

## New Criteria of Evolution and Involution of the Isolated Systems

V.A. Etkin\*

Togliatti State University (Russia)

\* etkin.v@mail.ru

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### Abstract

It has been shown that introduction of the parameters of heterogeneity into non-equilibrium thermodynamics allows us to offer non-entropic criteria for evolution, reflecting not only its anti-dissipative nature but also the speed of divergence from equilibrium as well as the new properties of the system thus acquired. Their use eliminates the disadvantages of entropy criteria and makes it possible to follow the evolution not only of the system as a whole but also each of its degrees of freedom. They reveal unity in the closed systems of the processes of evolution and involution, demonstrating the impossibility of the former in the absence of the second. Detection of these processes in interstellar space explains the evolutionary character of such processes in all observable forms of baryonic matter. The examples given in the article confirm this unity and prove the inevitability of some of the evolutionary processes. The proposed approach eliminates the contradiction of thermodynamics with the theory of evolution and excludes the "thermal death" of the universe, leading to the conclusion about the circulation of matter and energy.

**Keywords:** *Disequilibrium and irreversibility; the parameters of heterogeneity; the unity of evolution and involution; entropy and energy-dynamic criteria; ordered and disordered energy; dissipative and anti-dissipative processes; self-organization and structuralization.*

### 1. Introduction

"A glaring contradiction between thermodynamics and the theory of biological evolution" [1] is well known. This is mainly due to the use in the classical thermodynamics [2] of entropy-centered criteria of evolution [3]. Critically analyzing the history of its formation, it is difficult to find a parameter less appropriate to the analysis of the problems of evolution than entropy. In fact, in adiabatic processes, entropy is only able to grow, reflecting the degradation of the system as it approaches equilibrium. However, it remains unchanged when useful (reversible) work "against equilibrium" is done in a system, thus giving rise to a process of evolution, understood as the perfection and development of the system, its acquisition of new properties, etc. Further, the growth of entropy appears only as a consequence of irreversibility, whose origins are nowhere indicated. Finally, principles of entropy cannot reflect the existence of incomplete equilibrium in polyvariant systems; such an incomplete equilibrium is characterized by the cessation of only part of the processes taking place in those systems.

From the standpoint of modern science, the very attempt of the founders of classical thermodynamics to take irreversibility into account without taking into account its causes, that is, disequilibrium, is puzzling. This also applies to usage of entropy as a characteristic function. The historical use of the concept of entropy in this capacity was due to the rejection by the classical thermodynamics of the concept of force in the language of which the Lagrangian theory of equilibrium was formulated. It seems that with the advent of "semi-thermodynamics" of Lars Onsager [4] and the introduction of the understanding of the vector  $\mathbf{X}_i$  of "thermodynamic force" into the theory of the

thermodynamics of irreversible processes (TIP) [5,6], expressing the tendency of systems towards equilibrium in the accessible and understandable language of classical mechanics became possible. However, neither the linear theory of irreversible processes (TIP) [5,6], nor the "extended" thermodynamics of disequilibrium [7], nor even thermodynamic field theory, based on the principles of the calculus of variations in mechanics [8], followed this natural path.

As a result, the TIP did not eliminate the contradiction noted above, given that the thermodynamic forces  $\mathbf{X}_i$  and the fluxes  $\mathbf{J}_i$  which are found in that theory are based on the same principle of increasing entropy as in the contradiction. Such forces and fluxes only characterized the relaxation processes. Furthermore, they did not provide an unambiguous assessment of losses due to irreversibility, as their product depended on the manner of partitioning it into factors. In addition, they could not reflect the conditions of incomplete equilibrium, because in TIP these fluxes and forces disappear only with the onset of complete equilibrium.

In this situation it is undoubtedly of interest to approach the problems of evolution from the standpoint of energy dynamics, which, unlike the "near-equilibrium thermodynamics" of L.Onsager [4] or the "pseudothermodynamics" W.Tjimson [9], does not exclude from consideration any (reversible or irreversible) part of real processes [10]. It presents itself as a consistent generalization of the classic method of characteristic functions, first to inhomogeneous systems [11] and non-static processes [12], and furthermore to non-thermal forms of energy, thereby ensuring that the theory is consistent with the collection of problems to be solved. This theory offers heterogeneity parameters which are then able to

reflect the tendencies away or towards equilibrium, not only for the whole system but also for each of its inherent degrees of freedom. As regards the entropy  $S$ , in energy dynamics it plays a more modest role as merely one of "commensurate" coordinates for the expression of the state and is interpreted as "thermal impulse" (total momentum of the particles, having lost its vectorial nature due to the randomness of the thermal motion). Thermal impulse is associated with absolute temperature  $T$  just as the mechanical impulse is associated with the absolute velocity of ordered motion [13]. It increases both with the input of thermal energy from outside the system and with the conversion into thermal energy of other forms of energy. However, it is not able to reflect the new properties acquired by the system in the process of evolution. This role is assumed by intensive and extensive parameters of the spatial heterogeneity of the systems under study. This allows one to make corrections, thus invalidating the remarks of Ilya Prigogine concerning the contradictions between thermodynamics and the theory of biological evolution.

