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THERMODYNAMIC FOUNDATIONS AND METHODOLOGICAL ASPECTS OF SYNERGETICS

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Annotatsiya: Maqolada sinergetikaning tabiiy-ilmiy jihatlari ochiq tizimlar termodinamikasi va boshqa fizik paradigmalar asosida metodologik jihatdan tahlil qilingan. Bunda sineregetika ilmi insoniyat ilmiy tafakkurining zamonaviy manzarasini o’zida ifodalovchi hamda olam haqidagi bilimlarni integratsiyalovchi soha sifatida talqin etiladi. Shuningdek, dissipativ sistemalar va fraktal strukturalardagi o’z-o’zini tashkillashtirish jarayonlarining shakllanish mexanizmini bilishda Sinergetika tamoyillarining ahamiyati ko’rsatilgan.

Kalit so’zlar: sinergetika, o’z-o’zini tashkillashtirish, termodinamika, ochiq va yopiq sistema, dissipativ struktura, entropiya, tartib va xaos, nochiziqlilik, fraktallik, bifurkatsiya.

Аннотация: В статье методологически проанализированы естественно-научные аспекты синергетики на основе термодинамики открытых систем и других физических парадигм. При этом наука синергетика трактуется как область, представляющая современную картину научной мысли человечества и интегрирующая знания о Вселенной. Показано также значение принципов синергетики в познании механизма образования самоорганизующихся процессов в диссипативных системах и фрактальных структурах.

Ключевые слова: синергетика, самоорганизация, термодинамика, открытая и закрытая система, диссипативная структура, энтропия, порядок и хаос, нелинейность, фрактальность, бифуркация.

Annotatsiya: The article methodologically analyzes the natural-scientific aspects of synergetics based on the thermodynamics of open systems and other physical paradigms. At the same time, the science of synergetics is interpreted as a field that represents the modern picture of the scientific thought of mankind and integrates knowledge about the Universe. The importance of the principles of synergetics in understanding the mechanism of formation of self-organizing processes in dissipative systems and fractal structures is also shown.

Key words: synergetics, self-organization, thermodynamics, open and closed system, dissipative structure, entropy, order and chaos, nonlinearity, fractality, bifurcation.

Introduction. Synergetics has entered the modern scientific picture of the world as a theory of the development of self-organizing, open, nonlinear complex systems. However, in the classical sense, it cannot be called a theory, since the latter is defined as a form of knowledge that creates a complete picture of the regularity of a certain area of reality, a high stage of the systematic organization of knowledge, a developing dynamic system of concepts, ideas, principles, laws, and methods. When we talk about a theory, we usually recall the Newtonian dynamics, which is characterized by internal perfection, logical consistency, structural accuracy and provides a harmonious agreement of the concepts, principles, laws, and mathematical apparatus used by it. But in comparison with classical mechanics or the theory of relativity, synergetics is very far from such internal perfection, from the possibility of meeting the serious requirements imposed on theories. Therefore, we propose to perceive it at the current level of development not as a mature theory, but as a scientific direction that tries to give an adequate image of self-organizing open complex systems. One of the outstanding scientists in the field of synergetics, G.Haken, known as the author of the concept of “synergetics”, in one of his speeches, evaluating this concept as a “direction of research”, writes: “After I gave a general picture of this area, this line of research was proposed in a slightly different form and under different names. And so this field has other names: complexity theory, self-organization theory, etc.” [1].

An invaluable contribution to the development of this science is I. Prigogine, who, based on his discoveries in the field of non-equilibrium thermodynamics, showed that in non-equilibrium open systems, effects are possible that lead not to an increase in entropy and the tendency of thermodynamic systems to a state of equilibrium chaos, but to the “spontaneous” emergence of ordered structures, to the birth of order from chaos. Synergetics studies the coherent, coordinated state of self-organization processes in complex systems of various natures. In order for the application of synergetics to be possible, the system under study must be open and nonlinear, consist of many elements and subsystems (electrons, atoms, molecules, cells, neurons, organs, complex organisms, social groups, etc.), the interaction between which can be subject to only small fluctuations, insignificant random changes, and be in a state of instability, i.e., in a non – equilibrium state.

Synergetics uses mathematical models to describe nonlinear processes, which can be self-organizing processes in the study of a laser or self-sustaining and self-developing structures in a plasma. Synergetics determines what processes of self-organization occur in nature and society, what type of nonlinear laws govern these processes, and under what conditions, at what stages of evolution, chaos can play a positive role, and when it is undesirable and destructive.

