Part 6

ELEMENTS OF THE ENERGODYNAMIC THEORY OF EVOLUTION

There are enough facts that have been accumulated to date evidencing not only a destructive, but also a creative tendency inherent in nature. However, in the theories of evolution based on classic thermodynamics an idea of isolated systems tending to “chaos” has dominated so far. This conclusion following from the statistical-and-mechanical interpretation of entropy has been considered indisputable for a long time. From here the statement ensued of the “glaring contradiction between thermodynamics and the theory of biological evolution” (I. Prigogine, 1984) that was understood as the development “from the simplex to the complex”.

On that base a new concept of natural science has even arisen, which acknowledged the fundamental difference between objects with the equilibrium and non-equilibrium organization. It has been even affirmed that for these objects two diamentrically opposite physical principles exist as governing processes with different directivity: toward equilibrium and out from equilibrium (A.P. Rudenko, 1980). If classic science follows this concept, it would have to cancel the idea of existing universal laws of nature as valid for any material systems.

It will be shown in the following chapters that the world does not go into the frames of classic and statistical thermodynamics, and new answers will be given to a number of “difficult” questions of natural science, which energodynamics will enable doing.

Chapter 21

ELIMINATION OF CONTRADICTION BETWEEN THERMODYNAMICS AND SELF-ORGANIZATION PHENOMENA

An opinion is widespread about the "glaring contradiction between the second law of thermodynamics and the theory of evolution" (I. Prigogine, 1984). The technological revolution of the 20th century has led to a comprehension that the world can not be confined within the frames of classic thermodynamics and statistical physics and that not only a destructive, but also a constructive tendency inheres in nature. There are enough facts accumulated in science by the late 20th century and evidencing that non-uniformly scaled systems studied by various scientific disciplines have a unitary algorithm of transition to more complex and ordered states. That demanded also a unitary theoretical description of such processes in the time and space domains. On this basis a new scientific trend arose in natural science named *synergetics*. Introduced by H. Haken (1980) this term accents the concerted interaction between parts while forming the structure of a whole. This term comes from the Greek "synergen" meaning co-action, cooperation. The investigations in this field, due to its specificity, are being conducted by efforts and means of many sciences, each possessing its own specific methods. This chapter considers the contribution non-equilibrium thermodynamics can make to the theory of evolution and attempts to answer the question how a certain order can be maintained in the surrounding world despite the evident irreversibility intrinsic to real processes.

21.1. Non-Entropy Criteria of Order for Real Processes and Systems

Despite the noticeable successes in explaining the self-organization phenomena in animate and inanimate nature from the positions of the theory of irreversible processes and synergetics (A. Rubin, 1964; S. Keplen, E. Essigh, 1968; L. Blumenfeld, 1977; I. Prigogine, 1977; A. Prits, 1980; D. Nichols, 1985; J. Edsall, C. Gotfrend, 1986; G. Gladyshev, 1988; et al.) the investigation of the evolution problems on the strict physico-mathematical basis encounters great difficulties.The major part of them is caused by the fact there are no potential state fuctions in thermodynamics of open systems, which variations could serve as rather general and strict criteria for the evolution of biosystems in ontogenesis and phylogenesis. Entropy S is inapplicable for this purpose since in biosystems exchanging substance with the environment it can vary due to heat exchange or mass exchange and, on the contrary, remain invariable if moving a system from or to equilibrium is caused by useful work done. The so-called "entropy generation" $P = d_iS/dt$ does not meet the requirements either since this criterion has minimum in only a very particular case of stationary processes in linear systems and states nearby equilibrium (I. Prigogine, 1947). However, the evolution processes are non-stationary in principle, while biological systems are far from equilibrium. All this hampers applying the method of thermodynamic potentials to biological, ecological, cosmological, etc systems.

As shown earlier (Chapter 8), any parameter other than R. Clausius' entropy could hardly be more improper to analyse the ordering processes for various systems since entropy remains invariable as the system is moving from equilibrium due to reversible work done on it. It is this property of entropy as the parameter not varying in reversible adiabatic (non-thermal) processes which R. Clausius needed when was looking for the heat exchange coordinate. However, it is the property that makes entropy incapable for essentially describing the state variations that lead to ordering of some, whereas to unordering of other degrees of freedom for a polyvariant system or its separate parts.

Understanding this many investigators are trying to substitude the entropy antipode – negentropy – for thermodynamic entropy or to attribute a new content to entropy by introducing statistical, informational, etc entropy. However, this just obscures the crux of the energy conversion processes occuring in heterogeneous systems and leading to activation of some, whereas to suppression of other properties of animate and inanimate nature.

Energodynamics gives the cardinal solution to the said problem by introducing the ordered energy E as a function of all independent parameters for system spatial heterogeneity of vector nature $\mathbf{F}_i$,$\mathbf{r}_i$, which due to (2.2.9) and (10.4.11) may be expressed in a more general form:

$$-\,dE = \Sigma_i\,\mathbf{X}_i{\cdot}d\mathbf{Z}_i. \tag{21.1.1}$$

This function of non-equilibrium state is the most general measure of system order defined by system macro- and micro-heterogeneity. When speaking of the advantages the ordered energy has against entropy it is worth noting its simple and clear sense as a value describing the system capability for any work (useful or dissipative, external or internal). Since a system in the state of internal equilibrium can not do any work (external or internal), the decrease of ordered energy is a necessary and sufficient criterion that the system is approaching equilibrium:

$$dE = -\,\Sigma_i\,\mathbf{X}_i{\cdot}d\mathbf{Z}_i \le 0\,. \tag{21.1.2}$$

The sign"<" means here approaching equilibrium, the sign "=" – reaching equilibrium.

It is also an extremely important fact that the ordered energy can be found directly for any current state of the non-equilibrium system and for any degree of its freedom from known fields of temperatures, pressures, concentrations, etc. This allows prognosticating the direction of system variation in various processes by the behavior of usual thermostatic variables without whatever calculations.

Another advantage of the inergy E making it a flexible tool for analysis of evolution and self-organization problems may be construed as its capability to describe both the system in whole as spontaneously approaching the equilibrium state

$$dE = -\Sigma_i\, \mathbf{X}_i \cdot d\mathbf{Z}_i < 0, \tag{21.1.3}$$

and moving from it caused by ordered work done on the system:

$$dE = -\Sigma_i\, \mathbf{X}_i \cdot d\mathbf{Z}_i > 0. \tag{21.1.4}$$

It is even more important that the inergy provides a unique possibility to follow the evolution of any degree of system freedom separately marking some degrees of freedom as approaching equilibrium,

$$dE_i = -\mathbf{X}_i \cdot d\mathbf{Z}_i < 0, \tag{21.1.5}$$

whereas other as moving from it:

$$dE_i = -\mathbf{X}_i \cdot d\mathbf{Z}_i > 0. \tag{21.1.6}$$

Ultimately, distinguishing the ordered energy allows indroducing extremely important criteria of order for the system as a whole η_ε and for each degree of freedom separately $\eta_{\varepsilon j}$:

$$\eta_\varepsilon \equiv E/U; \quad \eta_{\varepsilon j} \equiv E_j/U_j. \tag{21.1.7}$$

All this makes the inergy E a quite "physical", convenient and extremely informative criterion of evolution of systems with any finite number of degrees of freedom.

Let us consider the additional positives the inergy E introduced provides as compared with the exergy, free energy and entropy. First of all, it should be shown that the capability-for-work function expressed in terms of energy carrier fluxes in the form of (15.1.2) is a shortcut to obtain the same results as from the exergy that is currently the most informative function of system capability for work. Furthermore, the ordered energy (inergy) E of an extended system is expressed directly in terms of the energy carrying flows and the thermodynamic forces $\mathbf{X}_i$. Due to this, it can be found under the boundary conditions set by the flows $\mathbf{J}_i$ or forces $\mathbf{X}_i$, i.e. similar to those in the heat-mass transfer theory. One more advantage of the external energy is that it may be differentiated by the degrees of freedom of the system. It is important also that, unlike Gibbs or Helmholtz energy, the decrease of the ordered energy E defines the useful work value at any process conditions (not only at T,p = const or T,V = const). This further extends the sphere of application of the thermodynamic potentials method. Due to all these merits the ordered energy is one of the most universal thermodynamic potentials.

Ultimately, exergy, being a state function of the system under investigation itself (regardless of the environment), is irreplaceable under the necessity to define the "reserve" of the system reversible energy in the absence of a heat/substance "inflow from outside". This is quite important when defining the external energy of an "independent" system not needing the environment to be used. The external energy in this case allows estimating the reserve of the ordered energy per each of its components $E_i = \mathbf{X}_i \cdot \mathbf{Z}_i$. This facilitates the analysis of system energy form-to form conversion.

Let us assume an available heat Q well with a constant temperature of T_1, and the environment with a temperature of T_0 as a heat sink of so large capacity that the entropy flow does not change its intensive parameters. The power of the heat engine using such energy well can be found from equation (18.1.2). The entropy flow $I_s^e = dS/dt$ thru the heat engine is related with the heat flow at its inlet $J_q = \text{đ}Q/dt$ simply as $J_s^{\mathrm{e}} = J_q/T_1$. In this case, integrating (18.1.2) over a temperature interval of $T_1 - T_0$ and assuming I_s^e = const (which is equivalent to assuming reversibility of Carnot heat engine based on these heat wells) gives:

$$N_q = -\int (J_q/T_1)dT = (1 - T_0/T_1)\,\text{đ}Q/dt, \tag{21.1.8}$$

which corresponds to the expression for heat well exergy (A. Andrushchenko, 1975) $W^e_{max} = Q(1 - T_0/T_1)$.

Similarly the exergy of working medium can be expressed taking into account that in this case a substance well with a chemical potential of μ_1 exchanges not only the mass M with the environment (the mass flow $J_m^{\mathrm{T}} = dM/dt$), but also the entropy S so that the energy converter power is derived as the sum:

$$N_T = -\int J_m^{\mathrm{e}} d\mu - \int J_s^{\mathrm{e}} dT\,. \tag{21.1.9}$$

Integrating this expression over temperature and chemical potential intervals of $T_1 - T_o$ and $\mu_1 - \mu_o$, respectively (где $\mu_1 = h_1 - T_1 s_1$; $\mu_o = h_o - T_o s_o$) gives:

$$N_T = [(h_1 - T_1 s_1) - (h_o - T_o s_o)]\, dM/dt, \qquad (21.1.10)$$

which corresponds to the expression for working medium exergy (A.Andrushchenko, 1975) $W^e_{max} = H_1 - H_o - T_o\,(S_1 - S_o)$. Similarly the chemical exergy of reacting systems can be found.

The identity of the results obtained based on both interpretations of the working capacity function is caused by the fact that these interpretations refer to the same value. However, unlike exergy, expressions (21.2.9) and (21.1.10) derive the value of work maximum possible and with system parameters inconstant. Thus the concept of external energy is a further generalization of the exergy concept. This imparts all advantages of the characteristic state function to external energy. First of all, its value as a state function does not depend on the path the system comes to equilibrium. This excuses from the necessity to invent the ways of system reversible state-to-state transfer, which was characteristic for any working capacity functions in classic thermodynamics.

Now we are going to show on concrete examples that the processes obeying the criterion of their spontaneity (21.1.1) can lead to ordering of a number of degrees of freedom for a system.

21.2. Self-Organization of Chemical Elements by Their Similarity Principle

The material object chemistry studies are, strictly speaking, spatial structures formed by atoms of the same or different types (homo-compounds and hetero-compounds, respectively). These compounds form a certain sequence of atoms fixed in space and time. The atoms in this sequence neither migrate, nor break its integrity, which defines the stability of the compounds of a higher structural level. At present time entropy is the basic measure of atomic structural organization in the world of chemical substances. As calculations show, the entropies for inert gases are maximal and decrease with increasing atomic order in the compound structure, whereas the entropies for all chemical elements of polymer structure[1] are minimal (Y. Cherkinsky, 1992) and obey the empirical rule of *linear logarithmic curve*:

$$S^o = -\,31.8 + 19.2 \ln N_A\,, \tag{21.2.1}$$

where N_A – atomic charge corresponding to atomic number of a particular element in the periodic system.

In accordance with (21.2.1) the molar value of entropy is expected to decrease with increasing degree of polymerization. Such a linear dependence is characteristic for all chemical elements. However, the entropy found from relationships of the (21.2.1) type does not reflect the periodicity in variation of the properties pertaining to elements and associated with their structure heterogeneity. In this respect energodynamics provides some additional chances. From its positions the properties of spatially heterogeneous (including structured) systems such as a population of atoms or their compounds can not be investigated unless the spatial distribution of their extensive properties is taken into account. In particular, to investigate chemical properties of elements, the distribution of electrons in atoms of the chemical elements must be taken into account. These properties are known to be defined by the number of electrons in the outermost electron shell. Herein the elements having the same number of the valence electrons in the outermost shell belong to the same group of the periodic system. This allows the distribution of only valence electrons to be taken into account. This distribution can be described by the same distribution moments $\mathbf{Z}_i$ as other physical properties of heterogeneous systems.

Imagine an atom as a set of opposite charges: positive Θ_e^+ concentrated in the atomic nucleus located in the point of space with a radius vector of $\mathbf{r}_e^+$, and negative Θ_e^- surrounding the nucleus as a multi-layer cloud with the center in a point with a coordinate of $\mathbf{r}_e^-$. Then the center position of the whole set of charges will be defined by a known expression

$$\mathbf{Z}_e = \Theta_e^+\mathbf{r}_e^+ + \Theta_e^-\mathbf{r}_e^-. \tag{21.2.2}$$

Since $\Theta_e^+ = -\,\Theta_e^-$ (solitary atom is electrically neutral), this expression may be written as

$$\mathbf{Z}_e = \Theta_e^-(\mathbf{r}_e^- - \mathbf{r}_e^+) = \Theta_e^-\Delta\mathbf{r}_e, \tag{21.2.3}$$

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[1] Typical polymers are such elements as boron, carbon, silicon, phosphorus, sulfur, arsenic, selenium, oxygen, homologues of aliphatic series, etc.

where $\Delta\mathbf{r}_e = \mathbf{r}_e^- - \mathbf{r}_e^+$ – dipole arm having the sense of the electron cloud center displacement relative to the nucleus. Thus the electrically neutral atom at an asymmetrical distribution of electrons relative to the nucleus acquires the properties of an electric dipole with a charge of $\Theta_e = \Theta_e^-$ and a dipole arm of $\Delta r_e = |\Delta\mathbf{r}_e|$. It is natural to assume that this is the polarization conditioning chemical properties of atoms in various compounds.