## 2. The Essence of the Energodynamic Method in its Application to the Problems of Evolution

The introduction of spatial inhomogeneity parameters is dictated by the existence in a non-equilibrium system of a specific class of "redistribution" processes of some extensive thermodynamic quantity  $\Theta_i$  (mass  $M$ , entropy  $S$ , charge  $Z$ , number of moles of  $k^{\text{th}}$  substances  $N_k$ , components  $P_k$  and  $L_k$  of their relative motion  $\mathbf{P}_k$ , and its moment  $\mathbf{L}_k$ , etc.) in terms of the volume of the system  $V$ . For clarity, such processes are illustrated in Fig. 1, which shows the distribution curves of their density  $\rho_i(\mathbf{r}, t)$  and the potentials  $\Psi_i$  conjugated to them along the radius vector  $\mathbf{r}$ .

As follows from the figure, the deviation of the density  $\rho_i = \partial\Theta_i/\partial V$  of the quantity  $\Theta_i$  (hereafter referred to as "the energocarryer") from the equilibrium energy is accompanied by the transfer of some of its quantity  $\theta^*$  from one part of the system to the other in the direction indicated by the dotted arrow. Such a transfer causes the center of this magnitude to shift from the original position  $\mathbf{R}_{i0}$  to the current  $\mathbf{R}_i$ , determined in a known way:

$$\mathbf{R}_{i0} = \Theta_i^{-1} \int \bar{\rho}_i(t) \mathbf{r} dV; \quad \mathbf{R}_i = \Theta_i^{-1} \int \rho_i(\mathbf{r}, t) \mathbf{r} dV, \quad (1)$$

where  $\mathbf{r}$  is the traveling (Euler) spatial coordinate.

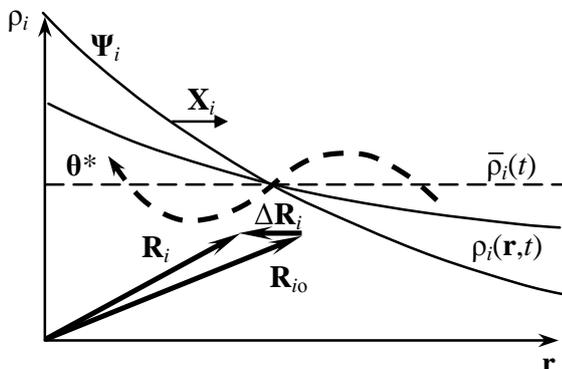


Figure 1. To the formation of the distribution moment

Hence it follows that the current state of the system differs from the equilibrium by the appearance of specific "distribution moments":

$$\mathbf{Z}_i = \Theta_i \Delta \mathbf{R}_i = \int [\rho_i(\mathbf{r}, t) - \bar{\rho}_i(t)] \mathbf{r} dV \quad (2)$$

with the arm  $\Delta \mathbf{R}_i = \mathbf{R}_i - \mathbf{R}_{i0}$ , which we called the "displacement vector" of the center of the quantity  $\Theta_i$  [14]. Since, in homogeneous systems,  $\mathbf{R}_{i0}$  coincides with the center of the fixed volume  $V$ , the coordinate  $\Theta_i$  can be taken as the origin of any of the parameters  $\mathbf{Z}_i$ . Thus, in non-uniform (internally non-equilibrium) systems, any  $i$ -form of their internal energy  $U_i$  is characterized not by one but by two parameters  $\Theta_i$  and  $\mathbf{R}_i$ , i.e.  $U_i = U_i(\Theta_i, \mathbf{R}_i)$ <sup>1)</sup>. In this case, the total differential of the internal energy  $U = \sum_i U_i(\Theta_i, \mathbf{R}_i)$  can be represented in the form of the identity:

$$dU \equiv \sum_i \Psi_i d\Theta_i - \sum_i \mathbf{F}_i \cdot d\mathbf{R}_i, \quad (i = 1, 2, \dots, n) \quad (3)$$

where  $\Psi_i \equiv (\partial U / \partial \Theta_i)$  is the average value of the generalized potential of the system  $\psi_i$  (the absolute temperature  $T$  and the pressure  $p$ , the chemical  $\mu_k$ , the electric  $\phi_k$ , the gravitational  $\psi_k$  potential of the  $k^{\text{th}}$  substance, the relative velocity of its displacement  $\mathbf{v}_k$ , etc.);  $\mathbf{F}_i \equiv -(\partial U / \partial \mathbf{R}_i)$  - forces in their usual (Newtonian) understanding [10,14].

