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# CHAOS as the Basis of Order. Entropy as Measures of CHAOS

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**ABSTRACT:** This work considers the issues of order and disorder in nature, since their relationship in nature is very relevant, and this is indisputable, because order and disorder surround us in our daily life everywhere. The concepts of order and disorder in nature are often used to describe the state of a thermodynamic system. This work describes one of the most important thermodynamic laws - the law of increasing entropy. The study of the elements of disorder in an ordered molecular structure and, conversely, the study of the elements of order in the chaos of a disordered arrangement of particles led to the establishment of new important regularities linking the structure of matter with its properties, explaining a number of phenomena by changes in the degree of ordering of the structure.

**KEYWORDS:**“Order” and “disorder”, thermodynamic laws, “chaos”, correlation, coherence, entropy, Universe, Clausius, Hubble, Boltzmann, “dissipation”, gravitational interaction, electromagnetic interaction, diffusion.

## I. INTRODUCTION

Consideration of the issues of order and disorder, their relationship in nature is very important, and this is indisputable, since both order and disorder surround us in our daily life everywhere. The bodies around us are made up of atoms and molecules. Previously, they wrote that in nature there are bodies consisting of particles arranged in a random manner, these are gases, liquids, amorphous solids, and bodies built of particles arranged in a strict order, laid by nature in rows and grids - these are crystals. Is the categorical division of the bodies around us correct? The development of science has shown that such a judgment is wrong. Along with bodies for which the words "order" and "disorder" are a fairly accurate description of the arrangement of particles in them, very often there are bodies in which disorder and order exist together, are inseparable from each other.

The concepts of order and disorder in nature are often used to describe the state of a thermodynamic system. This work describes one of the most important thermodynamic laws - the law of increasing entropy. The study of the elements of disorder in an ordered molecular structure and, conversely, the study of the elements of order in the chaos of a disordered arrangement of particles led to the establishment of new important regularities linking the structure of matter with its properties, explaining a number of phenomena by changes in the degree of ordering of the structure. This formed the basis for the second part of the work, in which we move from closed systems to considering open systems that exchange matter or energy with the environment. The study of the phenomena associated with the transitions from order to disorder and vice versa is of equal importance; such transitions underlie the most important technological processes.

## II. MATERIALS AND METHODS

Chaos is the tragic image of the cosmic primacy, the beginning and end of everything, the eternal death of all living things and at the same time the principle and source of all development, it is disordered, omnipotent and faceless. Consider the kinetic energy of a collection of particles. If it suddenly turns out that all the particles are moving in the same direction at the same speeds, then the whole system, like a tennis ball, will be in flight. In this case, the system behaves similarly to one massive particle, and the usual laws of dynamics apply to it, such a motion is called the motion of the center of mass. There is, however, another kind of movement. It is possible to imagine that the particles of the system move not in an orderly, but chaotically: the total energy of the system can be the same as in the first case, but now there is no resulting motion, since the directions and velocities of the motion of atoms are disordered. If we could follow any individual particle, we would see that it travels a short distance to the right, then, colliding with a neighboring particle, shifts slightly to the left, collides again, etc. The main feature of this type of motion is the absence of correlation between the movements of different particles; in other words, their movements are incoherent (disordered). Random, chaotic, uncorrelated, incoherent, disordered motion is called thermal motion. Obviously, the concept of thermal motion is inapplicable to an individual particle, since it makes no sense to talk about the uncorrelated motion of one particle. In other words, when we pass from considering the motion of an individual particle to systems of many particles and at the same time the question arises of the presence of correlations in their motions, we essentially move from ordinary dynamics to a new field of physics called the term the dynamics.

So, there are two types of motion of particles in complex systems: motion can be coherent (ordered), when all particles move in concert (“in step”), or, on the contrary, disordered, when all particles move chaotically.

"All processes in the world occur with an increase in entropy" - this common formulation turned entropy from a scientific term into some kind of immutable evidence of a man's doomed struggle with the disorder around him. But what is hidden in the original behind this physical quantity? And how can you calculate entropy? "Theories and Practices" tried to understand this issue and find salvation from the impending decay.

For the first time the term "entropy" was introduced in 1865 by the German physicist Rudolf Clausius. Then it had a narrow meaning and was used as one of the quantities to describe the state of thermodynamic systems - that is, physical systems consisting of a large number of particles and capable of exchanging energy and matter with the environment. The problem was that the scientist could not fully formulate what exactly entropy characterizes. In addition, according to the formula he proposed, it was possible to determine only the change in entropy, and not its absolute value.