In order to facilitate the definition of Δr_e, allow for the fact that chemical compounds change the configuration of the so-called valence shell only. Therefore, in (21.2.3) only the summary charge of the valence electrons $\Theta_e^- = en_e$ is enough to be allowed for, where e – electron charge; n_e – valence of a chemical element. Take into consideration further that the more the valence electron shell is packed and the more uniform the distribution of electrons therein is, the less the dipole arm Δr_e and the moment of electron distribution $Z_e = \Theta_e \Delta r_e$ are. In particular, for neutral elements like the "noble" gases having the shell completely filled with a number of electrons of n_{max} this resultant at any moment of time appears to be close or equal to zero. A different situation arises with the valence shell filled with valence electrons only partially ($n_e < n_{max}$). Then the center of the electron cloud appears to be displaced relative to the atomic nucleus. In this case the atom forms a "dynamic" (varying in value and direction) electric dipole which mean statistical value is what conditions the atomic dipole moment Z_e.

According to the energodynamic concept of equilibrium the spatially heterogeneous systems (in our case the set of valence electrons) being isolated are tending to equilibrium where $Z_e = 0$. In case of chemical elements this means their tending to a more stable electron configuration with the filled valence electron shell of n_{max} electrons. For neutral gases $n_{max} = 8$, which underlies the known G. N. Lewis's "octet rule" (1916). For other cases n_{max} may be different, e.g., equal to 18. Let us assume in the first approximation that the relative value of the dipole arm $\Delta r_e/r_A$ (relative to the atomic radius r_A) increases proportionally to the "*filling degree*" of the electron shell k_z defined as:

$$k_z = (n_e - 1)/(n_{max} - 1). \qquad (21.2.4)$$

As follows from (21.2.4), at $n_e = n_{max}$, when the electron shell is filled completely and located symmetrically about the atomic nucleus, $k_z = 1$ and $\Delta r_e = r_A$, which corresponds to the maximal value of the dipole arm Δr_e. On the contrary, at $n_e = 1$, when the shell is filled minimally, $k_z = 0$, and the atom is electrically and chemically neutral.

In this case the atomic dipole moment Z_e is defined as:

$$Z_e = e\, n_e\, r_A\, (n_{max} - n_e)/(n_{max} - 1), \qquad (21.2.5)$$

where e = 1,6021·10 $^{-19}$ C – electron charge; r_A – atomic radius; n_e – chemical element valence. In the particular case of the elementary substances obeying the octet rule (n_{max} = 8) this expression becomes [7]:

$$Z_e = e\, r_A\, n_e(8 - n_e)/7. \qquad (21.2.6)$$

According to this expression the atomic dipole moment $Z_e = Z_e(n_e, r_A)$, i.e. generally depends both on the atomic valence n_e and the atomic radius r_A. Since r_A, in its turn, is conditioned by the connection of the atom with other elements in different compounds depending on the atomic number N_A of the element, $r_A = r_A(N_A, n_e)$. Thus the obtained periodic relation, despite its approximate character, nevertheless, allows for not only the chemical element number, but the valence zone filling degree, too. This relation obtained by calculation as per (4) using the data available in literature with regard to covalent atomic radii for chemical elements of the Mendeleev periodic table [7] is plotted in Fig.21.1.

This plot attracts attention with not only the strict periodicity in the value Z_e variation, i.e the atomic dipole moment, but also with the identity of the repetitive figures, each of which expresses the dependence of the valence electrons distribution Z_e on the ordinal number of the element in this period, i.e. on its valence (or, more strictly, on the maximal oxidation level). This fact may be called the *similarity principle for chemical elements*. At r_A = const this principle expresses the *periodical dependence of chemical elements on their valence shell structure*.

Since at n_e = const the dependence of dipole moment on radius $Z_e = Z_e(r_A)$ already does not exhibit the periodic character, the similarity principle reads that the periodicity of the properties for elements is caused by exclusively the structure of their valence shell that for elements with similar structure (n_e = const) does not depend on the element atomic number. This confirms the hypothesis N. Bohr put forward in 1921 and needs a reformulation of the Mendeleev periodic law [8] reading that the properties of chemical elements and compounds they form are in a periodic dependence on their atomic masses (later – on their atomic numbers). From the positions of energodynamics it becomes clear that the "*properties of chemical elements and their compounds are in a periodic dependence on structure of their valence shells*". Such refocusing from element atomic number to structure of element valence shell means that the recurrence of valence shell structure for chemical elements is recognized as the basic physical reason of periodical alternation of their properties[1].

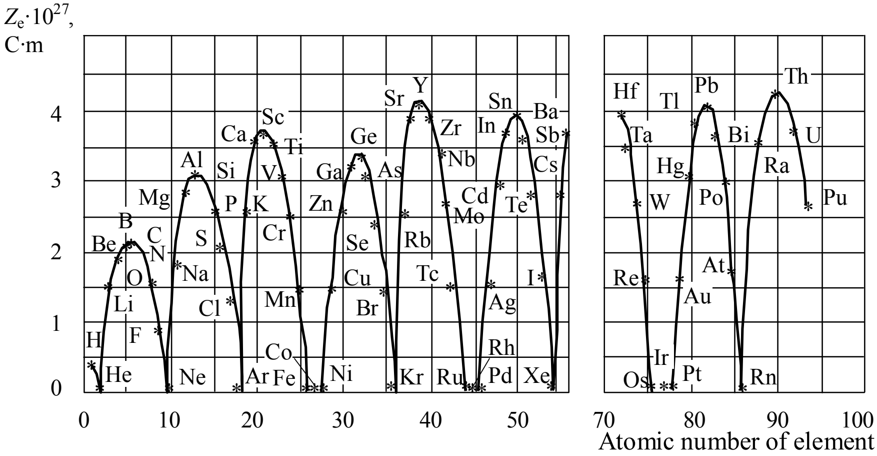

Fig.21.1. Similarity Plot for Chemical Elements

Relation (4) that is a mathematical expression for the similarity principle can be easily shaped into a criterion equation if the valence shell filling degree k_z (3) is taken as a dimensionless determining criterion of similarity, while as a determined criterion the dimensionless value $K_e = 1 - Z_e/en_er_A$ is taken, which should be reasonably called the "criterion of atom electronegativity" due to its behavior similarity to the electronegativity by L. Pauling [9]. In this case the criterion equation describing the similarity of chemical elements will take the form of the functional relationship:

$$K_e = f(k_z) \qquad (21.2.7)$$

As in the similarity theories for hydrodynamics and heat and mass exchange the character of this relation is established by test-theoretical way . With the simplifying assumptions above adopted this relation becomes:

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[1] Strictly speaking the Mendeleev periodic table also reflected the dependence of element properties on valence rather than on element atomic mass or atomic numbers since it assumed a group of transition metals Fe, Co, Ni, Ru, Rh, Pd, Os, Ir, Pt existing with different atomic numbers, but close properties (relating to the same 8th group). What is more, the table assumed the even more wide group of lanthanides with atomic number of 57…71 that could be placed into the same box of the periodic table.

$$K_e = 1 - k_z = (n_{max} - n_e)/(n_{max} - 1). \qquad (21.2.8)$$

As follows from this equation, too, the electronegativity criterion K_e is linearly rising to the end of each period, as well as the Pauling electronegativety itself (i.e. the mean binding energy of outer atomic electrons, which describes the ability of atom in molecule to "attract" the common electron pairs). Thus the property of similarity for the periodic table can be expressed by the only equation (4) that may be considered as the mathematic expression for the periodic law of chemical elements and for their similarity principle. Naturally, this similarity is approximate since it explicitly allows for neither the magnetic properties of atoms nor the spins of nuclear particles or their other quantum properties.

Another fundamental distinction of the similarity plot in Fig.21.1 consists in gradually increasing distribution moment of valence electrons Z_e for each short period from some maximum (nearby $n_A = 4$) followed by its same gradually decreasing down to zero, i.e. the continuity of the relation $Z_e = Z_e(n_e)$. This differs the plot from the empirical dependence on n_e of other known parameters: *atomic ionization energy, electron affinity, electronegativity and atomic radii.* Such relations feature discontinuity not only at transition from the elements of the 8th group to the 1st group, but inside the same 8th group of elements. Meanwhile, the oxidation level for the metals of the 8th group – Fe, Co, Ni, Ru, Rh, Pd, Os, Ir, and Pt – reaches 8 far from always[2], so that it should have been expected the gradual transition from the above elements to neutral gases – He, Ne, Ar, Kr, Xe and Rn – for which the valence is not always equal to 8.

Comparing the dependence of Z_e on the element number with the atomic ionization energy reveals their opposite character. This fact is quite explainable if considered from the physical sense of this energy as a work to be done for electron removal: the less the work done to remove all valence electrons, the higher the value Z_e. As for the element "activity" that does not have a clear definition, its distinction from Z_e is more noticeable. According to the existing concepts the activity is maximal for the elements of the 1st group, decreases with the element atomic number increasing and increases again by the end of a short period (for halogens) when the electron shell lacks only one electron. Thus the "activity" increases at the beginning and at the end of the period, whereas the parameter Z_e, value, on the contrary, decreases to minimum at the beginning and at the end of each period. It may be assumed that the parameter Z_e features maxumum just because of the opposite character of variation in the ionization energy and electronegativety. The former is maximal at the be-

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[2] The Delhian column made of iron and having resisted corrosion for many centuries may serve an example of the chemical neutrality reached

ginning of the period and decreases by its end, whereas the latter, on the contrary, increases here.

The next distinction of the similarity principle from the periodic table shows up in prognosticating an internal periodicity for lanthanides and actinides – as existing for other elements. These elements are usually placed either in one box of the Mendeleev table or marked out as a separate "subtable" series. This is equivalent to the statement about the independence of chemical properties on their atomic number, i.e. essentially to the negation of the periodic table as itself. The incompleteness (break) of the curves in Fig.21.1 in the zone of lanthanides and actinides explicitly evidences those need to be included in the periodic table.

The parameter Z_e having an absolute reference zero is one more characterisic feature of the proposed periodic system. Strictly speaking this property should pertain to only those elements which valence is always equal to 8. Such are He, Ne, Ar, Kr, Xe and Rn. In this respect the curves in Fig.21.1 have the advantage because allow describing the true valence of an element by a leg of the corresponding period, but not a single point plotted or a box of the periodic table.

Fig.21.1 shows also that hydrogen in its dipole moment is closer to the elements of the 7th group despite its valence equal to unit[3]. Ultimately, this plot prognosticates the monotonous increase in Z_e with period, which is caused by increasing atomic dimensions and radii. The "dips" in the mentioned maximum value indicate the necessity to correct the atomic dimensions.

While estimating the periodic system $Z_e = Z_e(n_e)$ as a whole it may be concluded that here we encounter the quite natural phenomenon confirming the connection of the spatial heterogeneity parameter Z_e with structure and properties of chemical elements. Using this parameter allows describing the similarity property of the periodic system by the only formula (21.2.4) which may be considered as a mathematical expression for the periodic law of chemical elements and the principle of their similarity.

It is significant that chemical elements spontaneously (i.e. without interference of external forces) form compounds which due to the "collectivization" of the valence electrons approximate them to the structure of the atoms pertaining to neutral elements with a valence shell completely filled. Here the most significant for us is the fact that this tendency complies with the evolution criteria of energodynamics ($Z_e \rightarrow 0$; $E \rightarrow$ min) and involves the ordering of the electron shell structure rather than the growth of "chaos". In this respect any partial equilibrium construed as the equality of opposite-directed forces fundamentally differs from complete equilibrium. It only remains to show that such a behavior is characteristic to not only the microworld, but also to systems of other hierarchical level.

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[3] Hydrogen was first placed in the 7th group by O. Masson, who later proposed also the 8th group of neutral gases

21.3. Spontaneous Character of Structure Formation Processes at Crystallization

Let us show now by particular examples that the self-organization processes obey the enerdodynamic criteria of spontaneous process directivity (21.2.3). One of such examples describes the crystallization processes leading to growth of single crystals with certain configuration from a solution or a melt. On the local (microscopic) level such processes bear the vector character like the valence electron rearrangement processes described above, whereas from the macroscopic positions the evolution criterion should be more relevant to application as based on the minimum of inergy, i.e. on the minimum of the free surface energy E_f in this particular case:

$$dE_f = \Sigma_j\, \sigma_j\, df_j \le 0, \tag{21.3.1}$$

where σ_j – surface tension on the jth face of single crystal (j = 5,6…), f_j – face surface.

As a single crystal is growing, its volume V varies. This volume may be considered as the sum of the volumes V_j of imaginary pyramids which base is the corresponding j^{th} face of the single crystal, while the vertex is located in a common point inside the crystal, i.e.

$$V = \Sigma_j\, V_j = ⅓\, \Sigma_j f_j h_j\,, \tag{21.3.2}$$

where h_j – height of the pyramid. In this case the volume V_j variation of the pyramids, to an accuracy of the second infinitesimal order, is equal to $dV = ½\, \Sigma_j\, h_j\, df_j$ (I. Bazarov, 1991).

The face surfaces f_j increase in the structure formation process with generally different rate. This process of face surface value redistribution, when the equilibrium crystal forms, belongs to the processes the addend in equation (2.2.6) describes and thus does not depend on the cubic strain of the crystal as a whole (i.e. on its volume V). Therefore this process may be considered under constancy of the volume V of the single crystal as a whole, when

$$dV = ½\, \Sigma_j\, h_j\, df_j = 0\,. \tag{21.3.3}$$

Taking (21.3.3) and (21.3.2) jointly gives that the (21.1.1) criterion is satisfied at

$$\sigma_j / h_j = \text{const.} \tag{21.3.4}$$

Thus the equilibrium form of a single crystal features that its faces are away from the common pyramid vertex (the so-called “Wulf point”) at distances proportional to the surface tensions on the faces. This statement constitutes Wulf theorem declaring that the buildup rate for separate faces of a single crystal is proportional to the specific surface free energies (specific inergies) of these faces. It can also be shown that the spontaneous chemical transformations are as well associated with such molecular restructure when the configuration component of chemical affinity is minimal. However, this would demand cumbersome calculations and is inapplicable herein.