It is convenient to express the terms of the second sum of the identity (3) in terms of the thermodynamic forces  $\mathbf{X}_i$  in their so-called "energy" representation [6], defining them by the relation:

$$\mathbf{X}_i \equiv -(\partial U / \partial \mathbf{Z}_i). \quad (4)$$

At the same time, energy flows  $\mathbf{J}_i$  take a quite definite and unambiguous meaning of the energy carrier pulse  $\Theta_i$ :

$$\mathbf{J}_i \equiv d\mathbf{Z}_i / dt = \Theta_i \mathbf{v}_i, \quad (5)$$

where  $\mathbf{v}_i = d\mathbf{R}_i / dt$  is the relative velocity of the energy carrier  $\Theta_i$ .

The thermodynamic forces  $\mathbf{X}_i$  represent the specific value of the force  $\mathbf{F}_i$ , since  $\mathbf{X}_i \equiv -(\partial U / \partial \mathbf{Z}_i) = -\Theta_i^{-1} (\partial U / \partial \mathbf{R}_i) = \mathbf{F}_i / \Theta_i$ . They characterize the intensity of the corresponding (temperature, electric, gravitational, etc.) field. The work  $\mathbf{X}_i \cdot d\mathbf{Z}_i$  performed by such forces can be external or internal, mechanical or non-mechanical, useful (directed "against equilibrium") or dissipative (associated with overcoming of scattering forces). However, it always remains a quantitative measure of the process of transforming the energy of the  $i$ -th form into the  $j$ -th. This is important for understanding the evolution processes.

Thus, energodynamics gives a unified definition of different natures forces. This allows us to obtain the basic principles, laws and equations of mechanics, thermodynamics, electrodynamics, the theory of heat-mass transfer and other disciplines as a consequence of energy dynamics [15]. It is important that the identity (3) characterizes the change in the internal energy of a non-equilibrium system  $U$ , regardless of whether it is caused by external energy exchange or internal (including dissipative) processes. This makes it possible to apply it to isolated systems with non-static processes taking place in them:

$$dU / dt \equiv \sum_i \Psi_i d\Theta_i / dt - \sum_i \mathbf{X}_i \cdot \mathbf{J}_i = 0. \quad (6)$$

This makes it possible to substantially simplify the investigation by eliminating external energy, external work and heat exchange, and applying the conservation laws in

<sup>1)</sup> In an even more general case, the reorientation of the  $\mathbf{R}_i$  vector in space [12] is also taken into account.

their simplest forms. The identity (6), supplemented by equations of state found empirically, and transport of the general form

$$\Psi_i(\Theta_i, \mathbf{X}_i); \mathbf{J}_i = \mathbf{J}_i(\Theta_i, \mathbf{X}_i), \quad (7)$$

allows us to solve a wide class of problems connected with the transfer and transformation of various forms of energy. The forces  $\mathbf{X}_i$  and the flows  $\mathbf{J}_i$  contained in them reflect not only the causes of the occurrence of certain processes but also their generalized velocities. In contrast to the production of entropy  $d_iS/dt$ , they indicate a specific cause of irreversibility. The uniqueness of their meaning eliminates the known arbitrariness in their choice by splitting the "entropy production"  $d_iS/dt$  into factors  $\mathbf{X}_i$  and  $\mathbf{J}_i$ <sup>1)</sup>. This eliminates the need to compose cumbersome equations for the balance of mass, charge, momentum and entropy.

At the same time, identity (6) makes it possible to easily distinguish energy transfer processes (energy exchange without changing the form  $d\bar{U} = \sum_i \Psi_i d\Theta_i$ ) and energy conversion (energy exchange with a change in the form  $d\tilde{U} = -\sum_j \mathbf{X}_j \cdot d\mathbf{Z}_j$ ). Their character depends on what part of the energy of the system they affect: the equilibrium (scattered, disordered)  $\bar{U}$  or the nonequilibrium (ordered)  $\tilde{U}$ . In an isolated system, a part not in equilibrium can undergo mutually opposite changes, whereas, in the equilibrium part, only the term  $TdS$  changes due to the laws of conservation of mass, charge, pulse. The characteristic functions  $\tilde{U}$  and  $\bar{U}$  referred to in energodynamics, for reasons of brevity, respectively as *inergy* and *anergy*, generalize the concepts of free energies of Helmholtz and Gibbs [2] and make the analysis of evolutionary processes more informative.

### 3. Energetic Criteria of Evolution

Intensive  $\mathbf{X}_i$  and extensive  $\mathbf{Z}_i$  parameters of disequilibrium allow one to easily distinguish the processes of evolution from the opposite processes of involution (degradation) of the system. Their combination allows us to reflect the quantitative and qualitative parts of these processes for each  $i$ -th degree of freedom of the system

$$\begin{aligned} d\mathbf{Z}_i > 0 \text{ or } d|\mathbf{X}_i| > 0 & \text{ (the evolution);} \\ d\mathbf{Z}_i < 0; d|\mathbf{X}_i| < 0 & \text{ (the involution),} \end{aligned} \quad (8)$$

where  $|\mathbf{X}_i|$  is modulus of force  $\mathbf{X}_i$ .