Simplified, this formula can be written as $dS = dQ / T$.

This means that the difference in the entropy of two states of a thermodynamic system (dS) is equal to the ratio of the amount of heat expended to change the initial state (dQ) to the temperature at which the change of state takes place (T). For example, to melt ice, we need to give it some heat. To find out how the entropy changed during the melting process, we will need to divide this amount of heat (it will depend on the mass of the ice) by the melting point (0 degrees Celsius = 273, 15 degrees Kelvin. The counting starts from absolute zero Kelvin (- 273 ° C), since at this temperature the entropy of any substance is zero). Since both values are positive, when calculating we will see that there is more entropy. And if we carry out the reverse operation - freeze water (that is, take heat from it), the value of dQ will be negative, which means that the entropy will become less.

Approximately at the same time with this formula, the formulation of the second law of thermodynamics appeared: "The entropy of an isolated system cannot decrease." Looks similar to the popular phrase mentioned at the beginning of the text, but with two important differences. First, instead of an abstract "world", the concept of an "isolated system" is used. An isolated system is one that does not exchange either matter or energy with the environment. Second, the categorical "increase" changes to a cautious "does not decrease" (for reversible processes in an isolated system, the entropy remains unchanged, and for irreversible processes it increases).

The main thing is hidden behind these boring nuances: the second law of thermodynamics cannot be applied without looking back to all phenomena and processes of our world. Clausius himself gave a good example of this: he believed that the entropy of the Universe is constantly growing, and therefore one day it will inevitably reach its maximum - “heat death”. A sort of physical nirvana in which no processes take place anymore .. But in the 1920s. American astronomer Edwin Hubble proved that the Universe is expanding, which means that it can hardly be called an isolated thermodynamic system. Therefore, modern physicists are quite calm about Clausius's gloomy forecasts.

Since Clausius was never able to formulate the physical meaning of entropy, it remained an abstract concept until 1872 - until the Austrian physicist Ludwig Boltzmann deduced a new formula to calculate its absolute value. It looks like $S = k * \ln W$(where, S is the entropy, k is the Boltzmann constant, which has a constant value, W is the statistical weight of the state). Thanks to this formula, entropy began to be understood as a measure of the orderliness of a system and, under certain conditions, entropy becomes the progenitor of order.

The natural tendency of energy to dissipate determines the direction in which physical processes occur in nature. This means the scattering of energy in space, the scattering of particles with energy, and the loss of order inherent in the movement of these particles. The first law of thermodynamics, in principle, does not deny the possibility of events that would seem to contradict common sense and everyday experience: for example, a ball could begin to bounce due to its cooling, a spring could spontaneously compress, and a piece of iron could spontaneously become hotter than the surrounding space ... All these phenomena would not violate the law of conservation of energy. However, in reality, none of them occurs, since the energy needed for this, although available, is not available. If you do not take seriously the existing, in principle, but extremely small chance, you can boldly assert that energy can never be localized by itself, having collected in excess in any small part of the universe. However, even if it did, it is even less likely that such localization would be orderly. Natural processes are always processes that accompany the scattering, dissipation of energy. From this it becomes clear why a hot object cools down to ambient temperature, why

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ordered motion gives way to disordered motion, and, in particular, why mechanical motion due to friction completely transforms into thermal motion. It is just as easy to realize that any manifestations of asymmetry, in one way or another, are reduced to the dissipation of energy. The manifestation of any imbalances in the organizational structure of the object leads to the formation of asymmetry both in relation to the environment and to the structure itself, in particular, this can lead to an increase in potential energy or, with a large accumulation of this energy, to the disintegration of the system, as contrary to the laws of nature. An object is created from chaos by one or more excited atoms and falls into chaos upon liquidation. Natural, spontaneously occurring processes are a transition from order to chaos. Let us now pose the next question: how many ways can one carry out a restructuring within the system without an external observer noticing it? Note that the formulation of the question takes into account the essential that characterizes the transition from the world of atoms to a macroscopic system, namely, the “blindness” of the external observer in relation to the “individuals” of the atoms that form the system. Thermodynamics deals only with the averaged behavior of huge collections of atoms, and the behavior of each individual atom does not matter. If an external observer studying thermodynamics has not noticed that a change has occurred in the system, then the state of the system is considered unchanged, only a “pedantic” observer who carefully monitors the behavior of each atom will know that the change has occurred.