As can be seen, the structure formation processes obey the energodynamic (non-entropic) criteria of evolution which allow ordering of the system for some degrees of its freedom and disordering for others. At the same time the example considered shows that a fact a system spontaneously approaches equilibrium not always leads to “chaos buildup” in the system as a whole, but, on the contrary, may involve its ordering.

21.4. Coherence of Laser Radiation as a Result of Radiative Equilibrium

As far as we know, till the present the question has never been raised in scientific literature as to find specific motive forces causing the radiant energy tranfer processes like in thermal conduction, electric conduction, mass exchange and other explicitly distinguishable processes. This may be explained by the fact that physicists of the XX century, despite active objections from P. Lebedev, ascribed a certain temperature to the radiation in black body cavity on the ground that this radiation is in “thermal equilibrium” with the black body (J.M. Gelfer, 1981) Meanwhile, the notion of thermal equilibrium is applicable only to the so-called thermal radiation occupying just a minor part of the spectrum with a wave length of 0.4 to 4 μm and received by bodies as heat due to the energy dissipation. The overwhelming part of the radiation responsible for such phenomena as photosynthesis, photoeffect, photoionization, photoluminescence, photoacoustical phenomena, photonuclear reactions, etc, is an ordered form of motion and by no means reducible to heat. Neverthless, a certain temperature (2.73 K) became later to have been ascribed to also the so-called Universal “background” that had left the celestial bodies many billions years ago and have not evidently been in thermal equilibrium with galaxies [2].

The gap appeared in describing the transfer processes for various forms of energy may be filled in through finding a parameter which gradient or drop generates a flux of radiant energy carrier in the same way as the gradient or drop of temperatures T, pressures p, velocities $\mathbf{v}$, chemical μ_k, electrical φ, etc potentials generates the transfer of entropy S, gas volume V, momentum $m\mathbf{v}$, mass m_k of the kth substance, charge Θ_{e}, respectively, etc. To solve this problem, let us use a known expression for the density $\rho E_{\text{в}}$ of the travelling wave energy $E_{\text{в}}$, which is the same for both longitudinal (e.g., acoustic) and transverse (e.g., hydrodynamic) waves (F. Crawford, 1965):

$$\rho E_{\text{в}} = \rho A_{\text{в}}^2 \nu^2/2 \,, \qquad (21.4.1)$$

where ρ – density of the oscillation-transferring medium; $A_{\text{в}}$, ν – wave amplitude and frequency.

According to this expression

$$dE_{\text{в}} = A_{\text{в}}\nu d(A_{\text{в}}\nu). \qquad (21.4.2)$$

Compare (21.4.2) with the general expression for the work of the ith kind dW_i as the product of the force $\mathbf{F}_i$ and the associated displacement $d\mathbf{r}_i$ of the object the force is applied to $\Theta_i \equiv S$, V, $m\mathbf{v}$, m_k, Θ_{e} , etc. Considering the fact that the specific force $\mathbf{F}_i/\Theta_i$ (related to the unit value Θ_i it transfers) is generally expressed through the negative gradient $-(\partial\psi_i/\partial\mathbf{r}_i)$ of the corresponding potential ψ_i (2.4.8) gives the alternative expression for the work dW_i under the stationary conditions ($\psi_i = \psi_i(\mathbf{r}_i)$):

$$dW_i = \mathbf{F}_i{\cdot}d\mathbf{r}_i = -\,\Theta_i\,(\partial\psi_i/\partial\mathbf{r}_i)\,{\cdot}d\mathbf{r}_i = -\,\Theta_i d\psi_i\,. \qquad (21.4.3)$$

The known expression for the flowing gas work $dW_i = -\,Vdp$ is a particular case. Comparing (21.4.2) and (21.4.3) gives that for the wave form of motion $\psi_i = A_{\text{в}}\nu$. Hereafter for the sake of certainty we will call this value as the *amplitude-frequency potential*:

$$\psi_{\text{л}} = A_{\text{в}}\nu \qquad (21.4.4)$$

Thus the negative gradient of the amplitude-frequency potential is the motive force for the radiant energy exchange:

$$\mathbf{X}_{\text{в}} = -\,(\partial\psi_{\text{в}}/\partial\mathbf{r}) \equiv -\,\nabla\,\psi_{\text{в}}\,, \qquad (21.4.5)$$

as well as for all other energy transfer processes in continuums. According to (21.4.5) any wave (including the electromagnetic one) is propagating in an absorbing or a dissipating medium in the direction of its potential decrease. This means that the resonance between the radiation field and the eigenfrequency of oscillations ν_p for a body corresponds to the state of radiant equilibrium between them. This statement does not depend on the model representations of physical nature for the wave form carrier and, therefore, is equally applicable to acoustic, hydraulic, electromagnetic, ether, etc waves.

Hence it follows that when a system of radiating oscillators is tending to internal equilibrium ($X_л \to 0$) the frequencies of their radiation are being arbitrarily synchronized. It has been shown in Chapter 9, when substantiating the Planck radiation law, that this leads to appearing "similar' orbits radiating at the same frequency. This throws new light on the reason of the coherent radiation from lasers and masers thus confirming, in defiance of H. Haken (1981)¹⁾, the deterministic character of self-organization processes. This fact stresses once again that tending to equilibrium does not at all and always mean the growth of "chaos" as the Boltzmann principle postulates.

21.5. System Ordering in Orientation Processes

There are enough facts stored in natural science to date indicating an unusual behavior of the classic spin (intrinsic moment of particles rotation)-oriented systems. Yet in the early XX century the American physicists D. Bloch (1936) and G. Uze (1947) observed that the neutrons with spins oriented parallel to magnetic field more intensively dissipated on the magnetized plate. In the forties-fifties E. Purcell and R. Pound (1951), as well as A. Abragam and W. Proctor (1959), in their nuclear magnetic resonance experiments discovered a specific spin-spin interaction led to the unified orientation of nuclear spins set in at low temperatures. It was experimentally found in the sixties that when neutrons passed thru a spin-polarized target the neutron precession appeared with a value several orders higher than the one magnetic field-induced. (V. Baryshevsky, M. Podgoretsky, 1964). In the eighties on the test stand for measuring the Lamb shift unusual features of interference were revealed for hydrogen in its different spin states, and the spin polarization of atomic hydrogen was discovered to have impeded its merger in molecules (Y. Sokolov, V. Yakovlev, 1982; A. Silver, Y. Valraven, 1983). In that time in experiments with ^{3}He the dependence of its thermal conductance on nuclear

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[1)] Who discovered that the formation of internal structures in laser bore a strong resemblance to the molecular pattern competition M. Eigen described spin state was discovered (C. Lhuiller, 1983). It was also found in the nineties that the protons with the spins oriented opposite to the target spins as though “permeate thru” the target protons (with no evident interaction), whereas with the spins in the beam and target same oriented the proton dissipation will occur in complete accordance with the theoretical interpretation (A. Krisch, 1987). That experiment and many others showed the system energy depended on the system sum spin. Since only the spin orientation, but not the spin value varied in those experiments, they surely suggested the existence of a special category of *orientation* processes. The processes of such a kind are intrinsic to not only micro-, but also macro-systems. Due to special state variations, qualitatively distinguishable and irreducible to others, which these processes cause they have been earlier (see Chapter 2) qualified as a separate group of the reorientation processes. Though it has been known for a long time that different positions of a body in space and its different orientation therein are non-equivalent from a mechanical standpoint (L. Landau, E. Livshits, 1976), the investigation of orientation processes have been, in our opinion, insufficiently regarded up to date. It might be attributed to the fact that, to solve many practical problems, the laws of bodies’ motion could be more conveniently reduced to the laws of motion of particular material points which spatial orientation did no more matter. That allowed to confine consideration to the so-called central fields which potential energy U(**r**) depended on only the distance between the bodies (on the radius-vector of their center of inertia **r**). It’s quite another matter with the object of investigation selected as such a set of interacting (relatively moving) bodies where the positional relationship of the system elements plays the predominant part. For such systems according to fundamental equation of energodynamics (2.4.5) the elementary work $đW_i$ of some force $\mathbf{F}_k$ is the sum of the body translation work $\mathbf{F}_i \cdot d\mathbf{R}_i$ and the body rotation (reorientation) work $\mathbf{M}_i \cdot d\boldsymbol{\varphi}_i$, where $\mathbf{M}_i$ – torque to some part of the system. The field of torques $\mathbf{M}_\mathrm{i}$ transmitting the orientation variation from some bodies to others is, generally speaking, intrinsic to any ordered forms of energy. E.g., the dielectric polarization is known to involve not only the spatial separation of positive and negative charges (i.e. the generation of dipoles), but also the in-field-direction reorientation of the “stiff” steady-arm dipoles already available. The latter process is called the *orientation polarization*. It takes the part of polarization work $đW_e = \mathbf{E} \cdot d\mathbf{Z}_\mathrm{e}$, where **E** – electric intensity, $\mathbf{Z}_\mathrm{e}$ – polarization vector. As evidenced from the foregoing, this part is defined by the expression $đW_e = \mathrm{Z}_\mathrm{e}\mathbf{E} \cdot d\mathbf{e}$ and may be represented as the product of the torque $\mathbf{M}_\mathrm{e}$ to the electric dipole and the elementary angle of its rotation $d\boldsymbol{\varphi}_\mathrm{e}$ in the field **E**. Similarly in the magnetization process the magnetic dipoles, while changing their arms, will also reorient themselves in the external magnetic field **H**. The work consumed for this $đW_m = Z_m\, \mathbf{H} \cdot d\mathbf{e}$ (where Z_m – magnetization vector modulus $\mathbf{Z}_\mathrm{m}$) may also be represented as the product of the torque $\mathbf{M}_\mathrm{m}$ to the electric dipole and the elementary angle of its rotation $d\varphi_m$ in the field **E**. This refers to the full extent to also gravitational fields, which can be easily made sure of when comparing, e.g., the energy of a dumbbell-shaped body in its horizontal and vertical positions in the gravity field. Thus there is an *orientation component* that may be distinguished in known force fields besides the central forces and that acts on bodies with non-spherical symmetry. It is defined by the additional work that needs to be spent to orient such bodies in the field direction. This means that the ordered part of the body energy Є generally includes two components depending on the body position Є = Є(R) and the body orientation $E = E(\varphi)$, respectively. Taking the orientation component of exergy into account allows ascertaining a specific class of system ordering spontaneous processes existing in nature and obeying the common energodynamic criterion of evolution $dE = \Sigma_j dE_j \leq 0$.

Let us consider for example a spontaneous system of rotating bodies with non-spherical symmetry (from balanced spinners or gyroscopes to galaxies). Let us assume that the angular momentum $\mathbf{L}_k$ of any kth body of such a system does not coincide for whatever reasons with the axis of its proper rotation (Fig.21.2).

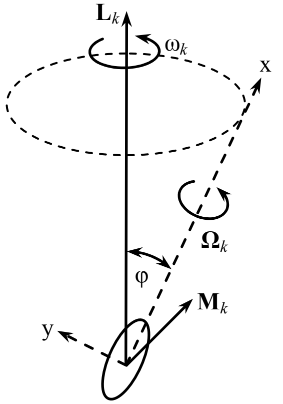

Fig. 21.2. Spinner Prcession.

In this case the body, besides the proper rotation about its axis with a constant angular speed of $\mathbf{\Omega}_k$, undergoes a regular precession with an angular speed of $\boldsymbol{\omega}_k$. If, using the arbitrariness of the coordinate axes selected, the X-axis is aligned with the axis of symmetry of the spinner, while the Y-axis – with the plane the vectors $\mathbf{L}_k$ and $\mathbf{\Omega}_k$ form, then the angular speed of the spinner's proper rotation about its axis $\Omega_k = |\mathbf{\Omega}_k|$ and the angular speed of its precession $\omega_k = |\boldsymbol{\omega}_k|$ can be expressed as

$$\Omega_k = L_k \cos \varphi / I_x ; \quad \omega_k = L_k / I_y , \qquad (21.5.1)$$

where $L_k = |\mathbf{L}_k|$; I_x, I_y – moments of inertia of the spinner about the x and y axes, respectively; φ – angle the vectors $\mathbf{L}_k$ and $\mathbf{\Omega}_k$ form. These angular speeds are associated with the kinetic energies of self-rotation E^k_s and precession rotation $E^{\text{к}}_{\text{p}}$ equal to:

$$E^k_{\text{s}} = L_k^2 \cos^2\varphi / 2I_x ; \; \text{E}^{\text{k}}_{\text{p}} = L_k^2 / 2I_y . \qquad (21.5.2)$$

Thus the total kinetic energy of the spinner

$$E^{к} = E^{k}_{s} + \mathrm{E}^{k}_{p} = L_k^{2}\,(\cos^{2}\varphi + I_x / I_y)/2I_x, \qquad (21.5.3)$$

is generally a function of not only the angular momentum $\mathbf{L}_k$, but also the angle $\boldsymbol{\varphi}$ defining the spatial orientation of its proper rotation axis $E^{k} = E^{k}(\mathbf{L}_k, \boldsymbol{\varphi})$. Comparing $E^{k}(\mathbf{L}_k, \boldsymbol{\varphi})$ with its value $E_{ko} = L_k^{2}/2I_x$ at the same L_k value and $\varphi = 0$ gives:

$$E^{к} - E^{к}_{o} = L_k^{2}\,(I_x / I_y - \sin^{2}\varphi)\,/2I_x. \qquad (21.5.4)$$

According to (21.5.3) at $\sin\varphi < (I_x/I_y)^{0.5}$ the kinetic energy of the spinner with precession E_k exceeds that with no precession (at $\varphi = 0$). This means that a certain work needs to be done to induce the precession motion. In a closed system with the invariable total angular momentum $\mathbf{L}_o = \Sigma\mathbf{L}_{ko}$ this may be caused by only the conversion of the energy of bodies reciprocal orientation $E = E(\boldsymbol{\varphi})$ into its kinetic energy**.** This work can be calculated and thus the orientation energy variation can be found proceeding from the following considerations.