What is fundamentally new here is not only the simplicity of the clarity of the physical meaning of these parameters but also the discovery of the possibility of the simultaneous evolution of processes of evolution and involution in different domains or degrees of freedom of the system, i.e. their dialectical unity. This is especially obvious in the case of isolated ( $dU/dt = 0$ ) conservative ( $dS = 0$ ) systems. For them, by virtue of the laws of conservation of

<sup>1)</sup> In particular, for processes of diffusion of the  $k$ -th substance in multi-component systems, the TIP admits, as motive forces, the expressions:  $-\Delta c_k$ ;  $-\Delta(c_k/T)$ ;  $-\Delta c_k/T$ ;  $-\Delta h_k$ ;  $-\Delta(h_k/T)$ ;  $-\Delta h_k/T$ ;  $-\Delta \mu_k$ ;  $-\Delta \mu_k/T$ ;  $-\Delta(\mu_k/T)$ , where  $c_k$ ,  $h_k$ ,  $\mu_k$  are the concentration, enthalpy and chemical potential of the  $k$ -th substance, resp. [3,4].

mass, charge, pulse, etc (see note above).  $d\Theta_i/dt = 0$ , so that it follows directly from (6) that:

$$\sum_i \mathbf{X}_i \cdot \mathbf{J}_i = 0. \quad (9)$$

For  $\mathbf{J}_i \neq 0$ , this is possible only for processes in different degrees of freedom of the polivariant system having opposite signs (directions). In view of the special significance of this provision we will call it the "*principle of the unity of evolution and involution*". This principle in no way follows from the TIP since in TIP the product of the streams  $\mathbf{J}_i$  and the thermodynamic forces  $\mathbf{X}_i$  has always been purely positive.

Thanks to the allocation of the ordered part of the energy of the system (inergy), this principle can be extended to non-isolated (including open and non-closed) systems.

$$\begin{aligned} d\tilde{U} &= -\sum_i \mathbf{X}_i \cdot d\mathbf{Z}_i > 0 \text{ (the evolution);} \\ d\tilde{U} &= -\sum_i \mathbf{X}_i \cdot d\mathbf{Z}_i < 0 \text{ (the involution).} \end{aligned} \quad (10)$$

When the dissipative (involutionary) and antidissipative (evolutionary) processes take place simultaneously in the system, their total result depends on the prevalence of one or the other. This depends on the ratio of the power dissipative processes in some ( $i$ -th) and antidissipative processes in other ( $j$ -th) degrees of freedom of the system:

$$dU/dt = -\sum_i \mathbf{X}_i \cdot \mathbf{J}_i - \sum_j \mathbf{X}_j \cdot \mathbf{J}_j. \quad (11)$$

In the presence of the equations of state and transport (7), this result gives researchers an additional tool for analyzing problems of evolution in objects of animate and inanimate nature.

### 4. The Dialectical Opposite of Processes in the Universe

One of the results of applying energy dynamics to the study of the problems of the evolution of the universe is the discovery of subsystems developing contrary to prediction. Recent astrophysical discoveries have established that along with the observed (baryonic, structured) matter, its antipode dominates in interstellar space. This appears to be latent (non-baryon) matter that does not participate in electromagnetic interaction and is manifested only due to gravitational forces [16]. Since the share of the mass of the observable universe of this "dark matter" is not less than 95% [17], it should be considered that it is the primary form of matter, from which all other forms of baryonic matter during a "condensation" are formed. Similarly, the "strong" gravitation inherent in it should be considered the primary form of the energy of baryonic matter [18].

In order to clarify the cause of the phase transition of non-baryonic matter to baryonic matter, we first see that the homogeneous distribution of matter in the universe is unstable and spontaneously transfers to an inhomogeneous state which we observe in the form of dust-gas clouds, nebulae, stars, and galaxies. To this end, we represent the magnitude of the acceleration of gravity  $g = GM/R^2$  in Newton's law as a function of the density  $\rho$ . To do this, we write this expression for a sphere of unit volume  $V$  with radius  $R_0$  and mass  $M = \rho V$ :

$$g = (GV/R_0^2)\rho. \quad (12)$$

According to this expression, the acceleration of gravity  $\mathbf{g}$  on the surface of such a sphere of unit volume is directly proportional to the density  $\rho$ . This means that if in any region of the universe, the density of matter increases spontaneously, then the gravitational forces will cause it further increase up to the formation of superdense celestial bodies. This unique feature of non-baryonic matter sheds new light on all subsequent stages of the process of the circuit of matter and energy in the universe. We assume that the initial stage of this cyclic process is the condensation of non-baryonic matter of some regions and rarefaction of others. The result of such processes is a change in its density of  $\sim 10^{-27}$  g/cm<sup>3</sup> and less for the intergalactic medium to  $\sim 10^{18}$  g/cm<sup>3</sup> or more for white dwarfs. The baryonic substance formed as a result of such "condensation" of non-baryonic matter acquires new forms of energy (thermal, chemical, electrical, etc.). Since in this process the energy of non-baryonic matter decreases, it undergoes an *involution*.