To the characteristics of synergetics, we also add the fact that, aimed at finding common patterns of evolution and self-organization of natural, social and cognitive systems, formulating the foundations of a new representation of the world, it acts as one of the important paradigms of natural science, including physics. Therefore, synergetics, being closer to philosophy in terms of its content, exists as a theoretical and methodological approximation to the image of self-organizing complex systems.

Before we find out the place and role of synergetics in the theory of natural science knowledge, we will pay attention to a number of points that adequately reflect its complex and multifaceted nature. Note that at present, two directions have emerged in synergetics, as well as in quantum mechanics. Therefore, it is necessary to distinguish between two types of synergy: natural-scientific synergy (“synergy-1”) and philosophical synergy (“synergy-2”). Philosophical synergetics is usually portrayed as “X science”. This expression denotes the not yet fully defined name of a still not fully established scientific direction that studies the processes of self-organization, development, storage and destruction of structures in systems that differ in their nature (physical, chemical, biological, etc.) [2]. The main goal pursued by us in the article is to characterize synergetics not as a philosophical science, but as a natural science.

The emergence of synergetics, which emerged in the second half of the twentieth century at the intersection of nonlinear dynamics, nonlinear physics and chemistry as a new scientific direction, was due to three important discoveries of the second half of the twentieth century. First – the discovery of “strange attractors” that make up a special type of phase trajectory (a trajectory that takes place in the mathematical layer of the state space).

Secondly, the opening of a new type of objects, called “autowaves” and the active environment. Unlike classical waves, the characteristics of an autowave do not change with time, the amplitude and speed of its movement are constant, they are not dissipated. Autowaves that do not obey either the superposition principle or the phase law (the interference principle) destroy each other during the interaction (annihilation).

The reason for this behavior of autowaves, in contrast to classical waves associated with an ordinary medium, is that they are generated by an energetically saturated active medium, in which they acquire the ability to receive any amount of energy. Natural models of the active medium are most often found in chemistry[3].

Third – the discovery of the transition of the active medium from a structureless state to a structural one. This discovery is connected with the emergence of a new type of systems. Observations show that changes in the parameters of media in the isotopic state can put an end to the stability of their equilibrium state, and in such cases the concentration of different spatial points is also different. This model was first described at the beginning of the last century by Thuringian and was called the Thuringian model, or self-organization.

Literature review. Thus, in the 70s of the twentieth century, the emergence of synergetics as a new direction of science is primarily associated with the discovery of spatial self-organization of chaotic systems, active media, autowaves, and self-oscillations in chemical systems within the limits of nonlinear dynamics. This is evident from the definition of G.Haken, one of the founders of synergetics. He brings to the fore the question: what are the common qualities that take place in the development of various natural and social systems? And he says so himself: this general quality – the spontaneous emergence of the structure, the qualitative changes occurring at the macroscopic level, the emergence of a new quality in an emergent way-is a process of self-organization characteristic of open systems [4].

According to G. Haken, the difference between synergetic and traditional analysis is that here the study of simple systems is replaced by the study of complex systems, the study of linear systems – nonlinear, the study of closed systems – open, the study of the equilibrium of processes – their delocalization [5], instability.

Synergetics uses a number of new concepts: bifurcation, dissipative structures, fluctuation, chaosomality, strange attractors, nonlinearity, uncertainty, irreversibility, etc.to express the observed patterns of complex systems located at different levels of organization and connected through chaos [1]. The synergetic paradigm, which explores the hierarchy of disequilibrium in self-organizing complex systems, reveals the superposition of the systems it studies, and reveals such patterns of formation of a complex system from simpler ones that are still unknown to science. In this case, the mechanism of combining simple structures cannot be attributed either to the principle of superposition or to the principle of interference: here the whole is not equal to the sum of its parts, it is neither greater nor less than this sum.

In short, a synergistic system is a new qualitative state that has not been previously studied by science. The process typical for a synergetic system can be described as follows: there is an initial state of the system in which the movement and the state of its elements – subsystems – have relative independence. There is a transition from this state of the system to a state of dynamic microstate, in which the relationship of microelements-subsystems is strengthened. The quality of this transition process lies in the fact that although in this state the initial factors – “environment-system”, external influence – do not have a structure, but there is a structure of its result, due to the properties of “environment-system”. G.Haken, taking into account these qualities, called this process self – organization, and the science of systems of this kind – synergetics (the Greek word synergetics-together, together). In synergetics, it is possible to study and sequence the complexity of dynamic structures and the chaotic motion of simple dynamical systems [5].