Let us now take the last step towards a complete definition of chaos. Suppose the particles of the universe are not fixed and can, like a state of excitement and energy, freely move from place to place; for example, this could happen if the universe were gas. Let's also assume that we created the initial state of the universe by sending a stream of gas into the lower right corner of the vessel. Intuitively, we understand what will happen: a cloud of particles will begin to spread spontaneously and after a while will fill the entire vessel. This behavior of the universe can be interpreted as the establishment of chaos. Gas is a cloud of randomly moving particles (the very name “gas” comes from the same root as “chaos”). The particles rush in all directions, colliding and bouncing off each other after each collision. Movement and collisions cause the cloud to quickly dissipate, so that soon it is evenly distributed throughout the available space. Now there is only a negligible chance that all the gas particles will someday spontaneously and simultaneously re-gather in the corner of the vessel, creating the original configuration. Of course, they can be assembled into a corner using a piston, but this means doing work, therefore, the process of returning particles to their original state will not be spontaneous. It is clear that the observed changes are explained by the tendency of energy to dissipate. Indeed, now the state of excitation of atoms has turned out to be physically scattered in space due to the spontaneous scattering of atoms over the volume of the vessel. Each atom has kinetic energy, and therefore the propagation of atoms through the vessel leads to the propagation of energy.

Now, from closed systems, we come to the consideration of open systems that exchange matter and energy with the environment. From the molecular-kinetic point of view, in isolated systems, the state of equilibrium corresponds to the state of maximum chaos. Internal relaxation is opposed to processes that disturb the equilibrium in the system. In the case of rarefied gases, these are collision processes. If the perturbing processes are less intense than the relaxation processes, then one speaks of local equilibrium, i.e., it exists in a small volume. In this case, it is not at all necessary that in other parts of the system the state was close to equilibrium. For example, gas is located between planes heated to 100 ° C. The process of thermal conductivity is extremely slow, the gas is in a nonequilibrium state, and somewhere in the system there will be a small region in local equilibrium. This idea was put forward by Prigogine and made it possible to describe states in this region by equilibrium parameters, for example, temperature. Le Chatelier wrote: “If one of the equilibrium factors is changed in a system in equilibrium, for example, to increase the pressure, then a reaction will occur, accompanied by a decrease in volume, and vice versa. If such reactions occur without a change in volume, a change in external pressure will not affect equilibrium. " Le Chatelier-Brown's principle in modern presentation about means that the system, brought out of the state by an external influence with a minimum production of entropy, stimulates the development of processes aimed at weakening the external influence. At the same time, out of chaos, structures can arise that will begin to gradually move into more and more ordered ones. The formation of these structures occurs not due to external influence, but due to the internal restructuring of the system, therefore this phenomenon is called self-organization. Prigogine called the ordered formations that arise in dissipative systems in the course of nonequilibrium irreversible processes dissipative structures. Since "dissipation" comes from the Latin word dissipatio "to disperse, to dissipate," they say that these structures are volatile and arise from the dissipation of free energy. In open systems, it is possible to change the flows of energy and matter and thereby regulate the formation of dissipative structures. It turned out that under the action of large-scale fluctuations, collective forms of motion appear, called modes, between which competition arises, the most stable of them are selected, which leads to the spontaneous emergence of macroscopic structures. The chaotic state contains uncertainty, probability and chance, which are described using the concepts of information and entropy.

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Now let's think about the gravitational and electromagnetic interactions, as well as the gravitational forces in nature. Gravitational forces are always constant. They can not be more or less. This is confirmed by the existence of galaxies, stars, planets and even atoms. Indeed, if the gravitational interaction is weaker. the present, the stars would be smaller and the pressure exerted by gravity on the inner parts of the stars could not raise their temperature to the level necessary for nuclear fusion. The sun could not shine. And nothing would have happened. And if the gravitational interaction were a little bit If the electromagnetic interaction were weaker than planned, electrons would not be able to stay around the nucleus, atoms would not form molecules. If this interaction were stronger, electrons would not be able to come off from the nucleus of an atom, chemical reactions would become impossible, and therefore life But why is it so? After all, there is a precisely calibrated electromagnetic interaction. Take the forces acting in atoms. One of them, let's call them consolidating, hold together protons and neutrons in the atomic nucleus. Due to this, various chemical elements are formed - both light and heavy. If the action of these forces were weaker even by 0.00… .1%, then only hydrogen would surely exist. And if on the contrary, then the presence of only heavy elements is quite obvious, and hydrogen simply could not exist. And in the absence of hydrogen in the universe, therefore, there would be no stars, no sun, no life itself. Thus, the electromagnetic interaction can be neither more nor less. This quantity is constant. Take our sun-light. The slightest change in this interaction could lead to a change in the intensity of light reaching our planet. As a result, there would be no photosynthesis on the Earth and water would be deprived of its unique properties necessary for life. An important role is played by strictly verified forces of interaction between neutrons and protons in the nucleus of the atom. These forces keep the nucleus from decay. Thus, the strictest ratio of gravitational and electromagnetic interactions ensures the life and evolution of the Universe. Any slightest deviation in this ratio in any direction would not lead to the formation of the Physical Universe.