Thus, the astrophysical discoveries of recent times lead to the inevitable conclusion about the opposite direction of processes in the baryonic and non-baryonic phase of the matter of the Universe. Since in an isolated system all processes are spontaneous, the term "self-organization" is quite acceptable for the processes of evolution of baryonic matter. This process obeys the condition:

$$dU_i/dt = -\mathbf{X}_i \cdot \mathbf{J}_i > 0. \quad (13)$$

Nevertheless, from the standpoint of cause-effect relations, the process of self-organization looks like a forced, stimulated by the involution of its non-baryonic part of the matter of the Universe:

$$dU_g/dt = \Psi_g dM_g < 0. \quad (14)$$

This "opposite direction" of evolutionary processes in the Universe does not allow us to speak of its "self-organization" as a whole. It is more correct to talk about the unity of the processes of evolution and involution, in which the processes of structuring in some parts (regions, phases, components) of the system are accomplished through the accomplishment of internal work "against equilibrium" on the part of other, degrading parts or degrees of freedom of the same system. Therefore, it is important to show that the formation of baryonic matter is accompanied by ordering and not by scattering of energy, and therefore has an evolutionary rather than a dissipative character.

## 5. The Emergence of Standing Waves as an Evolutionary Process

A fundamentally new proposition of energodynamics is the assertion that, according to (14), the processes of involution are by no means reducible to energy dissipation. This, in particular, is the quasistatic process of mass redistribution in non-baryonic matter, accompanied by a decrease in the equilibrium part of its gravitational energy  $U_g$  (ie, its anergy). However, it leads to the appearance of baryonic matter. It is easier to identify the specificity of this process by expressing its mass  $M$  in the form of the integral  $M = \int \rho dV = \int \bar{\rho} dV$  from its local  $\rho$  and average density  $\bar{\rho}$ :

$$\int (\rho - \bar{\rho}) dV = 0. \quad (15)$$

It follows directly from (15) that the density of matter in non-baryonic matter grows in one region of space of

volume  $V$  and decreases in another region of volume  $V'$ . However, in an ordinary wave (Fig. 2), the amplitudes of  $\rho - \bar{\rho}$  in the positive and negative phases are equal. This means that the density at the antinode of the wave does not exceed  $2\bar{\rho}$ , so that wave formation can not be the cause of the "condensation" of non-baryonic matter. For this, it is necessary that  $(\rho - \bar{\rho}) \gg (\bar{\rho} - \rho)$  in the negative phase of the wave. It is possible if the volume of this phase is  $V'' \gg V'$ . In this case, the standing wave that appears is like a soliton as a "wave of elevation" with an unlimited maximum density at its antinode. This is the nature of any structural elements of baryonic matter, from microscopic waves to giant stars sizes. The length of such soliton-like waves, judging by experience and astronomical observations, can be the most diverse. Such, in particular, are microwaves that leave a point trace in the cloud of the Wilson cloud chamber and therefore are taken as particles. Shock waves formed ahead of rapidly moving celestial bodies [19] or concentric waves sporadically arising in the intergalactic medium (called "radio-mirrors") [20], as well as giant waves (with a radius of  $\sim 500$  million light years), formed by concentric clusters of galaxies [21]. Such waves are very stable, and in view of the absence of dissipation in the non-baryonic matter, they can exist indefinitely also after the cessation of their condensation.

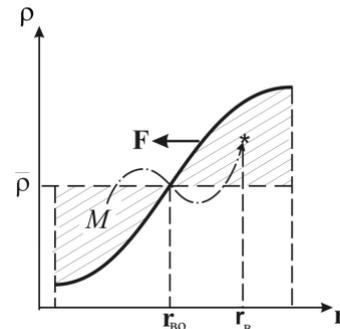


Figure 2. Half-wave as a dipole.

The waves that arise under the conditions  $V'' \approx V'$  have a different character. They are closer in properties to harmonic waves and are characterized by the opposite direction of mass displacements in each half-wave. As a result, its total displacement is zero, and the wave remains standing at every point between the reflecting "walls". The process of wave formation in such waves is illustrated in Figure 2. For simplicity, it depicts only one half-wave. It follows from the figure that the deviation of the local density  $\rho$  from its mean value in the half-wave is accompanied by the transfer of the center of its mass  $M$  from the position of  $\mathbf{r}_{Bo}$  to the position of  $\mathbf{r}_B$ , i.e. its displacement in each half-cycle by a distance  $\Delta \mathbf{r}_g = \mathbf{r}_B - \mathbf{r}_{Bo}$ , equal to a quarter of the wavelength  $\lambda$ . This displacement acquires the opposite sign in the next half-period of the oscillation, as a result of which an oscillatory motion of the non-baryonic substance arises in which the quantity  $\Delta \mathbf{r}_g$  changes its sign. Such oscillations do not lead to the transfer of the oscillating mass beyond the limits of the wave, i.e. the wave formed is a standing wave. The length of such waves, judging by observation, including astronomical observations, can be the most diverse - from microwaves leaving a point trace in a Wilson chamber or on a photoemulsion, to shock waves formed ahead of fast

moving celestial bodies [19], to concentric waves ("radio mirrors") sporadically arising in the intergalactic medium [20], or even to larger waves forming concentric clusters of galaxies with a radius of ~ 500 million light-years [21]. The reason for such an ordered arrangement of galaxies is considered to be "baryonic acoustic oscillations of the primary plasma of the Universe" [22].