Synergetic ideas gradually but surely enter the natural-scientific, including the physical picture of the world. It is known that in the twentieth century, the formation of cosmogonic views on the universe was more static and structurally guiding in nature. And it was during this period that A.Eynshteyn put forward stationary equations about the development of the universe, and in 1922-1924 their veracity was confirmed by the exact calculations of A. A. Fridman. In 1929. The American astronomer A. Hubble expressed in the form of a law the displacement of the red boundary of light coming from distant Galaxies, and established that this event is the result of the distance from the Earth of other Galaxies, and the speed of their distance from the Earth is directly proportional to the distance of the distance.

In this concept, the development of the Universe, the question of its evolution, starting from the “Big Bang”, put forward in the cosmogonic ideas of that time, is evaluated as the joint evolution of the phenomena of the micro-and macrocosm, the existence of differential and complex phenomena is associated with the evolution of the micro - and macrocosm, which occurred in different time sections. In connection with the idea of the development and evolution of the inanimate world in the physical picture of the world, elementary particles began to be depicted more vividly.

To express the idea of development in theoretical knowledge, new concepts were created. One of these concepts was the concept of “open system”. This concept was first proposed in 1929 by a representative of the Brussels school, a physicist by profession, R. Defay. In 1932, L. von Bertalanfi, applying this concept to biological systems, somewhat expanded its scope. On the basis of physical chemistry, genetics and thermodynamics, he created a new concept-the theory of the “biological organism”. This theory, having significantly changed the mathematical apparatus of differential equality, attracted the fundamental qualities of open systems to scientific research: integrity, finiteness, self-organization, etc. Thus, the discussions conducted within the framework of the scientific picture of the world led to a synergistic approximation of reality.

According to the idea of self-organization, which is the basis of the synergetic approximation, there is no sharp boundary between living and non-living systems in their self-regulation [6, p. 58]. The principle of self-organization, which was formed as the fundamental position of Darwin's theory of evolution, subsequently crossed the boundaries of this theory and entered the natural-scientific picture of the world.

In modern science, the synergetic approximation is an exemplary manifestation of integrative thought. The emergence of synergetics in the arena of modern natural science is associated with the evolutionary synthesis of all types of natural science knowledge. In the nineteenth century. In classical physics, there was a concept that matter from the very beginning is characterized by a violation of order, a tendency to the initial state of equilibrium. In the language of synergetics, this is called chaos, disorder. This view of the phenomena was formed under the influence of equilibrium thermodynamics, which studies the processes of mutual conversion of various types of energy. This science has revealed that in nature, the processes of converting heat and work into each other are not equal. While work can be completely converted into heat by friction and other means, heat cannot be completely converted into work by any means. This phenomenon shows that in the transformation of energy from one type to another, there is an unchangeable direction chosen by nature itself.

The second principle of thermodynamics-the law that expresses the conservation of thermal energy in nature and its uniform distribution between bodies-is interpreted by the German physicist R. Clausis as follows: “Heat cannot spontaneously pass from a cold body to a warmer one”. Although the law of conservation and transformation of energy (II principle of thermodynamics) does not prohibit such transitions under the condition of quantitative conservation of energy. The second law of thermodynamics reflects exactly one-sidedness, unidirectionality in the distribution of energy for closed systems. To reflect this process in thermodynamics, a physical quantity called “entropy” is used. The concept of entropy is understood as disorder, disunity in the system. After the introduction of this concept in physics, a more accurate expression of the second principle of thermodynamics was as follows: in the processes occurring in systems with constant energy, entropy always increases [7].

The physical meaning of increasing entropy means that a closed system consisting of a large number of particles always tends to move to a state in which the regularity and order in the movement of particles are minimal. This state, in which the particles move randomly, is called the simplest state, or the state of thermodynamic equilibrium of the system. The maximum entropy is equivalent to a state of thermodynamic equilibrium, complete chaos in the motion of its particles. However, the general result that follows from this is very sad: the irreversibility of the processes of energy conversion in closed systems will sooner or later lead to the conversion of all types of energy into thermal energy, and the latter, evenly distributed between the bodies, will eventually cause the thermodynamic equilibrium of the Universe or the appearance of chaos. If the universe is finite and closed, then its not at all joyful fate will be just that. Ancient Greek thinkers confirm that the universe arose out of chaos, and classical thermodynamics proves that it will turn into chaos again.

This raises a paradoxical question: if the Universe evolves only in the direction of chaos, then how did it appear, how did the complex structures in its composition arise, how did its current ordered, regular state form? Of course, it is impossible to explain this phenomenon with the help of random “excitations” of the Universe, which is generally in equilibrium: to describe the existing general picture of the world, matter must be attributed not only to a destructive-destructive, but also to a creative-constructive tendency. It is necessary to take into account that matter is able to perform work against thermodynamic equilibrium, i.e., self-organize, self-complicate. The emergence of synergetics as a theory of self-organization was associated exclusively with the realization of this truth in natural science thought in the 70s of the XX century. Currently, the main meaning of the complex of synergetic ideas developed in various directions consists of two main theses [5]:

1) the processes of origin and destruction, evolution and degradation occurring in the universe are equal;

2) regardless of the nature of the system, the processes of origin occurring in it (increasing the degree of complexity and order) have a single algoritm.