The precession of a spinner or gyroscope (i.e. their additional rotation about an axis not coinciding with their proper rotation axis) appears with a certain torque of $\mathbf{M}_k = d\mathbf{L}_k/dt$ applied to them. The work $dW_k = -\mathbf{M}_k \cdot d\boldsymbol{\varphi}$ spent to deviate the gyroscope axis from its initial position (at $\varphi = 0$), when $\Omega_k = \mathrm{const}$ и $L_{ko} = I_x\Omega_k = \mathrm{const}$, is evidently equal to the additional kinetic energy $dE_{kp} = \omega_k dL_k$ which the gyroscope acquires with the precession. In this case the precession angular speed $\omega_k = |\boldsymbol{\omega}_k|$ is defined by a known relationship:

$$\omega_k = M_k / I_x\,\Omega_k \sin\varphi\ . \qquad (21.5.5)$$

Substituting (21.5.5) into the dE^{k}_{p} expression and equating the latter to the dW_k value gives $dL_k = L_{ko}\sin\varphi d\varphi$ so that integrating this expression for φ at $\mathbf{L}_k$ being constant gives:

$$L_k\omega = L_{ko}\int\sin\varphi\, d\varphi = L_{ko}\,(-\cos\varphi + C). \qquad (21.5.6)$$

Since at $\varphi = 0$ the precession is zero, C = 1, which finally gives:

$$L_k = L_{ko}\,(1 - \cos\varphi). \qquad (21.5.7)$$

According to this expression $\partial L_k/\partial\varphi = L_{ko}\sin\varphi$, so the precession kinetic energy $E^k(\varphi)$ may serve as a measure of “disorder” of a rotating bodies system.

Thus in accordance with the general energodynamic criterion of evolution $dE_k < 0$ the orientation equilibrium condition is:

$$\partial L_k/\partial\varphi = 0. \tag{21.5.8}$$

From this it follows that the orientation equilibrium in a system of rotating bodies features the same orientation of the axes of bodies or particles rotation, i.e. the precession motion disappearance ($\varphi = 0$). It may be easily seen that the equilibrium of such kind is also associated with not a “chaos”, but ordering of the rotation axes. This is what we observe in cosmology for the planet orbits, Saturnian rings (satelloids), galactic discs, etc.

On the other hand, the example considered evidences that when a set of rotating bodies deviates from equilibrium, an additional degree of freedom appears pertaining to this system in the form of a precession motion, and also an additional kinetic energy of internal rotation E_ω corresponding to this degree of freedom. It is such complication of the system with its withdrawing from equilibrium, but not at all the increasing fluctuation, that constitutes system evolution from the positions of energodynamics.

21.6. Structure-Forming Character of Mass Redistribution Processes in the Universe

Now let us show that the non-uniform distribution of masses in the Universe under gravitation also belongs to the spontaneous processes reducing the inergy of its gravitational degree of freedom. For this process the equilibrium criterion according to (21.1.3) is

$$\partial E^g/\partial r = 0, \tag{21.6.1}$$

where E^g – gravitational energy of any pair of attracting bodies. Taking into consideration that the specific gravitational energy of a trial body with a mass of m in the gravity field of another body with a mass of M_1 is a gravitational potential $\psi_g(r)$, this criterion may be most conveniently expressed in accordance with equation (3.5.6) as:

$$\psi_g(r) = (G_g M_1/4\pi)(1/r_c - 1/r) = 0. \tag{21.6.2}$$

From this it follows that the gravitational equilibrium means the equality $r = r_c$, i.e. maximum possible approach (coalescence) of the attracting bodies. This spontaneous process when a matter drops down onto a celestial body (star) out from the ambient space was termed as *accretion* (from the Latin “accretio” meaning “buildup”). As shown in Chapter 3 by the example of a three-body system, the gravitational forces acting on the trial body are equal to zero according to (3.5.7) if this body is located in-between the field-forming bodies at a distance inversely proportional to their masses. This state is unstable and with any fluctuation according to the energodynamic evolution criterion $dE^g < 0$ the trial body approaches that one of two masses (M_1 or M_2) which attractive forces prevail. This process is especially evident for closely located (double) stars one of which intensively gives its matter to the other one. Such an approach means a spontaneous deviation of the Universe from the homogeneous distribution of masses in it and appearance of a material structure therein. Thus the stellar generation from the dust mass of the Universe absolutely agrees with thermodynamics if more general criteria (21.1.1) are used rather than the Boltzman’s law of maximum entropy stating that the Universe must develop toward the most probable (homogeneous) distribution of its matter. Thereby one more example arises regarding a process where partial equilibrium sets in along with the ordering of the system and the generation of a certain structure therein.

Thus nature tends to not only a “chaos”, which classic thermodynamics proclaims, but to the “order” as well. This fact once again confirms the concept of the unity and struggle of opposites. The conflict between these two tendencies is what exactly causes the continuous sequence of birth and death processes intrinsic to organisms and worlds.

Chapter 22

ENERGODYNAMIC DIRECTIVITY OF BIOLOGICAL EVOLUTION

One of the most characteristic features of living systems is construed as the structuring processes running therein and featuring the increase in their complexity degree (heterogeneity) and the intensification of interrelations between the functionally distinguishing parts of such systems. Yet in the end of the XIX century the prominent German embryologist H. Drisch, based on an ample experimental material, proved that the biostructure formation processes were determined by not only the properties of cells as themselves, but rather by their position in the developing embryo as a single whole. Hence it followed that the properties of a whole living system were not the sum of properties pertaining to its parts and, therefore, had to be considered as a single system spatially heterogeneous. This concept has been described in the principles of theoretical biology stated by E. Bauer. His first principle runs as follows: “All living organisms are never being in equilibrium, but constantly doing, due to their free energy, a work counter equilibrium required by laws of physics and chemistry in existing environment”. It has been little by little understood that the principal cause of the said contradiction lies in the consideration of evolution problems from the positions of classic thermodynamics that considers only spatially homogeneous subsystems and, according to its zeroth law, excludes any heterogeneity that could arbitrarily appear therein. However, despite the theory of linear irreversible processes rapidly developing in the XX century the attempt to reach a complete concordance between thermodynamics and the biological evolution concept failed. The reason, as we see it, lies in the fact that the above theory has excluded from consideration the free energy useful conversion processes as mentioned in the Bauer principle. Therefore, the success in this direction should be forthcoming from the positions of energodynamics generalizing the theory of irreversible processes to systems doing useful work.

22.1. "Survival Principle" as Basic Law of Biological Evolution and Reflection of Process Counterdirectivity

Using the ordered energy as a more general criterion for evolution of natural systems cardinally modifies our ideas of the evolution, its reasons, motive forces and consequences. According to this criterion the behavior of a polyvariant system is conditioned by the summary variation of the ordered energy (inergy) E for all inherent degrees of freedom. These variations may be caused both by the ordered (useful external) work W_i^{e} (including the non-equilibrium part of external mass-, heat-exchange, etc) done on the system (or by the system) and by the internal dissipative proceses $W_i^{\text{д}}$). As a result, the ordered energy of a non-isolated system as a whole may both increase and decrease:

$$-dE = \Sigma_i \mathbf{X}_i \cdot d\mathbf{Z}_i \neq 0, \tag{22.1.1}$$

where $i = 1,2,\ldots n$ – number of degrees of freedom for a system under consideration, i.e. the number of the independent processes running therein.

In isolated systems due to the inevitable dissipation ($W_i^{\text{д}} > 0$) the inergy of the system as awhole can decrease only:

$$dE_{\text{из}} = -\Sigma_i \mathbf{X}_i \cdot d\mathbf{Z}_i < 0. \qquad (22.1.2)$$

The criterion of evolution (22.1.2) for such systems due to the invariability of their internal energy U should be more conveniently expressed in terms of the system order degree (21.2.6):

$$(d\eta_\varepsilon)_{\text{из}} = dE_{\text{из}}/U < 0. \qquad (22.1.3)$$

According to this expression spontaneous (irreversible) processes in isolated systems are running toward decrease of their order degree. Thereby energodynamics not only does not cancel the 2nd law of thermodynamics, but rather lays it in the foundation of the spontaneous process concept.

However, the 2nd law of thermodynamics has nothing to do with the rate an isolated or a non-isolated system is approaching equilibrium, whereas in energodynamics this rate is defined by the following expression:

$$-dE/dt = \Sigma_i \mathbf{X}_i \cdot \mathbf{J}_i , \qquad (22.1.4)$$

where $\mathbf{J}_i = \mathbf{J}_i^p - \mathbf{J}_i^e$ – summary (resultant) flux of the ith *energy carrier* (substance, charge, momentum, entropy, etc) as the algebraic sum of the spontaneous (relaxational) flux $\mathbf{J}_i^p$ and the external flux across the system borders $\mathbf{J}_i^e$ caused by external work done. Then expression (22.1.4) may become:

$$-dE/dt = \Sigma_i \mathbf{X}_i \cdot \mathbf{J}_i^p - \Sigma_i \mathbf{X}_i \cdot \mathbf{J}_i^e . \qquad (22.1.5)$$

Since the positive direction of the force $\mathbf{X}_i$ in the theory of irreversible processes and in energodynamics is adopted as the direction approaching the system to equilibrium (and coinciding with the direction of the relaxational fluxes $\mathbf{J}_i^p$), then $\mathbf{X}_i \cdot \mathbf{J}_i^p > 0$. In such a case it follows from (22.1.5) that:

$$dE_{\text{из}} = -\Sigma_i \mathbf{X}_i \cdot \mathbf{J}_i^p dt_p , \qquad (22.1.6)$$

so that the time t_p, for which the system will reach equilibrium $E = 0$ (time of relaxation as call it), will be defined by the integral:

$$t_{\text{р}} = E / \Sigma_{\text{i}} \int \mathbf{X}_i \cdot \mathbf{J}_i^p = E / \Sigma_{\text{i}} \bar{\mathbf{X}}_i \cdot \bar{\mathbf{J}}_i^p , \qquad (22.1.7)$$

where $\overline{\mathrm{X}}_i, \overline{\mathrm{J}}_i$ – mean values of forces and fluxes in the relaxation process.

In a similar way the equilibrium establishing time t can be found in the case when, along with the relaxation, the system is subjected to useful external or internal work done on it (counter equilibrium):

$$t = E / \sum_{\mathrm{i}} \int \mathbf{X}_i \cdot (\mathbf{J}_i^p - \mathbf{J}_i^e) = E / \sum_{\mathrm{i}} \overline{\mathbf{X}}_i \cdot (\overline{\mathbf{J}}_i^p - \overline{\mathbf{J}}_i^e), \qquad (22.1.8)$$

Hence it follows that antirelaxational processes appearing in a system $(\sum_{\mathrm{i}} \overline{\mathrm{X}}_i \cdot \overline{\mathrm{J}}_i^e \leq 0)$ and necessarily ensuing from the counterdirectivity principle will extend the "lifetime" of the biosystem at the same value of the relaxational fluxes and forces by the amount of

$$t - t_{\mathrm{p}} = -E / \sum_{\mathrm{i}} \overline{\mathbf{X}}_i \cdot \overline{\mathbf{J}}_i^e \geq 0. \qquad (22.1.9)$$

Since the opposite relaxational processes relate to the structure forming ones, any processes of ordering of a system, its complication (increasing number of degrees of freedom) also appears to be directed to increasing the lifetime of the system. This is the key to understanding the general directivity of the evolution of a biological system construed as a transition from the simplex to the complex. Such a directivity of the evolution is not an end in itself or something evoked by the high nous or Darwinian competition – reaching maximal lifetime for biosystems is a result of purely physical reasons as a reflection of the process counterdirectivity principle.

At the same time the "delay" in reaching equilibrium of biosystems gained due to antidissipative processes running therein is so close to the Darwinian survival concept that it may be called the "**survival principle**": *The evolutional processes arising in biological systems are directed toward extending their lifetime* 1).

This statement is so general that may be considered as a fundamental law of life. On this basis any processes in objects of animate or inanimate nature lengthening their transition to the equilibrium state should be referred to evolutional ones. Hereafter we will consider some of such processes.

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1) This wording stresses that useful work is connected with the energy convertibility, for which the system must have two degrees of freedom, at the least (to be polyvariant)

22.2. Ordering Character of Heterogeneous Biochemical Reactions

Chemical reactions running in biological systems are the basis of their vital activity. They do the work "counter equilibrium", which maintains biosystems in the non-equilibrium state and provides their "survival" in accordance with the fundamental law of evolution. However, according to energodynamics only those heterogeneous reactions are capable for useful external (ordered) work, which are running in flow and, therefore, have an ordered (vector) character. The validity of this statement can be obviously instantiated by the work of chemical current sources, which design provides for the spatial separation of reagents and the possibility of their transfer in space. In the absence of such a possibility chemical reactions are known to inevitably acquire the thermodynamically irreversible character and their chemical affinity is realized in the form of the released dissipation heat equivalent to work.

However, in classic thermodynamics and in the theory of irreversible processes chemical reactions are considered as processes of scalar nature, while their affinity is entirely referred to the dissipation heat sources (5.1.3). This results in the contradiction between these theories and the Curie principle that excludes the possibility of conjugation (interaction) between phenomena of different tensor rank and kind. In our case this means that homogeneous chemical reactions can not interact with the transfer processes having vector nature (S. De Groot, P. Mazur, 1967). As a result, the theory of irreversible processes is not in a position to satisfactorily explain the vital activity of biosystems requiring them to do ordered (useful external) work.

In attempts to solve this contradiction TIP has to resort to arbitrary hypotheses like the "stationary conjugation" of chemical reactions. This hypothesis assumes that the interaction between scalar chemical reactions and vector processes appears due to some additional bonds occurring in stationary state because of the entropy balance existing therein (I. Prigogine, 1973).

This conflict may be settled with the help of thermokinetics stating the difference in tensor order between the motive forces and the coordinates of ordered and disordered works, as well as the vector character of transfer processes and the chemical energy conversion for substances in biological membranes. To show this, let us consider an arbitrary r^{ht} chemical reaction with the k^{th} substances running in an open system of a type of flow reactor, fuel cell, plasma membrane, etc. In this case the flow $\mathbf{J}_k$ of the k^{th} substance is related with the total flow of reacting mixture $\mathbf{J}_c$ thru the evident relationship $\mathbf{J}_k = \mathbf{J}_c c_k$, where $c_k = N_k/N$ – current (local) value of molar concentration of the k^{th} substance in a particular cross section of the flow reactor. Expressing the c_k value by a known way in terms of its value c_{ko} at the flow reactor inlet, the degree of completeness ξ_r of the r^{th} reaction and the stoichiometric coefficients ν_{kr} of the k^{th} substances in this reaction (R. Haase, 1967; I. Gyarmati, 1974) gives:

$$c_k = c_{ko} + \Sigma_r \nu_{kr} \xi_r . \qquad (22.2.1)$$

According to this expression the variation in the concentration c_k of the k^{th} substance in an open system occurs both due to the diffusion of the substances not participating in the chemical reactions (i.e. by equilibrium mass transfer) across the system borders and due to the internal chemical conversions. Now let the motive force $\mathbf{X_c}$ enabling the transfer of reacting mixture composed of the k^{th} substances be expressed in terms of the negative gradient of mixture chemical potential $\mathbf{X}_c = -\nabla\mu_c = -\Sigma_k\nabla(\mu_k c_k)$. Substituting this force into expression (22.2.1) reveals it as the algebraic sum of motive forces enabling the processes of two kinds:

$$\mathbf{X}_c = -\Sigma_k\nabla(\mu_k c_{ko}) - \Sigma_r \nabla\psi_r = \Sigma_k \mathbf{X}_k + \Sigma_r \mathbf{X}_r . \qquad (22.2.2)$$

Here $\psi_r = A_r(1-\xi_r)$ – local potential of the r^{th} flow reaction; $\mathbf{X}_k = -\nabla(\mu_k c_{ko})$ – motive force enabling the transfer of the k^{th} substances not participating in the chemical reaction (diffusion); $\mathbf{X}_r = -\nabla\psi_r$ – motive force of the r^{th} flow reaction. Both forces have certainly the same tensor order, which evidences the vector character of such reactions.