In order to estimate the magnitude of the emerging kinetic energy of the vibrational motion  $U_k$ , we take into account that the displacement by a distance  $|\Delta \mathbf{r}| \approx \lambda/4$  occurs over a half-cycle of  $1/2\nu$ . Therefore, the average rate of mass displacement  $v_g$  at the frequency  $\nu$  is equal to:

$$v_g = 2\nu/\Delta \mathbf{r}_g \approx \lambda\nu/2 \approx c/2. \quad (16)$$

In this case, the density of the kinetic energy of the vibrational motion is

$$\rho^k \equiv \rho v_g^2/2 = \rho c^2/8 \quad (17)$$

If the density of the initial "gravitational" energy of the non-baryonic substance is taken equal to (in accordance with the principle of equivalence)  $\rho_g = \rho c^2$ , then this kinetic energy will be about eighth of it. It is appropriate to call this energy "gravodynamic". It can easily be transformed into any other form of energy, which makes non-baryonic matter capable of performing work even with the unchanged position of celestial bodies [23]. The establishment of the presence of such a source of energy (inertia) in the universe constitutes a fundamental feature of the energy-dynamic approach.

## 6. The Emergence of New Forms of Energy in Baryonic Matter

As we have shown above, spontaneous processes of redistribution of the non-baryonic matter lead to the appearance of two new degrees of freedom. Their result is the formation of a baryonic substance consisting of polarized structures. These are different charges, spins, magnetic poles, and so on. These structures, which we call particles, have new forms of energy. Thermal energy is not an exception since part of the vibrational energy of the baryonic substance is disordered (chaotic) because of the different orientation of the displacement vectors  $\Delta \mathbf{r}_g$ .

The evolution of the bound energy  $TS$  is subject to the condition:

$$dU_T = TdS + SdT > 0. \quad (18)$$

This expression is equivalent to the equation of the second law of thermodynamics in the form proposed by I. Prigogine [1]:

$$T(d_e S/dt + d_i S/dt) > 0, \quad (19)$$

where  $d_e S = \delta Q/T$  and  $d_i S = \delta Q^d/T$  are entropy increments caused by external heat transfer  $\delta Q$  and internal sources of heat dissipation  $\delta Q^d$ . To see this, we represent the total time derivative of the entropy  $S$  as the sum of its local and convective parts:

$$dS/dt = (\partial S/\partial t)_r + (\mathbf{v}_s \cdot \nabla)T. \quad (20)$$

The last term in (20) can be represented in the form:

$$dU_T/dt = T(d_e S/dt + d_i S/dt) = \delta Q^e/dt - \mathbf{J}_s \cdot \mathbf{X}_s > 0, \quad (21)$$

where  $\mathbf{J}_s = S\mathbf{v}_s$  is the entropy flux;  $\mathbf{X}_s = -\nabla T$  - its driving force, as is customary in the thermodynamics of irreversible processes [5,6].

In adiabatically isolated inhomogeneous systems,  $\delta Q = 0$ , and the last term (21) can be positive or negative, depending on the direction of the entropy flux  $\mathbf{J}_s$ . Thus, the change in the bound energy  $U_q$  in thermally inhomogeneous systems can be the opposite of that prescribed by the second law of thermodynamics if an internal work is performed against the thermal equilibrium in an isolated system. This means that thermal energy, like any other, contains both the equilibrium "scattered" part of  $\bar{U}_q = \bar{T}S$ , where  $\bar{T} = S^{-1} \int T \rho_s dV$  with density  $\rho_s = \partial S/\partial V$ , and the non-equilibrium part  $\tilde{U}_q = U_q - \bar{U}_q$  a part capable of performing work in thermal machines, i.e. by transformations into other forms of energy. In other words, also for thermal energy, both evolution and involution are possible. This becomes especially obvious in the processes of "supernova explosion," which are accompanied by the reverse transformation of the baryonic substance into a non-baryonic substance, in which there is no thermal motion. In this boundedness of the second law of thermodynamics with baryonic matter lies the reason for the incompetence of the theory of "thermal death of the universe" [3].

## 7. Crystallization of Baryonic Matter as an Evolutionary Process

Processes of structuralization in ordinary (baryonic) matter are often referred to as processes of "self-organization." In fact, they should be attributed to the same class of "conjugate" processes as chemical reactions that take place in the direction of increasing chemical affinity, ascending diffusion (the transfer of matter towards an increase in its concentration), "active transport" in biological membranes, creation of "inverse population" of energy levels in a system of nuclear spins, and so on. All such processes are stimulated, i.e. caused by the performance of work "against equilibrium" by external energy sources or other components of the same system. A distinctive feature of such processes is their evolutionary (antidissipative) character, manifested in an increase in the ordered part of the corresponding form of energy (inergy), contrary to the general tendency to establish equilibrium in the system.