Research Methodology. As can be seen from the theses, synergetics is the desire to create a universal mechanism by which it would be possible to depict the self-organization of living and inanimate nature. In this case, self-organization is understood as the process of spontaneous transition of an open, unequal system from a relatively simple and poorly ordered form of self-organization to a more complex and more ordered form. Hence, it becomes clear that not any systems, but only those that meet the following requirements, can be self-organizing synergistic systems:

a) the synergistic system should be open, i.e. it should exchange matter, energy and information with the environment;

b) the synergetic system must be unbalanced(unstable), remain distant from the state of thermodynamic equilibrium.

Most of the systems we know meet these requirements. In the development of such systems, two phases are observed:

a) an even evolutionary period that allows us to predict linear changes that eventually lead the system to an unstable (nonequilibrium) critical state;

b) the period of instantaneous abrupt transition of the system from a critical state to a complex, ordered and equilibrium state.

The quality that characterizes this phase is that the transition of the system to a new stable state is not at all ambiguous. Systems whose parameters have reached a critical state (the “bifurcation point”) pass into one of the possible stable states. At the point of bifurcation, the evolutionary path of the system branches off and the choice of the trajectory along which the continuation of its development takes place is completely random. And after the system chooses the orientation of development, it has no way back and the process is irreversible [8]. Although the calculation of possible variants of the evolution of such systems is practically possible, it is still impossible to predict unambiguously in advance which of these paths will be given preference.

Conclusion. Thus, the synergetic interpretation of phenomena creates new opportunities for their adequate study. The novelty of the synergetic approach to the study of phenomena can be briefly described as follows:

1) one of the important characteristics of the modern world is its constant improvement, the irreversibility of development processes, the ability to have a serious impact on the overall course of phenomena, even the most insignificant events and influences;

2) chaos is not only destructive, but also creative, constructive in nature: development is implemented precisely through unstable (chaotic) states;

3) the linear nature of the evolution of complex systems, which is customary in classical science, is an exception, not being an inviolable rule. The nonlinear nature of the development of most such systems means that there are always several ways of development for complex systems. However, this does not exclude the possibility of a serious quantitative determination of complex systems and the most optimal options for their development;

4) it is impossible to determine the direction of development of complex systems from the outside. And so it is necessary not to interfere grossly with their development, but simply to adapt them to the tendency of their particular development. However, we should not forget that human thinking is not yet able to influence natural and social processes in the most optimal form in order to ensure the desired development bias;

5) the interaction of a self-organizing system with the outside world and its entry into the nonequilibrium condition is the cause of the formation of new dynamic states – dissipative structures [9];

6) there are significant fluctuations in the system near the “Bifurcation” point. Such systems seem to “hesitate” in choosing one of the paths of evolution. At this time, a small fluctuation can cause the emergence of a new direction in the evolution of the system;

7) at all levels of self-organization, the primary source of order is irreversibility, “creating order out of chaos”, causing the emergence of a new unity;

8) chaos can turn into a constructive mechanism of the creative beginning of evolution;

9) if quantum mechanics has determined the dualism of the particle-wave properties of micro-objects, then nonlinear dynamics has revealed deterministic and stochastic (random, probabilistic) dualism;

10) the complexity of the organization of the system becomes the reason for speeding up the processes occurring in them, and reducing the degree of stability;

11) knowing the tendencies of self-organization of the system, you can speed up the evolution by bypassing a number of its mazes [10].

First, it would be a complete absurdity (if not macro-madness) to say anything against synergetics, which has been developing rapidly in recent years, and whose ideas and methods are widely invading the natural and socio-humanitarian sciences, increasingly defining the face of science at the end of the twentieth century.

Secondly, synergetics, as its founding fathers believe, is a general scientific, not a philosophical discipline, and even more so-not philosophy as such. These are different (though related) methodological levels: philosophy (and dialectics as one of its methods) is on the top floor, synergetics is on the lower (general scientific) floor. And although, of course, synergetics is already initially philosophical – like any science-but to declare it a "philosophy of modern culture" [11] would, in our opinion, be a clear exaggeration.

Thus, the fact that synergetics has its own natural-science foundations and meta-methodological significance has made it the main ruler of post-classical scientific thinking.

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