From expression (16.1.2) it also follows that each summand of its first sum, including the term $\Sigma_r A_r d\xi_r$ describing the r^{th} scalar chemical reactions in homogeneous media, receives the matching additional summand of the second sum $\Sigma_r \mathbf{X}_r \cdot \mathbf{J}_r$ having vector character and describing in this case the chemical reactions running in the flow (in galvanic and fuel cells, plasma membranes, Van't Hoff's box, etc.). The meaning of the motive forces $\mathbf{X}_r$ of such reactions and their generalized rates (flows of reagents $\mathbf{J}_r$) is unambiguously defined by the general expression $\mathbf{X}_i \equiv -\nabla\psi_i$ и $\mathbf{J}_i = \Theta_i \mathbf{v}_i$. In this case the motive force of the r^{th} chemical reaction means, as also in other cases, the negative gradient of the local potential $\psi_r = A_r(1-\xi_r)$ pertaining to this reaction in a particular section of the flow reactor or plasma membrane, while the generalized rate of the process means the flow $\mathbf{J}_r$ of the reagents participating in this reaction:

$$\mathbf{J}_r = -L_r \Sigma_r \nabla\psi_r, \qquad (22.2.3)$$

Thus under the conditions of spatial separation of reagents chemical reactions take the directional (vector) character, which causes their interaction with transfer processes in the full compliance with Curie law. The validity of this law for chemical reactions can be easily confirmed with the reagents preliminarily mixed before fed to the electrodes of a fuel or galvanic cell: their EMF will then drop to zero, while the reaction becomes thermodynamically irreversible. Such a “microheterogeneity”, when not only a separate organ, tissue, but also a separate cell is a microheterogeneous system, constitutes the specific character of biological systems. As shown in Chapter 10, for such systems the motive forces of heterogeneous reactions $\mathbf{X}_r$ ($|\mathbf{X}_r| \equiv \mathrm{A}_r$) and their coordinates $\mathbf{Z}_r$ (10.4.9) acquire vector character. In this case the work of chemical reactions enters as a rightful term (10.4.11) in the expression of the system ordered energy as its “chemical” component:

$$- dE = \Sigma_i\, \mathbf{X}_i{\cdot}d\mathbf{Z}_i + \Sigma_r\, \mathbf{X}_r{\cdot}d\mathbf{Z}_r \quad (i=1,2,\ldots, r, r+1, r+2,\ldots, n). \tag{22.2.4}$$

Specific role among heterogeneous reactions play the reactions of adenosine triphosphate (ATP) synthesis from the molecules of carbohydrates and fats nutrients contain and the reactions of the ATP subsequent decomposition. The biochemical reactions of ATP synthesis proceed with useful work done and both the cell and the system in whole removing from the state of equilibrium. From the positions of energodynamics this means that an ordered “counter equilibrium” work is done on the system. The gradients of chemical potentials thereby created (i.e. the chemical inergy accumulated) can be then used by the biosystem to do useful work and, partially, to actively transport reagents to the reaction zone. This is the way the cyclic processes of ATP synthesis and subsequent decomposition with energy supply and release are proceeding.

It remains to show that such cyclic processes extend the life of any element in a biological system. For this purpose compare the energy dissipation rate in the system wherein the thermodynamically irreversible reactions are running

$$- dE/dt = \Sigma_r\mathbf{X}_r{\cdot}\mathbf{J}_r^p > 0 \tag{22.2.5}$$

with the rate that would occur in the case when at least a part of these reactions contains the reversible component $\mathbf{J}_r^e$. In the first case all terms in the right-hand sum (22.2.5) are positive so that the rate of system approaching equilibrium is equal to the summary rate of all reactions. In the second case the value $\mathbf{J}_r^p$ decreases and for a reversible reaction ($\mathbf{J}_r^e = -\mathbf{J}_r^p$) the corresponding term $\mathbf{X}_r{\cdot}\mathbf{J}_r^p$ becomes zero. The right-hand sum (22.2.5) decreases accordingly. Thus, when cyclic reactions are running in a system, the rate of system approaching equilibrium decreases. Therefore cyclic reactions are a kind of evolutional processes, too.

22.3. Antidissipative Character of Active Transfer Processes

One of the major targets of modern biophysics consists in stating laws describing principles and processes of functioning living organisms. Thermokinetics is most applicable to these targets. Firstly, it considers each cell of a bio-system as a spatially heterogeneous system being the same full-value micro-organism as the whole organs and organisms these cells form. Secondly, unlike non-equilibrium thermodynamics, thermokinetics is not limited to studying dissipation processes, but considers, along with them, also the processes of useful energy conversion inseparably associated with the vital activity of bio-organisms (E. Bauer, 1930). Thirdly, it is not limited to the stationary non-equilibrium states, as TIP is, and allows investigating the cyclic state variations characteristic for bio-organisms at all stages of their evolution. Fourthly, it is applicable to also the states which are, like bio-systems, rather far from equilibrium. Therefore the methods of thermokinetics are most adequate to the circle of the problems biophysics and bioenergetics solve.

One of such problem consists in determining the motive forces and generalized rates of biological processes. Specific role among them play the reactions of adenosine triphosphate (ATP) synthesis from the molecules of carbohydrates and fats nutrients contain and the reactions of the ATP subsequent decomposition. The biochemical reactions of ATP synthesis proceed with useful work done and both the cell and the system in whole withdrawing from the state of equilibrium. This is achieved due to the active transport of substances in biological membranes (i.e. due to their transfer in the direction of increasing concentration). The differentials of chemical potentials thus generated enable then the passive transport of the reagents to the reaction zone. The combination of these processes provides the cyclic process of ATP synthesis and subsequent decomposition with the associated energy consumption and release.

The determination of such forces and rates is currently provided based on expression (4.1.4) for the entropy generation rate. Meantime the application of TIP to analysis of reversible processes is a method involving certainly unfit means. The useful work bio-systems do in the course of their vital activity relates, as per classic thermodynamics, to adiabatic processes which in principle can not cause entropy variations. Therefore the entropy generation can not assure correct value of the motive forces for biological processes since their reversible component does not impact the entropy. E.g. the EMF of a reversible galvanic element derived from (4.1.4) will appear to be close to zero, the same for the entropy generation itself in this particular case.

Furthermore, expression (4.1.4) can not be basic for even the definition of the sign pertaining to these forces. In fact, in the active transport processes the k^{th} substances are transferred toward their increased concentration, i.e. the $\mathbf{J}_k$ flows are directed against the motive forces $\mathbf{X}_k$. In this case the product $\mathbf{X}_k\cdot\mathbf{J}_k$ is always negative. Meantime, all the summands of (4.1.4) are always non-negative as characterizing the share of any of the independent irreversible processes in the entropy production. It is easy to ascertain this if noticing that the sign of the derivative $X_i = (\partial S/\partial \alpha_i)$ always coincides with the sign of the force since the entropy production is always non-negative. In these cases the authors of many study guides interpret the situation $\mathbf{X}_k\cdot\mathbf{J}_k < 0$ as the "nega-entropy production", "negentropy consumption", etc., which is an apparent absurdity from the positions of classic thermodynamics.

Thermokinetics figures out an escape from the situation offering a more general method to find motive forces as derivatives of the system energy. In this case the terms of the second sum in (2.5.9) may have different sign depending on whether the system itself does work ($\boldsymbol{X}_i\cdot d\mathbf{Z}_i > 0$) or work is done on the system ($\boldsymbol{X}_i\cdot d\mathbf{Z}_i < 0$). This liberates from whatever violence against thermodynamics when applying equation (4.1.4) to biosystems consuming the free energy (inergy) from the environment.

A significant advantage thermokinetics offers is the possibility to find from its equations the resultant $\mathbf{F} = \Sigma_i\mathbf{F}_i$ of forces of various nature, which allows to directly obtain the simplest diagonal form of kinetic laws (2.6.11) with a minimal number of the transfer coefficients $\bar{K}_{ij}$ therein.

In particular, with temperature and pressure being constant the laws of passive transport of the k^{th} substances in the finite-thickness biological membranes become:

$$J_\kappa = L_k(X_\kappa)X_\kappa = -\,L_k\,\Delta\zeta_k. \qquad (22.3.1)$$

Here $X_\kappa = -\Delta\zeta_k$ – diffusive potential differential across the membrane; L_k – osmotic diffusion coefficients for the k^{th} substances depending on the fields of temperature, pressure and concentration of all independent components of the system. This relationship means that transfer equations (22.3.1) are non-linear since these fields themselves and the field-conditioned coefficients L_k vary with the $\mathbf{X}_\kappa$ variation. However, with the diagonal form of laws (22.3.1) this non-linearity does not anymore impede the determination of superposition effects. Let us show this by an example of the filtration and osmotic diffusion of the k^{th} substances running simultaneously in a biological membrane. In this case the bulk (filtration) flow $\mathbf{J}_v$ and the flows $\mathbf{J}_\kappa$ of the k$^{\text{th}}$ substances are interrelated ($\mathbf{J}_v = \Sigma_k \upsilon_k \boldsymbol{J}_\kappa$). This is especially evident for a binary system where only one of the flows is independent (say, the solvent flow $\mathbf{J}_v = \upsilon_1\mathbf{J}_1$). This flow is caused by the solely motive force $\mathbf{X}_\kappa = -\Delta\zeta_k$. Using the expression for the exact differential of this potential (see 18.3.5) law (22.3.1) may be written as:

$$J_{\text{к}} = -L_k[\Sigma_k \mu_{k\ell}\,\Delta c_\ell + (s_{k\text{o}} - s_k)\,\Delta T + \upsilon_k\,\Delta p]\,, \qquad (22.3.2)$$

where $\mu_{k\ell}$ – abridged symbol for the derivative $(\partial\zeta_k/\partial c_\ell) = (\partial\mu_k/\partial c_\ell)$. From here at T = const, $\mathbf{J}_\kappa = 0$ the stationary effect of osmotic pressure generation $\Delta\pi_s$ follows as:

$$(\Delta\pi_s/\Delta c_2)_{\text{ст}} = -\,(\partial\mu_\ell/\partial c_2)/\upsilon_1, \qquad (22.3.3)$$

where $\Delta c_{2\text{st}}$ – stationary differential of impurity concentrations on both sides of the membrane. This expression allows using in (16.3.3) the experimentally found value – $\Delta\pi_s$ $(\upsilon_1\Delta c_2/\Delta c_{2\text{ст}})$ instead of the value $(\partial\mu_\ell/\partial c_2)\Delta c_2$ which is hard to measure. In this case the laws of filtration and osmotic diffusion in biological membranes will become as proposed earlier (A. Katchalsky, P. Curran, 1967):

$$\mathbf{J}_\text{v} = L_\text{v}(\Delta p - \sigma_c\Delta\pi_s); \qquad (22.3.4)$$

$$\mathbf{J}_\text{к} = L_k(\Delta p - \sigma_c\Delta\pi_s), \qquad (22.3.5)$$

where $\sigma_c = \Delta c_2/\Delta c_{2\text{ст}}$ – the so-called selectivity factor.

As seen, the transfer equations in biological membranes acquire the same form as the kinetic equations of energy conversion in thermal and non-thermal, cyclic and non-cyclic, direct and reverse engines (18.3.7) – (18.3.8). It follows from them that the osmotic pressure rise $\Delta\pi_s$ leads to reducing the fluxes J_v и $J_\text{к}$, i.e. is a force that should be overcome in the course of diffusion ($J_\text{к}\Delta\pi_s < 0$). This reminds the operation of heat pumps wherein work is spent for the entropy transfer toward the temperature rise. In our case this work is spent for the substance transfer toward the substance concentration rise. Because of this property the biological membrane transferring the hydrogen ions toward their increased concentration is called the ”hydrogen pump”. The work is spent here to increase the ordered energy of the biosystem, which moves it away from equilibrium and extends hereafter the time of its relaxation. Thus the processes of substance active transfer featuring the ordered character and contributing to the accumulation of the chemical energy in the system becomes a kind of evolutional processes, too. This will serve hereafter the key to understanding the ordering processes in microstructures. We will be avoiding the application of the term “self-organization” to such processes since they are not spontaneous and can not run in the absence of an ordered energy spent from outside.

22.4. Establishing Partial Equilibrium as Ordering Process

In polyvariant systems equilibrium practically never occurs simultaneously for all of their degrees of freedom. The multiple examples in Chapters 16 and 17 show that as a system is approaching complete equilibrium the fluxes $\mathbf{J}_i$ disappear therein one after another. In the theory of irreversible processes such states are called the “stationary state of the *i*th order” ($i < n$). They are caused by the “external constraint”, i.e. by an artificial maintenance of the non-equilibrium state, at which the dissipative processes in the system are compensated by the ordered work done on the system from outside. Such a state can be maintained for an infinitely long time until the “ constraint forces” $\mathbf{X}_i$ dissapear in the environment being a free energy source.

However, for biological systems the term “external constraint” is inapplicable since in the biosystems comprising the environment around the organizm such processes are spontaneous and caused by such “extended” systems in whole tending to equilibrium. Besides, as shown in Chapters 16 and 17, the mutual compensation of fluxes ($\mathbf{J}_i^p = - \mathbf{J}_i^e$) may occur at non-stationary states, too. Such cases are considered in detail in Chapters 16 and 17 showing that all the so-called “ superposition effects" are caused by none other than this mutual compensation of counteracting forces. Therefore in energodynamics the states with $\mathbf{J}_i = 0$ are called the states of partial equilibrium of the *i*th kind (mechanical, thermal, electrical, chemical, etc). They are also called the "incomplete" or "current" equilibrium. Here come also the “retarded”, “metastable” and “labile” equilibrium.