## III. RESULTS AND DISCUSSIONS

If the outside forces do not act on the molecules, if there are practically no adhesion forces between the molecules, then an ideal disorder arises in their arrangement. To get rid of the adhesion forces between molecules, the body must be heated, melted and evaporated. It is more difficult to get rid of external forces, primarily gravity. However, in a vertically thin layer of gas, the influence of gravity will not affect. The molecules of such a gas layer are in perfect disorder. Let us try to answer the question: why does a random arrangement of molecules with a uniform density occur when molecules move randomly? It is necessary to place six different animals in three rooms so that each of them has two "residents". By a simple enumeration, it is not difficult to find out that there are 90 ways to evenly distribute the population of only 6 units over three houses. And how many ways to distribute 1000 animals evenly in 100 cages? Calculation shows that this number is roughly expressed as one with thousands of zeros! It is easy to understand that if we are talking about gas molecules (and there are a billion billion of them in one cubic centimeter), then the number of ways in which it is possible to carry out To have a macroscopically uniform distribution of molecules over the volume would be unimaginably enormous. At the same time, the number of ways in which a macroscopically non-uniform, more or less ordered distribution of molecules can be realized will be much less, and, moreover, the less, the greater the deviation from a uniform, ideally random distribution. In the case of a billion billion molecules, the distinction between uniform and uneven distributions will be even sharper. From our numerical example, it follows that if the arrangement of molecules is determined by a case, then the most "widespread", the most easily realized, the most probable distribution of molecules with complete isotropy and with a macroscopically uniform density, ie, ideally random distribution. Under those external conditions in which the gas is, the most probable is disorder, that is, such a state that can be realized in the maximum number of ways.

So, if the molecules are "left to themselves", if the forces interfering with their thermal motion do not act on the molecules, then the most probable is the disordered distribution of molecules. Does this mean that spontaneous deviations from disorder are incredible? Does it follow from this that there is a "tendency" for disorder? Yes, it should. To make this clear, let's pose two questions.

The first is this: can water be frozen by heating? Of course not, any of us will answer. But why? At first glance, the question seems meaningless, but only at first glance. Indeed, in every particular phenomenon we are looking for the manifestation of the general laws of nature, to which the material world around us obeys. What law of nature "forbids" the spontaneous freezing of water by heating? Maybe the law of conservation of energy? No, this law can be observed in the meaningless process of interest to us. You can imagine a vessel with water, placed on a massive electric stove, heated to 300 ° C, and then such a phenomenon: the stove heats up to 400 ° C, and the water in the vessel freezes. In this impossible event, the law of conservation of energy is not violated. The water gave off the heat, and the stove received it. Therefore, the explanation for the impossibility of the named phenomenon must be sought in

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something else. Let's think about the molecular mechanism of heat transfer. It is known that in a warmer body, molecules move more rapidly than in a cold one. When bodies with different temperatures come into contact, the slower molecules of one body will most often collide with the faster molecules of another body. And now it turns out that after a while the result of these collisions will be the equalization of the average velocities of molecules in contacting bodies. Let us now describe the molecular state of these touching bodies before and after temperature equalization. If there are white and black balls in the box, then the distribution of balls will be disordered such that the probabilities of taking out a white or black ball will be the same anywhere in the box. But we already know that order and disorder can be carried out in relation to any sign (for example, magnetic order). Therefore, one can also speak of order or disorder in terms of the mean velocities of molecules. A disorder is such a state when the average velocities of molecules at all points in space are the same. Thus, from a molecular point of view, two bodies in contact heated to different temperatures do not represent a random distribution of particles. We come to the conclusion that the transition of heat from a less heated body to a more heated body is a transition from disorder to order. But after all, a disorderly state is most likely. Hence, the transition from disorder to order will be a transition from a more probable to a less probable state. Therefore, such processes are usually not observed.