One such process is the formation of single crystals of various shapes. From the thermodynamic standpoint, the crystallization process is presented as an analog of the phase transformation associated with the formation of elementary volumes  $V_j$  of the new phase with the surface  $f_j$  and the surface tension  $\sigma_j$ . In the Woolf model, a single crystal is considered as a set of pyramids with a height  $h_j$  and a volume  $V_j$  whose vertices are at some common "Wolf point" inside the crystal. The basis of such pyramids is the corresponding  $j^{\text{th}}$  facet of a single crystal with area  $f_j$  [2]. In such a case, the formation of a single crystal can be interpreted as a process of volume deformation of a crystalline phase with a volume  $V = \sum_j V_j = 1/3 \sum_j f_j h_j$ .

According to this model, the equilibrium form of a single crystal is characterized by the fact that its faces are removed from the common vertex of the pyramids by a distance proportional to the surface tension of the faces  $\sigma_j$ . It follows from this that the rate of growth of individual faces of a single crystal is proportional to the surface tension (free energy) of these faces (Wolff's law)

$$\sigma_j/h_j = \text{const}, \quad (23)$$

which agrees with experiment. It is easy to see that such a model of the crystallization process is justified also from the standpoint of energodynamics since the coordinates of the centroid of each of the pyramids are displaced on the average by the value  $|\Delta \mathbf{R}_j| = \frac{2}{3}h_j$ . This leads to the formation of a "moment of volume distribution"  $|\mathbf{Z}_j|$ , which is conjugate to the force  $|\mathbf{X}_j| = \sigma_j$ . Thus, Wolff's law (23) is a direct consequence of the evolution criteria (8) and (10):

$$dU_f = -\mathbf{X}_f \cdot d\mathbf{Z}_f > 0, \quad (24)$$

The increase in the ordered energy of surface tension (its inertia) occurs in this process due to the decrease of its other forms. Therefore, crystallization is incorrectly considered a process of "self-organization." We cannot consider the emergence of "order" in crystalline structures arising from "chaos", since only those components of the system that themselves have ordered energy can perform the structuralization work.

### 8. The Processes of Evolution of Rotating Systems

Let us now consider an example where the evolution of a system consists in the appearance of additional forms of its kinetic energy. Suppose that we have an unbalanced top whose momentum  $\mathbf{L}_k$  does not coincide with the proper axis of its rotation, as a result of which, in addition to rotating around its own axis with angular velocity  $\boldsymbol{\Omega}_k$ , it undergoes precession with angular velocity  $\boldsymbol{\omega}_k$  (Figure 3). If you align the x-axis with the axis of symmetry of the top, and the y-axis with the plane formed by the vectors  $\mathbf{L}_k$  and  $\boldsymbol{\Omega}_k$ , then the angular velocity of rotation of the top about its own axis  $\boldsymbol{\Omega}_k = |\boldsymbol{\Omega}_k|$  and the angular velocity of its precession  $\boldsymbol{\omega}_k = |\boldsymbol{\omega}_k|$  can be expressed by the relation [17]:

$$\boldsymbol{\Omega}_k = L_k \cos \varphi / I_x; \quad \boldsymbol{\omega}_k = L_k / I_y, \quad (25)$$

where  $L_k = |\mathbf{L}_k|$ ;  $I_x, I_y$  are moments of inertia of the top with respect to the x and y axes;  $\varphi$  is the angle formed by vectors  $\mathbf{L}_k$  and  $\boldsymbol{\Omega}_k$ .

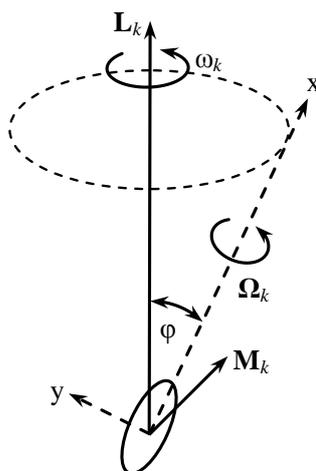


Figure 3. Precession of the Whirligig.

These angular velocities correspond to the internal kinetic energies  $U_k^c = L_k^2 \cos^2 \varphi / 2I$  and the energy due to its precession,  $U_k^p = L_k^2 / 2I_y$ , so that the total kinetic energy of this "whirligig"  $U^k = L_k^2 (\cos^2 \varphi + I_x / I_y) / 2I_x$  is in general not only a function of  $\mathbf{L}_k$  but also of the angle  $\varphi$ . Comparing it

with the value  $U_o^k = L_k^2 / 2I_x$  at  $\varphi = 0$ , we find that it exceeds the energy in the absence of precession by the quantity:

$$U^k - U_o^k = L_k^2 (I_x / I_y - \sin^2 \varphi) / 2I_x. \quad (26)$$

This corresponds to the criteria of evolution (8,10) and means that new degrees of freedom in the system arise as it moves away from equilibrium due to work which is done on it "against equilibrium", and not because of dissipation.