The aforesaid is illustrated by Fig.22.1, where a “cascade” of partial equilibriums is depicted in coordinates of “inergy E – displacement vector $\mathbf{R} = \Sigma_i \mathbf{r}_i$”. This vector has a single sense and a single dimensionality and describes the scale of spatial heterogeneity for a system. It is minimal for short-range nuclear forces and increases as transiting to long-range forces. Owing to this fact all known kinds of partial equilibrium may be plotted by a single stepwise curve (Fig.22.1). Each step on this plot corresponds to the partial equilibrium of the

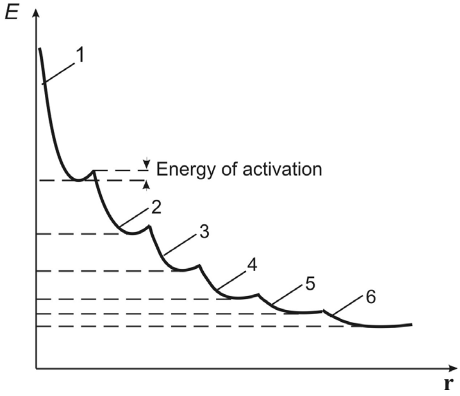

Fig. 22.1. Partial Equilibriun Cascade.
1 – nuclear, *2* – atomic, *3* – chemical,
4 – electrical, *5* – mechanical, *6* – thermal.

*i*th kind, which condition is the local minimum of inergy pertaining to a particular degree of freedom E_i for the system:

$$dE_i = -\,\mathbf{F}_i\cdot d\mathbf{r}_i = 0. \qquad (22.4.1)$$

As easily seen, the partial equilibrium of the *i*th kind appears with the motive force of this kind $\mathbf{F}_i$ becoming zero This condition may acquire a more conventional form with the exact differential of the inergy E_i expressed in terms of the parameters known from classic thermodynamics. Since according to (2.2.12) $đW_i^{\mathrm{e}} = -\,\Theta_i\, d\Psi_i(\mathbf{r})$, then

$$dE_i = -\,đW_i^{\mathrm{e}} = \Theta_i\, d\Psi_i(\mathbf{r}) = \ 0\ . \qquad (22.4.2)$$

where $d\Psi_i(\mathbf{r})$ – variation of the potential Ψ_i as a function of the field point **r**. Hence it follows that the condition of equilibrium of the *i*th kind means the corresponding potential Ψ_i being the same in different points of the system. This complies with the equilibrium conditions (4.6.7) – (4.6.9) earlier found in classic thermodynamics. However, the superiority of inergy over entropy explicitly manifests itself here as well. It consists first of all in the possibility to distinguish the partial equilibrium (where $E > 0$) from the complete one ($E = 0$). Here each kind of the partial equilibrium features a certain degree of the system ordered energy E and its order degree $\eta_\varepsilon \equiv E/U$ (21.2.6). Entropy S, which magnitude at the equilibrium state is unknown, does not provide such a possibility.

Let us now clarify the conditions of the partial equilibrium stability. Proceeding from the inergy minimum E_i at the steady equilibrium state the partial equilibrium stability condition will be construed as the positive second derivative of inergy with respect to the coordinate $\mathbf{r}_i$:

$$(\partial^2 E_i / \partial \mathbf{r}_i^2) > 0, \qquad (22.4.3)$$

Hence it follows that at each of the *i*th kind steady equilibrium state the system is in a "potential well" featuring a minimum of the ordered energy of a certain kind E_i. In order to "get out" of this well, it is necessary, according to the kinetic laws (2.6.10), to have some "theshold" value $\mathbf{F}_{io}$ of the force $\mathbf{F}_i$ enough to overcome the so-called "energy barrier". As a matter of fact, such a barrier exists for all forms of energy. So, to enable the thermonuclear reactions of light element synthethis, the repulsive forces between elements should be overcome, which needs the temperature rise up to tens of millions degrees; to initiate the spontaneous heavy nuclei fission reaction, the number of fast neutrons should be increased; to enable the chemical and biochemical reactions, the catalysts or enzymes should be introduced; to initiate a thermal process (e.g., phase transition), a certain phase potential differece, sometimes rather tangible, needs to be created. Even, to start the mechanical motion of bodies, the so-called “friction of rest” needs to be overcome. The work that needs to be spent in order to overcome the aforesaid barrier, is often called the “activation energy”.

The partial equilibrium may be metastable (relatively stable) and labile (unstable). The former is notable for its being disturbed only at finite variations $\Delta\Theta_j$, $\Delta\mathbf{Z}_j$ of the system parameters, whereas the latter – at their infinitesimal variations $d\Theta_j$, $d\mathbf{Z}_j$. These may be distinguished by specifying the said additional conditions in (21.3.3).

Overcoming the energy barrier becomes possible with the system moving away from the the internal equilibrium. This needs an external constraint. Therefore the majority of natural systems, while being at a stationary state, are actually at the state of incomplete equilibrium. Their evolution by no means may be interpreted as a sequence of stationary states of various order, which stresses the narrowness of the Prigogine’s theory of dissipative structures.

The introduced concept of partial equilibrium as caused by the mutual compensation of the dissimilar internal forces $\mathbf{X}_i$ of polyvariant heterogeneous systems extends our understanding the fundamental principles of their evolution. It assumes systems as existing, wherein approach to equilibrium for some degrees of freedom is compensated by removal of others from equilibrium. Examples of such kinds of processes are given in the previous chapter. They show that the ordering of some degrees of freedom for polyvariant systems may occur due to the "disordering" of others or the system as a whole. Which of the degrees of freedom inherent in the system is moving away from equilibrium and which is approaching it will entirely depend on the system spatial heterogeneity degree, which, according to (5.2.1), conditions the value $\mathbf{X}_i$ of the force associated. The dominating force dictates the direction of the process at a particular moment of time. Any oscillatory process, including the Belousov-Zhabotinsky’s cyclic reactions, may be the illustration to this case. Here lies the fundamental difference of energodynamics as a strictly deterministic theory from synergetics adhering to the concept of random bifurcations. The probabilistic interpretation does not expose the regularities of the sudden variation in the "behavior type" of a system, does not explain the reasons of the “collective processes competition” arising therein, the survival mechanism of the “most adapted modes”, etc. Such an interpretation does not comply with the Le Chatelier-Broun principle stating the uniqueness of the system reaction to an external influence of a certain type. Unlike this interpretation, energodynamics explains the bifurcations by a logical appearance of new degrees of freedom in the system *as it is moving away from equilibrium* and new heterogeneities are arising. This process may be clearly instantiated by the development of the crown of a tree as it is “branching”. The reverse process – disappearance of all degrees of freedom (one after another) in a system – may be observed as this system is approaching the complete equilibrium (Fig.22.1). The stepwise decrease of the ordered energy as a system is approaching the complete equilibriium entirely complies with the 2nd law of thermodynamics.

The feature specific for the states of partial equilibrium of the *i*th kind consists in a balanced action of all forces available therein, when any $\mathbf{F}_i$ of them is balanced by the resultant $\mathbf{F}_j$ of all other external and internal forces. Here the partial equilibrium differs from the complete equilibrium that features the absence of forces (inaction). The states, where the fluxes with the numbers $j > k$ disappear (i.e. a part of the system processes ceases), arise at the external constraint, too. Such states are called the "stationary states of the *k*th order" in the theory of irreversible processes. They are explained in TIP by the "superposition" of the counter processes (but not the mutual compensation between the dissimilar components of motive force for the same process) and differ from the partial equilibrium states in their forcing character, as well as in the requirement for stationarity. In this respect the notion of partial equilibrium is more general and concrete.

Since with the partial equilibrium of the *i*th kind or corresponding stationary state occurred the number of degrees of freedom for a system (i.e. the number of processes running therein) decreases, the rate of its approaching equilibrium decreases, too. Evidently, the more the number of such steps the system has passed, the more slowly it is approaching equilibrium. This means that the "counterdirected" forces and processes appearing in a system will extend the period of its relaxation and its "active" life. Thereby the relation is exposed between the evolution of the system according to the principle of its "survival" and the partial equilibrium states. At the same time, it becomes evident that the degree of "indeterminacy" or "unpredictability" of the system motion path in the abstract space of the variables Θ_i , r_j and $\boldsymbol{\varphi}_i$ will decrease as the system is approaching equilibrium and the degree of its *state* ordering $\eta_\varepsilon \equiv E/U$ is decreasing. Theredy the ambiguity of the relation between the "chaos" and the equilibrium appears to be confirmed once again. The aforesaid directly relates to the I. Prigogine's concept of "order" appearing from "chaos". It becomes extremely clear that *in a heterogeneous isolated system the ordering processes in some of its domains or degrees of freedom are caused by the disordering of others.* This statement is reasonable to be called for easy reference as the **basic self-organization principle**. Allowing for dissipative losses inevitable here it means that the "order" in some part of an "extended" system can appear only due to a still higher order in this system as a whole.

It is quite clear that with the partial equilibrium of the *i*th kind occurred in a system its resultant force $\mathbf{X}_i$ becomes zero along with the term $\mathbf{X}_i \cdot \mathbf{J}_i^p$. As the number of degrees of freedom for a system considered decreases, the sum (22.6.4) also decreases, which entails moving the system to a lower power level. This will reduce the complete equilibrium approaching rate for the system and, thereby, will extend its lifetime. Thus establishing the partial equilibroum in a system complies with the "survival principle" for biological systems.

22.5. Biomass as a Factor of Evolution. Bio-Organism Maturity Criterion

Biological objects relate to the category of open systems developing due to interchange with the environment of rather substance than energy. The development of such systems is known to be able to proceed by two – extensive and intensive – ways (D. Lurie, J. Vagensberg, 1984). In the first case, typical for, e.g., planktonic populations, the flux of ordered energy biomass consumes tends to a maximum attainable in a particular environment. In the second case, more typical for living organisms, in the phylogenesis process the consumption of free enegry (inergy) from the environment per unit mass or volume of the biosystem rises due to the improvement of their structure and the upgrading of energy conversion processes productivity in them. These are the metabolism processes (substance exchange) associated with chemical reactions running in biosystems that are a well of the ordered energy they dispose of.

To define within the energy of some system E the non-equilibrium (convertible) part associated with heterogeneous reactions, let us apply to relationship (22.2.1). According to it the equilibrium concentration of the k^{th} substance = $\bar{c}_k$ (at $\xi_r = 1$) is equal to = $\bar{c}_k = c_{k\text{o}} + \Sigma_r \nu_{kr}$. Substituting this expression into relationship (22.2.1) gives:

$$c_k = \bar{c}_k - \Sigma_r\, \nu_{kr}\, (1 - \xi_r). \qquad (22.5.1)$$

Multiplying (22.5.1) by μ_k and summing over all k^{th} components easily gives an expression for the chemical potential μ_m of mixture (Gibbs specific energy):

$$\mu_c \equiv \Sigma_k\, \mu_k c_k = \Sigma_k\, \mu_k\, \bar{c}_k + \Sigma_r\, \mathrm{A}_r (1 - \xi_r). \qquad (22.5.2)$$

This expression represents the Gibbs specific energy as a sum of the equilibrium $\Sigma_\mathrm{k} \mu_\mathrm{k} \bar{c}_k$ and non-equilibrium $\Sigma_r\, \mathrm{A}_r(1 - \xi_r)$ components. These components describe independent processes since mass transfer simultaneously and equally changes both c_k and $\bar{c}_k$ leaving the ξ_r invariable, whereas chemical reactions, on the contrary, change the coordinates ξ_r, while leaving the = $\bar{c}_k$ invariable. Note by the way that the last term in (10.4.2) is different from zero insofar as the chemical potentials μ_k of the reagents being introduced into the system are unequal to their equilibrium values $\bar{\mu}_{ik}$ (at $\xi_r = 1$). Thus in locally non-equilibrium systems both equilibrium and non-equilibrium parts of the Gibbs energy $G = \Sigma_k \mu_k M_k$. (sometimes termed as chemical energy of the system under consideration) may be distinguished. Multiplying the Gibbs chemical energy by the mass of the kth substance $M_k = \Sigma_r M_{kr}$ and introducing (to make the description general) $Z_r = M\nu_{kr}(1 - \xi_r)$ as the coordinate of the rth reaction gives:

$$U_x = \Sigma_k\, \mu_k \bar{M}_k + \Sigma_r \mathrm{A}_r Z_r \,. \tag{22.5.3}$$

Thus the energy of media chemically reacting may also be resolved into the non-equilibrium (convertible) part which, according to the classification herein adopted, should be termed as the *chemical inergy*

$$E_{ch} = \Sigma_r\, E_r = \Sigma_r \mathrm{A}_r Z_r \,, \tag{22.5.4}$$

and the equilibrium (inconvertible) part of this energy, i.e. the *chemical anergy*:

$$\bar{U}_{ch} = \Sigma_k\, \mu_k \bar{M}_k \;. \tag{22.5.5}$$

The chemical inergy of a system E_{ch} features its convertible part regardless of what this energy conversion will be – dissipative or useful (convertible). The latter means doing useful internal work, i.e. conversion of some forms of chemical inergy into other forms necessary to provide the vital activity. This is the specific character of bioenergetics. Strictly speaking, chemical reactions are also caused by spatial heterogeneity in distribution of atoms in chemical elements within chemical compounds. Chemistry in this sense has always been a science of substance restructuring. This process has the vector character when referred to molecular level. However, at macro-level a chemical reaction acquires the scalar character due to the chaotic arrangement and motion of all set of atoms and molecules.

Substance restructuring processes are a peculiar analog of chemical reactions. A convertible (useful) component available in these processes, differs them from the non-equilibrium phase transitions of the 1st kind, i.e. the substance restructuring processes imply a transition of some kind of energy to not only heat (anergy), but also to inergy of other kind. Such are, in particular, the processes of biological structures formation sometimes termed as “self-assembly” (G. Gladyshev, 1976).

