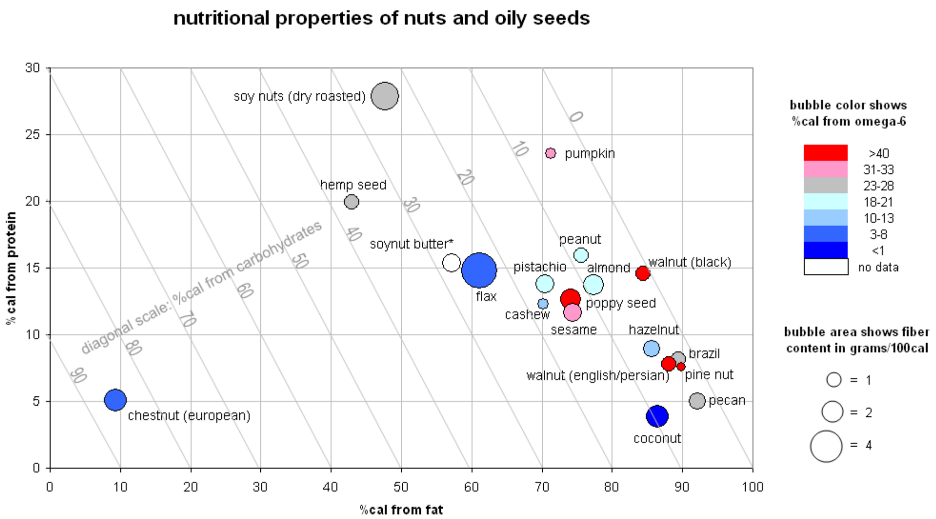



Fig. 5. Properties nuts and oily seeds.

There are new methods of complex hormonal therapy. For example, S. A Dzugan and colleagues made an important discovery http://www.lef.org/Vitamins-Supplements/Item33906/The-Migraine-Cure-paperback.html http://www.lef.org/Vitamins-Supplements/Item33820/Your-Blood-Doesnt-Lie.html . It was established that the maintenance of normal levels of specific hormones in the body contributes to the emergence of other hormones in the normal concentration. Everything happens in accordance with the chemical and supramolecular thermodynamics. It also confirms the fact that all processes in the body are the self-consistent processes (they are balanced) and occur in quasi-equilibrium conditions.

**The organism has a single common network of interacting quasi-equilibrium structures**. The optimal self-consistency of structures and their functioning emerged from evolution, the guiding force of which is hierarchical thermodynamics. This self-consistency was achieved by all the forces and factors, which are presented by members of the general relation (1).

This relation in differential form can be presented as [*Gladyshev*, 1997; *Gladyshev*, 2004*b*; *Gladyshev*, 2006; *Gladyshev*, 2007*a*; *Gladyshev*, 2007*b*; *Gladyshev*, 2014*a*; *Gladyshev*, 2014*b*]:

$$dG^* = \sum_i dG_i^* = -\sum_i S_i dT_i + \sum_i V_i dp_i - \sum_i \sum_{k_i} x_{k_i} dX_{k_i} + \sum_i \sum_{k_i} \mu_{k_i} dm_{k_i} \qquad (1)$$

where: G-Gibbs free energy; 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.

The 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.

In this case, the Gibbs equation is considerably simplified in connection with negligibly small values of the majority of its isolated or individual members. Symbolism or speculation consists in the fact that it is difficult to take into consideration simultaneously all multi-scale effects determining the behavior of complex heterogeneous poly-hierarchical system at once.

It is important to note that the simplified relations obtained from equation (1) are used in the study of tropisms [*Gladyshev*, 2014*a*], and in many physiological and other studies [*Gladyshev*, 1997]. The law of temporal hierarchies first substantiated the correctness of these approaches based on thermodynamics.

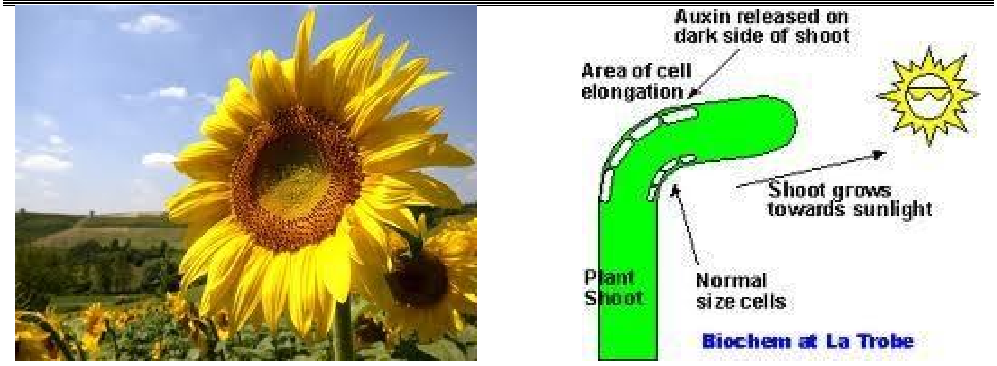



Fig. 6. Phototropism

It is important also to note that some medical recommendations can be based on the Weber-Fechner law [*Gladyshev*, 1997], which also has a thermodynamic origin.

The Weber-Fechner law (or Fechner's law) is the law of psychophysics (physiological law). It is the concept that the magnitude of a subjective sensation increases proportional to the logarithm of the stimulus intensity. This law can be presented as:

$\ln Y = bZ + \ln Y_0$ , (2)

were Z is defined by some authors as the intensity of sensation (the intensity of sound, of taste, etc.) and Y and $Y_0$ are the intensities (energy, concentration) of the stimulant which causes the given and threshold sensation. The Weber-Fechner law is fulfilled in many cases (nowadays, the formula most used is Stevens' formula). The Weber-Fechner law helps us to give some quantities' therapeutic, pharmacological and sport medicine recommendation.

## 5. Conclusion

Our results confirm the view that life originates and develops under the general laws of nature. Thermodynamics solves many puzzles of appearance and existence of life as a phenomenon of nature. Thermodynamics optimizes the physiology of life and helps us to provide us with medical recommendations. It is hoped that soon a new broad area of activity known as "the scientific optimization of medicine" will emerge.

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