### 9. Processes of Evolution and Involution of Biological Systems

In recent decades, the notion of "self-organization" in living and inanimate nature as a spontaneous process arising as a result of cooperative (synergetic) action has become popular [24]. Examples of "self-organization" processes are usually referred to as "Bénard cells", Belousov-Zhabotinsky reactions, processes of "active transport" in living organisms, "ascending diffusion", etc. It is interesting to show that all these examples demonstrate the principle of the unity of the processes of evolution and involution.

Indeed, if we include the environment surrounding it in the notion of an "extended" system, then we can isolate such a set of interacting bodies, which can then be regarded with sufficient accuracy as an isolated system. For such a system, by virtue of the laws of conservation of mass, charge, impulse (impulse = change in momentum; it is momentum which is conserved) and its moment, and taking (4) into account, the identity (6) takes the form:

$$TdS/dt = \sum_i \mathbf{X}_i \cdot \mathbf{J}_i. \quad (27)$$

This is the basic equation of the thermodynamics of irreversible processes [1-8]. If the thermodynamic forces  $\mathbf{X}_i$  are found as the derivatives  $\mathbf{X}_i \equiv T(\partial S / \partial \mathbf{Z}_i)$ , then any of the streams  $\mathbf{J}_i$  will have the same sign as the corresponding force  $\mathbf{X}_i$ . Then the products  $\mathbf{X}_i \cdot \mathbf{J}_i$  will be strictly positive. Meanwhile, when work is performed "against equilibrium" (as in the case of ascending diffusion or active transport), the flows  $\mathbf{J}_i$  are directed towards the forces  $\mathbf{X}_i$ , and their product  $dW_i = \mathbf{X}_i \cdot \mathbf{J}_i$  is negative. This contradiction means that TIP in its existing form cannot describe the processes of self-organization.

There are other cases in energodynamics in which forces are defined as derivatives of energy (4), and therefore may have a sign opposite to the flow. In such cases, identity (6) for isolated systems takes the form:

$$dU/dt = Td_i S/dt - \sum_i \mathbf{X}_i \cdot \mathbf{J}_i = 0. \quad (28)$$

In full accordance with thermodynamics, it follows that such processes can be both dissipative ( $\mathbf{X}_i \cdot \mathbf{J}_i > 0$ ), and antidissipative ( $\mathbf{X}_i \cdot \mathbf{J}_i < 0$ ), but the former should prevail. This removes any prohibition on the simultaneous occurrence in an isolated system of opposing processes of evolution and involution. Moreover, it can be shown that the course of antidissipative processes in any system slows its approach to equilibrium [25]. The latter circumstance plays a particularly important role in living nature, whereby evolution becomes a means of prolonging life. In energodynamics, this principle has been termed "the principle of survival": those species that have a higher proportion of evolutionary processes exist longer [10]. This state of affairs is not something inspired by a higher consciousness or the deliberate and purposeful Darwinian "struggle for existence": it is the result of purely physical

and completely natural causes. Thus all the contradictions inherent in equilibrium and non-equilibrium thermodynamics are eliminated in its application to the theory of evolution.

## 10. Conclusions

1. Using as criteria the parameters of disequilibrium and their functions instead of entropy and its derivatives allows us to follow the change in the state not only of the system as a whole but also of each of its inherent degrees of freedom, thus exhibiting the most complete information about its evolution and involution (degradation), energy effect, etc.

2. The understanding of features of the evolution of natural systems is greatly facilitated if one adheres to the principle of unity of the processes of evolution and involution (development and degradation) in different areas or degrees of freedom of the systems under investigation. The rationale for this principle proposed in the article can be considered as a mathematical proof of one of the most important laws of dialectics: the unity and struggle of opposites.

3. The non-baryonic (unstructured) matter of the universe, like the baryonic one, is characterized by involution (degradation) processes going in the direction of the decrease of its "gravitostatic" (with its antipode gravitokinetic) energy. Precisely they are the cause of its transformation into the baryonic matter and the acquisition of its new properties. Thus, the involution (degradation) of hidden mass leads to the opposite processes of evolution of all forms of matter studied in thermodynamics in spite of their dissipative processes.

4. The examples presented in the article testify to the acquisition by ordinary matter in the processes of evolution of new properties and forms of energy. This confirms the anti-dissipative nature of evolution as a necessary process due to the performance of external or internal work "against equilibrium." In this case, new degrees of freedom are acquired as the system moves away from equilibrium, and not towards it, which refutes the widespread opinion about the spontaneous nature of evolutionary processes and the origin of "order" out of "chaos."

5. The laws of evolution and involution (degradation) are the same for thermal and nonthermal forms of energy and objects of animate and inanimate nature, and are created by natural causes, not by a "higher intelligence" or by a purposeful Darwinian "struggle for existence." Their contradiction to the second law of thermodynamics for irreversible processes is due to the exclusion from consideration of any other forms of matter that do not possess the thermal form of energy.

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