It can be easily seen that the inergy E_{ch} possesses all properties of the characteristic state function. Its decrease defines the work being done in the course of the chemical reaction:

$$-dE_{ch} = \Sigma_r \mathrm{A}_r d\xi_r . \qquad (22.5.6)$$

Thus the inergy possesses potential properties. Unlike Gibbs energy, using the chemical inergy does not require the process character identification (p,T = const). Furthermore, the derivative of $\mathrm{Y_x}$ with respect to the reaction coordinate $\mathrm{Z_r}$, according to (22.5.4), defines the motive force of the reaction – its affinity:

$$\mathrm{A}_r = (\partial E_{ch} / \partial Z_r). \qquad (22.5.7)$$

The inergy-based method of chemical equilibrium conditions definition

$$(\partial E_{ch} / \partial \lambda_r) = 0,\ \mathrm{A}_r = 0, \qquad (22.5.8)$$

is straighter and shorter than that based on max entropy since does not require constancy of the equilibrium parameters Θ_i. This also refers to using inergy as the system stability criterion

$$\delta^2 E_{ch} = -(\partial \mathrm{A}_r / \partial \xi_r) > 0 . \qquad (22.5.9)$$

One more advantage of inergy consists in the fact that the true equilibrium $E_{ch} = 0$ can be distinguished from the so-called “retarded” equilibrium (when chemical conversions cease because of the absence of enzymes or catalysts), as well as from the “metastable” (relatively stable) equilibrium and the “labile” (absolutely unstable) one ($E_{ch} > 0$).

Availability of such criteria substantially extends the applicability of the thermodynamic potentials method to bio-systems. Let us consider an example of the inergy applied to develop the maturity criterion for organisms in ontogenesis.

The working capacity of an individual living organism adequately depends on its total mass and specific working capacity. Since the mass M of a living organism increases, whereas the specific working capacity (per unit of mass) decreases with its age due to senescence, the total working capacity of a particular living organism as the production of the above two parameters most exactly corresponds to the concept of its maturity in ontogenesis (E. Laifut, 1977, E. Rudakov, 1978)[1].

This statement is illustrated by curves on Fig.22.2 showing the mass M of a living organism, its specific inergy γ_x and its total inergy $E_{ch} = M\varepsilon_{ch}$ related to max values and plotted against the relative lifespan. The curve M (dotted line) describes the general character of mass variation for an organism in the course of its development and aging involving the dehydration. The curve of the specific inergy ε_x (conventionally called the chemical inergy) describes the steady variation in biotissue composition with the organism aging. Here the data on the Gibbs specific free energy is used (G. Gladyshev, 1988). In this case, along with the considered exponential reduction of ε_x, considerable variations are possible (up to the accelerated fall of the ordered energy per unit mass of the organism at the end of its life). Despite the approximate character of these curves, it is clearly seen from Fig.22.2 that the inergy E_x for the system as a whole reaches maximum earlier than its mass. This fact has been confirmed by multiple observations and may be considered as firmly proven. This confirms the validity of the organism development qualitative model considered. However, in this case the fact is more significant that the organisms are enlarging means they are accumulating a higher-level ordered energy, which, subject to other equal conditions, will extend their life. This means that the growth of mean mass of an individual, even if its organism structure does not become more complex, complies to some extent with the general evolutional directivity toward survival.

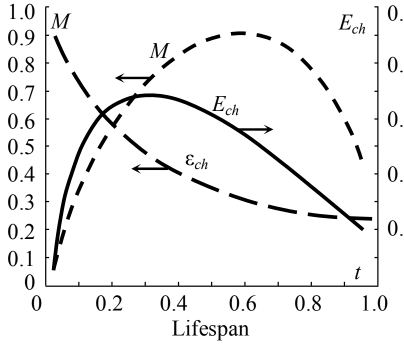

Fig.22.2. inergy as Maturity Criterion for Bio-Organisms

22.6. Energodynamic Conception of Biological Evolution and «Neodarwinism»

The question of the evolution directivity is most complicated. In the theories of evolution based on classic thermodynamics a conception has been up to date dominated that isolated systems tend to “chaos”. That conclusion of classic thermodynamics was considered irrefutable for a

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[1] It is relevant to note that using the concept of inergy is very promising for estimate of “buffering capacity” and “ecosystem development degree”.

long time. Meantime, as shown above, this conclusion is correct for only thermo-mechanical systems classic thermodynamics considers. In such systems heat and work are two solely possible forms of energy transfer so that any dissipation processes meant the conversion of work into heat as a chaotic form of energy. This entails the law of entropy rise. However, in poly-variant systems the workable part of energy (anergy) is represented according to (2.5.6) by not only the bound energy TS, but also by all other its components $\bar{U} = \Sigma_i \bar{\Psi}_i \Theta$. This means that the dissipation process is generally a spontaneous transition of *inergy* to *anergy* and not at all always associated with increase of the bound (chaotic motion) energy. It is rather this fact, but not the system openness, which is the true reason of the insufficiency intrinsic to the law of entropy rise (law of degradation of energy). In fact, the more general formulation of the law of entropy for open systems I. Prigogine offered in the form of (4.3.4) has kept the inevitability of the entropy rise (generation) $\sigma_s > 0$ for any spontaneous internal processes in a system irrespective of whether it is isolated or not. This means that a decrease of entropy in some part of the boundless Universe as a measure of "chaos" therein may occur only due to its "export" to other parts of the Universe, i.e. due to the further rise of entropy in these parts. This means that *in themselves* these processes lead to the rise of entropy in an open universe unless a "help" comes to it from other universes that are being substantially in the same position. The circle has evidently closed! The dead-lock of "heat death" of the Universe may be overcome by only proving that the law of entropy rise becomes invalid in any of such universes irrespective of whether those are isolated or not. That is what done in Chapter 11.

The concept of entropy decrease in the self-organization process has recently become all the rage. In this context let us consider one of the approaches to the "self-organization" phenomena currently most acknowledged, which owes its development to mostly the Belgium school by I. Prigogine (1973). This school ascribes the main part in the evolution processes to the *dissipation structures*. This is the term for a heterogeneous state maintained by outside flows of substance or energy and stable to minor disturbances. Thereby the basic concept of structure is intuitively opposed to the concept of chaos as a state completely without any structure. The fact there are no more adequate criteria of non-equilibrium system evolution in classic and non-equilibrium thermodynamics forced I. Prigogine to use as such a criterion the second variation of entropy $\delta^2 S$ which does not have the clear physical meaning and does not possess the exact differential feature necessary for the thermodynamic theory. According to this criterion the evolution of the systems following the linear constitutive laws leads to appearing stationary states of various order where the entropy generation σ_s is minimal. The "order" in a stationary system is maintained by doing a work on the system and removing the excessive entropy from it (or supplying the “nega-entropy”). The disappearance of a number of thermodynamic forces with approaching the total equilibrium is here interpreted as a transition of the system to a new stationary state of a lower order with a lower entropy generation, and so on till ultimately the system reaches the “zeroth order” stationary state, viz. equilibrium.

However, the concept of “dissipative” structures does not have the generality required. This name itself indicates that the structure will become the more apparent the more intensive the dissipation of energy is. In the absence of dissipation the structures of such a kind (Benar cells type) will disappear. Nevertheless, the majority of structures dealt with in nature have existed for a long time in also the absence of whatever processes at all including the dissipation processes. Hence the notion of dissipative structures covers just a part of the structures existing in nature, which may also be “static”, i.e. keeping however long in also the absence of the energy exchange. The validity of this statement is especially evident from the positions of energodynamics according to which the degree of order for an isolated system $\eta_\varepsilon \equiv E/U$ (21.1.7) is defined by the parameters of its state, but not the process.

Now let us consider from these positions what part in the evolution processes the “negentropy” plays as the value embodying the statistic-informational concept of “order”. The question is – if by removing from a system the entropy as a result of dissipative processes the stationary state can be maintained, could it be then possible to reach even higher order by removing the entropy (or supplying the negentropy) to even greater amounts? Energodynamics gives an answer to this question. As follows from (2.3.5), no heat removal from a system whatever can change the exergy $E = \Sigma_i X_i Z_i$ of the system as a measure of its ordering since according to the distribution moments Z_i (and the thermodynamic forces X_i as their functions) do not depend on entropy and other “thermodynamic” variables Θ_i and do not decrease until they are other than zero in any part of the system. Thus the “order parameter” Є being available and independent of entropy immediately spots everything, viz. the inergy increase due to the anergy decrease is a taboo as contradicting the laws of thermodynamics. Therefore using the notion of “negentropy” as a synonym for “order” is an attempt by *scienter* unfit means.

The validity of this statement is especially evident as applied to bioorganisms. Comparing the amount of the ordered energy required to maintain them in the non-equilibrium state with the bound energy flow removed from the organism to maintain the entropy balance therein gives that this flow for cold-blooded animals (for which the entropy removal with increments is the only way to remove the bound energy) appears to be much less the one that would be required under the entropy balance conditions. This circumstance evidences that maintaining the ordered state of bio-systems is provided by not at all removal of entropy, but by a free energy flow from outside (A. Rudenko, 1969; A. Rubin, 1984; J. Edsall, C. Gotfriend, 1986; G. Gladyshev, 2003; and others). This relates, in particular, to also such a self-organizing process as the photosynthesis of plants. In this process the free energy is supplied along with a flow of irradiation that is an ordered (directed) flow of photons and, therefore, relates to work. This work is done in the electron transfer to a higher energy level followed by the conversion of some forms of plant inergy into others, i.e. with a work being done "against equilibrium" (B. Crabtree, J. Taylor, 1982). The reason for which the theory of irreversible processes (TIP), instead of this simple and clear explanation of the ordering processes, has applied to the "entropy export" is extremely simple, viz. this theory has wittingly excluded the useful work processes from consideration leaving the entropy balance equation with only the terms associated with the entropy "generation" (Chapters 1, 5). It is just like "throwing the baby out with the bath water".

Let us for example refer to the "*S*-theorem" by Y. Klimantovich (1983). It proves that with the chaos degree reference point taken as the max-entropy "equilibrium state" corresponding to zero "control parameters" the entropy values related to the mean energy decrease due to variation of these parameters as withdrawing from the equilibrium state. However, this not at all means that entropy has become (directly or indirectly) a measure of the system order since the system may be deviated from equilibrium by only doing work on it, which is known to refer to the adiabatic disturbances and can not in principle decrease the system entropy in its classic interpretation. The entropy decreases only as related to the ordered system energy which is a function of the "control parameters". This should be adopted as a measure of the system deviation from equilibrium as it done in energodynamics.

The above investigation has led us to a conclusion that the useful work (both internal and external) plays a predominant part in the evolution processes. This is defined by decrease of some (i^{th}) forms of inergy and increase of others (j^{th}), which sum $dE \equiv \Sigma_i dE_i$ characterizes the direction of system evolution in whole, while each of them separately characterizes the evolution of a particular degree of system freedom. If $\Sigma_j dE_j > -\Sigma_i dE_i$, the system is in whole developing, otherwise it is degrading. The system may optionally be developing omitting the equilibrium state ($dE_j = -\Sigma_i dE_i$). The particular scenario which will actually be realized depends on the properties of the object of investigation and can not be "imposed" by whatever theory. However, the answer to the question whether the eternal circulation of energy and matter in the Universe is possible would be incomplete unless the fact is referred to that the heat form of motion as such may disappear. The conversion of the dissipated heat into work (ordered form of energy) is known to be excluded by the laws of thermodynamics. It seems as if that should be the reason of the inevitable heat death of the Universe. However, the thermodynamic exclusion refers to the unnatural processes of *anergy*-into-*inergy* conversion, but not the conversion of *anergy* from some of its forms into others. Meanwhile, this is exactly what happens with the dissipated heat in the Universe. It does not convert into work, but just disappears converting into other forms of anergy. The crux of the problem lies in the nature of heat motion as it is. Heat is a synthetic form of energy constituting the result of the relationship between two actually independent forms of energy – kinetic and potential. If kinetic energy is a function of only the particle momentum $\mathbf{P}_i$, i.e. $E^{\text{к}}=E^{\text{к}}(\mathbf{P}_i)$, while potential energy E^p – a function of only particle coordinates $E^p = E^p\ (\mathbf{R}_\mathrm{i})$, then the internal heat energy U_m is a function of both of them, i.e. $U_{\text{т}}=U_{\text{т}}(\mathbf{P}_i,\ \mathbf{R}_i)$. A telling argument in favor of such interpretation of heat is a known dependence of the internal energy of real bodies both on the temperature T as a function of the particles' velocity, and on the volume V as a function of the distance between the particles. The relation between these two forms of interaction is caused by the dynamic nature of equilibrium between them. Therefore, the heat motion as the result of a synthesis between kinetic and potential energies disappears as such with any of these forms of energy "degenerating". In particular, the kinetic energy of particles' motion degenerates at the stage a star is transiting to the superdense state (collapse) when the particle-to-particle distance becomes negligibly small. On the contrary, at the stage of "supernova" explosion, when substance is dissipating in the space, the potential energy of the particles' interaction becomes negligibly small. In both cases the heat as a form of motion is "degenerating" (disappearing). This process has absolutely nothing to do with the energy conversion in the heat and non-heat engines, which demands, as shown above, an ordered flow of both energy carriers. Any opposite standpoint is unacceptable as leading to the inevitable conclusion about the "indestructibility" (and, hence, "creation impossibility") of the heat form of energy unlike all other its forms, i.e. to the negation of evolution for any forms of motion. Thus the heat form of motion is inherent to not at all any of material objects and not at all any of their states. The processes leading to heat equilibrium is naturally failing with the heat form of energy "degenerating", and other spontaneous processes start dominating, e.g. those leading to ordering of the system and concentration of substance (its internal energy). Such processes are instantiated above. All of them do not provide strong evidence that the Universe is really tending to "chaos", which, therefore, can not be postulated.

Now let us consider the issue of the evolution motive forces. According to (2.3.6)

$$đW_i^{\mathrm{e}} = \mathbf{F}_i \cdot d\mathbf{R}_i = -\Sigma_i dE_i. \tag{22.6.1}$$

From this it follows that in energodynamics the motive forces $\mathbf{F}_i$ of any process, including the evolution of some degree of system freedom, can be found as a derivative of the inergy E_i with respect to a parameter $\mathbf{R}_i$ positioning the distribution center for a particular kind of energy:

$$\mathbf{F}_i \equiv -(\partial E_i/\partial \mathbf{R}_i). \tag{22.6.2}$$

Since E_i and $\mathbf{R}_i$ are current system state parameters, the force $\mathbf{F}_i$ value and, hence, the direction of the evolution process will momentarily be also defined by the system properties, i.e. by the resultant force value and nature. Thus energodynamics, unlike synergetics, adhere to the deterministic positions not assuming random bifurcations in the evolution. This also refers to the fundamental statement of synergetics interpreting the generation of ordered macrostructures as resulting from the loss of macrosystem stability due to the fluctuation expansion therein. However, the reason of the instability appeared and the fluctuation growing is not identified here, as well as that causing the mechanism changing the “type of behavior” for a great number of system elements and also the generation of collective processes (modes), from which the one most “adaptable” to the outward conditions “survives” by none-knows-what way and from god-knows-what competition. In energodynamics the bifurcations are explained by just new degrees of freedom regularly appearing in a system while deviating from equilibrium as mentioned in the example with the precession. This is the same evident and inevitable as the disappearance (one by one) of all degrees of system freedom with setting in total equilibrium in the system.

It should be correct to note that at present there are also other approaches to the self-organization processes besides non-equilibrium thermodynamics, synergetics and the catastrophe theory. In particular, the theory of oscillatory processes not damping in the absence of energy dissipation is conceptually rather close to energodynamics. This theory explains the appearance of both structures and waves by the available positive feedback just like in the radio engineering devices. This relation can be easily approximated by rocking a swing while meaning a finite speed of “signal” propagation and “response” delay in parts of such immense system as the Universe. If the “response” comes in phase with a process running in this particular area of the system, the process “fades in”. Therefore such processes are sometimes called self-waves by analogy with the self-oscillations (A. Zhabotinsky, 1974; L. Mandelshtam, 1979). These may be illustrated by the Belousov-Zhabotinsky's cyclic reactions. The independence of the specific spatial and time structures on initial conditions and, in some cases, on boundary conditions and geometrical dimensions of the system, are brought here to the forefront.

The cybernetic approach as having nothing to do with the "physical fundamentals and specific material forms" and, therefore, often opposed to the synergetic one played a significant part in comprehension of many essential features of the structure formation processes. This is the approach A. Turing (1952) followed when offered one of the basic models of structure formation and morphogenesis, viz. a set of two diffusion equations supplemented with terms describing the reactions between "morphogenes" He showed that a concentration distribution – both periodical spatially heterogeneous and stationary – might exist in such reacting diffusive system. Thus spontaneous processes with form-to-from energy transition, i.e. where disordering of some degrees of freedom or system parts is accompanied by ordering of others, may appear in non-equilibrium processes. In such cases replacing the stationary forces in the math model of energodynamics by the forces as time functions allows implementing the synthesis of the mentioned directions in the theory of evolution.

Potentiality of the energodynamic (pertaining essentially to natural-science) approach to the problems of evolution is substantiated by the fact that any phenomena in the surrounding world are ultimately based on the transfer and conversion of various forms of energy. It becomes especially evident from the positions of energodynamics that the reason of ordering for biological and engineering systems should be sought for not in the decrease of their entropy, but in using by them the ordered energy of the environment. In fact, according to energodynamics equilibrium of a system can be disturbed by only useful work done on the system. Since only non-equilibrium systems are capable for evolution, the neglect of the work the systems do as criteria of their evolution can not be regarded otherwise than an error.

Unlike classic thermodynamics, energodynamics considers the environment not only as a sink of the wasted (dissipated) heat, but as substantially a non-equilibrium system also having a great number of degrees of freedom (including electrical, magnetic, gravitational, radiant, spin, chemical, polarization, orientation, etc.). It takes into consideration that a system tending to equilibrium with such environment does not mean at all it approaches internal equilibrium. On the contrary, as shown by the example of the equilibrium in gravitational field, it is exactly this tendency to equilibrium with the whole "extended system" (a system plus the environment) where energodynamics traces the reason of ordering in one of the system parts and the structure formation processes running therein. Such processes run in full conformity with the general energodynamic criterion of equilibrium on this hierarchic level of matter structure, viz. the minimal ordered energy of the extended system.

Let us now show that all three foundations of the Darwinian evolution theory, viz. *variability, heredity* and *adaptability*, result from energodynamics in its application to biological systems. Considering the biological objects as non-equilibrium systems immersed into the non-equilibrium environment energodynamics extends our knowledge about equilibrium. One kind of equilibrium is when both a system and the environment are homogeneous (i.e. both far-range and short-range force fields are absent in them). Then their equilibrium corresponds to ceasing processes in both the system and the environment. Such an external equilibrium is conditioned by the equality of any potential (temperature, pressure, chemical, electrical, etc.) in all parts of the system and the environment. In this case the resultants of some forces $\mathbf{X}_i$ are equal to zero, which corresponds to *inaction*. This is exactly the type of external equilibrium classic thermodynamics deals with.

Another kind of equilibrium occurs when both a system and the environment are heterogeneous and the thermodynamic forces are therein other than zero. Then the external equilibrium means their *equal action*, which by no means excludes internal processes running in the system and the environment. Thus the external equilibrium not at all means the total (both external and internal) equilibrium. This is exactly the case thermodynamics of biological and ecological processes deals with. The processes when such kind of equilibrium is setting in are adiabatic and, therefore, do not obey the entropic criteria of evolution and equilibrium. These are exactly these processes responsible for the evolution of biological systems toward equilibrium setting in between them and the environment. The tendency to such equilibrium by no means deprives a bio-system of the capability for doing useful external work and for internal interconversions of energy. This is the *Darwinian adaptability* in its energodynamic interpretation. In the course of such processes an organism is acquiring new properties (new degrees of freedom), which it did not have in the state of internal equilibrium. This is the thermodynamic reason of the *variability* of organisms. In this case both a bio-system and the environment remains internally non-equilibrium. The striving of bio-systems for equilibrium may also influence the heredity. Should the external equilibrium be reached for at least one of the degrees of freedom a bio-system has, it may keep however long and, hence, be passed on from generation to generation according to the available heredity mechanism. This is the *thermodynamic nature* of heredity. It is significant that all three fundamental statements of the Darwin's doctrine of evolution appear to follow from the single “survival” criterion – minimal rate of approaching equilibrium for a system.

The available data evidences that the energodynamic approach not only contradicts none of the evolution theories, but can make a number of their statements more accurate. So, the energodynamic approach as applied to the “synthetic theory of evolution” called “neodarwinism” can provide a quantitative criterion of such “adaptability”, i.e. to indicate how far an organism stands from equilibrium with the environment. This complies with the fundamental concept of this theory stating the natural selection on genetic level proceeds in the direction of a better adaptation of an organism to the environment. As applied to the “theory of evolution neutrality” (L. Blumenfeld,1977), energodynamics can explain the mechanism of elimination (conservation of random genetic variations) since, from the energodynamic positions, only those variations are conserved which are associated with the decrease of inergy in an open system. In its application to the theory of “saltatory evolution” (“punctualism) energodynamics is capable to explain both the relative constancy of genetic variation rate and its stepwise increase as soon as some “critical point” has been reached since energodynamics allows for bifurcations and trajectory process branching. As applied to the theory of “molecular evolution”, energodynamics can explain the composition variation for living organisms in ontogenesis since their natural aging involves the decrease of their specific inergy.

Thus energodynamics may serve as a touchstone for any of the evolution theories.

Conclusions to Part 5

The consideration of the evolution and self-organization problems undertaken from the positons of energodynamics refutes the widely spread opinion of a glaring contradiction between the 2nd law of thermodynamics and the theory of biological evolution. It is not the 2nd law admitting the fact of spontaneous (irreversible) change from ordered forms of energy to unordered ones that contradicts this theory, but the wording of the 2nd law in the language of entropy that disregards the antidissipative processes preventing equilibrium from establishing in the system.

Introducing the inergy as a general measure of ordering in a system and the criterion of its evolution shows that in polyvariant systems disordering (destruction) of some degrees of freedom in a heterogeneous system will inevitably involve ordering (structurization) of other degrees of freedom or parts in this system. This means that “order” arises not from

”chaos”, but due to “disordering” in the system as a whole, which is in absolute compliance with the 2^{nd} law of thermodynamics.

The energodynamic analysis given in this part evidences major advantages of the energy (non-entropy) criteria of evolution, which allow following the evolution of each degree of freedom or each part of the system separately. Such an approach leads to establishing the "survival" principle for biological systems affirming the processes running therein as opposing equilibrium and extending the life of these systems. It is in tune with the Darwin’s conception of evolution though replaces the thesis of "struggle for existence” as a too simplistic one. Hence it follows also a more general conclusion of the “opposing” tendencies to “chaos” and “order” existing in nature, as well as of the circulation of substance and energy practically unlimited in time and possibly existing in the systems of metagalactic dimensions like the Universe. This allows bringing together the existing approaches to the processes of self-organization and evolution and uniting them in a single theory not violating the laws of energy conservation and degradation.

AFTERWORD

When encountering a new and somewhat unusual method of investigation the reader is used to ask himself a number of questions. What is the specific feature of the theory proposed? Is it a constructive theory? Was not it possible to adhere to more traditional notions, interpretations and methods? Do not we have to deal with logical constructions resulting just from a singular peculiarity of the author’s thinking? Are the grounds of the theory reliable? Does the theory allow obtaining new and really interesting results? And so on.

It would not take the attentive reader a lot of effort to find in this book answers to these and many other questions. The specific feature of energodynamics consists in its ability, due to introducing specific parameters of spatial heterogeneity, to consider for the first time the entire set of interacting bodies under investigation (up to the isolated systems like the Universe) as a single non-equilibrium whole. This allows implementing a system approach (from the general to the particular) and preventing the loss of “system-forming” links when studying separate parts of such systems. In doing so, counterdirected processes are discovered as existing in any heterogeneous systems and not obeying the superposition principle and also responsible for the functioning of structured systems at each level of the Universe. The heuristic value of such an approach has shown up first of all in the development of fundamentals for a number of new directions energodynamics may apply to, viz. the classic theory of quantum phenomena, the theory of similarity and productivity for thermal and non-thermal, cyclic and non-cyclic, direct and reverse engines, the theory of partial equilibrium and the theory of non-linear transfer processes based on it, the thermodynamic theory of self-organization and evolution for animate and inanimate systems, etc.

A special attention should be drawn to the methodological features of energodynamics, viz. the exclusion of hypotheses and postulates from the theory grounds, the non-idealization of processes and systems beyond the uniqueness conditions imposed, the spatial heterogeneity of systems and the irreversibility of processes running therein as explicitly allowed for in equations of energodynamics. These principles provide energodynamics with the universality, while its consequences – with the high reliability degree unattainable in a theory built on whatever concrete continual or discrete model of substance structure. In the monograph this is confirmed by the major laws and equations derived from the primary energodynamic principles for a whole number of fundamental disciplines: mechanics, thermodynamics, the theory of irreversible processes, the heat-mass exchange, hydrodynamics, electrodynamics and quantum mechanics (including the laws and equations considered as not derivable). Therefore the validity of this theory is confirmed by not only the experiments mentioned in this book and supporting the new statements of the theory, but also by the whole set of consequences ensuing from it. None of the " theories of all" exhibits the same degree of confidence. This is a long stride energodynamics makes not only in the direction of knowledge integration, but also toward creating a new paradigm of natural science as based not on hypotheses and postulates, but rather on experimental facts not needing an additional experimantal verification.

Energodynamics is constructive because it forms a self-consistent, logical and extremely compact form for the systematization of knowledge gained in various fields from the centuries-old experience. Obtaining the similar information by the conventional way would demand an extremely labor-consuming process including the study and development of a whole number of separate scientific disciplines with pooly foreseeable external links, an own notional system, a specific body of mathematics and a unique history of alternating truth and delusion. By "laying a bridge" in-between them energodynamics provides a shortcut to comprehending their specificity and place in modern natural science.

Energodynamics has exposed the diversity of natural forces when classifying them in terms of the process character they cause and proposed a unified method of their definition. The force fields have been discovered to be generated not by masses, charges or currents, but by their nonuniform distribution in space. Thereby an alternative has been proposed for the single theory of field unsuccessfully searched for. Energodynamics has substantiated an absolute reference system existing for each of the state parameters of isolated systems and the inapplicability of the relativistic transformation to them. Thereby an alternative has been proposed for the generalized principles of relativity, from where the reasonability follows to describe any physical laws in their simplest form most accessible for comprehension. At the same time this theory has provided the classic substantiation for the fundamentals of quantum mechanics, viz. the Planck radiation law and the reasons of the radiation energy quantization, the photoeffect and the spectral lines origin, the Schrödinger equation and the orbit quantization. Quantum mechanics has been shown thereby to be a part of classic physics , but not vice versa.

Energodynamics has exposed the unity between the processes of transfer and conversion of energy in any of its forms and the fallacy of their division into "convertible" and “non-convertible" ones. Energodynamics has shown that any form of energy is convertible as far as it is ordered and proposed a universal measure for the energy convertilility and the non-equilibriun systems order. At the same time energodynamics has demonstrated the narrowness of the entropy rise principle and exposed the reasons for a number of paralogisms appeared in thermodynamics due to the groundless extrapolation of this principle. Energodynamics has proposed here a new explanation for a number of phenomena in the micro- and macroworld, including the anti-entropy character of a number of spontaneous processes at various hierarchical levels of the Universe; the origin of multiple “superposition” effects for irreversible processes; the ordering of systems with their approach to equilibrium; the thermodynamic nature of "self-organization" for biosystems in metabolism processes; the thermodynamic directivity of the biological evolution; etc. A principle has been proposed describing the general directivity of this evolution.

The prognosticating capability of energodynamics is also impressive. In mechanics it shows in predicting the possibility of heterogeneous system configuration variation; in thermodynamics – the possibility to use the environmental heat in nonthermal engines and the field-form energy sources for creating the “surplus power generators; in the theory of irreversible processes – the possibility to further simplify the transfer laws and reduce the number of empirical coefficients therein; in the mass and heat theory – the determined dependence of the component potential on the process uniqueness conditions; in electrodynamics – the existance of longitudinal electromagnetic waves and the possibility of the single-wire energy transmission; in quantum mechnaics – the prediction of much lower radiation quantum value and the possibility to find mean statistical parameters of electron orbits; in the theory of thermal and nonthermal engines – the detection of similarity between processes of energy conversion in any forms; in cosmology – the substantiation of counterdirectivity of processes in separte parts of the Universe and the possibility of its long-term development omitting the equilibrium state.

All this imparts an extreme heuristic value to energodynamics and makes it a “touchstone” of any theory based on model representations.