A bag of black seeds is poured into a box, and then a bag of white seeds. Take a shovel and start mixing the grains. The grains will mix, just like molecules by thermal motion. Soon the grains will be mixed, and, taking at random a handful of grains, we find in them approximately equal amounts of white and black. The order turned into a mess. No matter how much stirring goes on, we will never achieve the sorting of the grains. On the contrary, a more or less uniform distribution of grains will be a steady state. For molecules, this state is called thermal equilibrium. In a state of thermal equilibrium, the velocities of gas molecules are distributed in accordance with Maxwell's law and do not have preferential directions. The tendency towards disorder in the arrangement of molecules explains many of the phenomena considered above, and above all the diffusion processes. What makes the molecules of a piece of sugar thrown into a glass of tea move upward (and sugar molecules are heavier than water molecules) and mix evenly with water? Desire for disorder. What causes zinc atoms to penetrate copper when the plates of these two metals are pressed against each other? Desire for disorder. Without considering this law of nature, we will not be able to understand anythi in the phenomena of phase transitions, in the phenomena of phase stability. If the molecules of a substance can create several arrangements, then, all other things being equal, the arrangement which makes it possible to "unfold" the thermal movement has an advantage, helps to realize the striving for the freest, that is, the most disordered movement.

As we know, the most likely distribution of molecules is disorder in both location and direction of velocities. As for the magnitudes of the velocities, here disorder is expressed in the ultimate freedom of movement. In the case of a gas, this ultimate freedom of movement leads to the Maxwell distribution. But if forces acting on particles interfere with the game, the picture changes. The action of the forces is directed towards the establishment of order. If atoms (molecules) are in thermal motion and forces act on them, then the most probable distribution of particles will no longer be disorder, and the distribution of velocities will no longer be Maxwellian.

The struggle between order and disorder can be seen in many examples. Almost all of the material presented earlier illustrates this important law of nature by a kind of balancing of two tendencies: to order, that is, to the most probable distribution characteristic of particles in thermal motion. A very simple and characteristic example is the distribution of molecules in a vertical column of air. If there was no thermal motion, the striving for equilibrium would force all the molecules to press against the earth's surface. And what really is? It is well known that the pressure, and hence the density of air, decreases with height. For 5.6 km, the air density drops by half. This striking example shows the compromise between both aspirations. In the presence of gravity, the most probable is no longer complete disorder, i.e. perfect uniformity of density. How can two different phases of a substance be in equilibrium with each other? Consider, for example, crystal and saturated vapor. The state of the crystal is long-range ordering. Work is required to detach a particle from a crystal and transfer it to a vapor state. It would seem that the state of steam is less stable. Nevertheless, both phases are in equilibrium. How is the lower stability of the vapor state compensated? The striving for order finds its realization in the crystalline arrangement of atoms. However, the tendency towards disorder in the crystal is suppressed. The atoms are cramped, their movements are difficult. In a pair, there is a much larger volume for each particle. Thermal motion has a place to unfold, it becomes "extremely" free. The desire for disorder is satisfied. We can say that the equilibrium between crystal and vapor requires that the "sum" of order and disorder be the same for both phases. The more order is in the crystal, the more disorder should be in its saturated vapor. It is known that saturated steam has different pressures at different temperatures. The lower the temperature, the lower the pressure, and hence the density of the saturated steam. Since the density is less, it means that the volume per molecule is greater, and, consequently, the degree of freedom is also greater, and hence the disorder in the pair. Since the crystal shrinks little with decreasing temperature, the volume per atom, and hence the degree of disorder, changes little. On the other hand, the degree of stability (tendency towards order) in a crystal increases: the lower the temperature, the more work is needed to tear off the molecule (or atom) from the crystal. By changing the conditions of equilibrium of saturated vapor with a crystal, we find different trade-offs between order and disorder. Nature balances the greater disorder in one phase with greater order in the other. By violating the equilibrium conditions, for example, by raising the temperature at the same pressure, we force the crystal to sublimate. The urge for disorder takes over. The thermal movement becomes so intense that the gain in crystal stability cannot withstand it. But what about the phase transformations in the solid state? In those cases when we are faced with phase transformations, the situation will be as follows. One phase has narrower amplitude, but deeper. The condition of equilibrium of these two phases occurs when the possibilities of thermal motion (the tendency to disorder) in one of them are compensated by greater stability (the tendency to order) in the other. If the temperature rises, then the mess takes over. If the temperature drops, then the tendency to stability (to order) leads to a corresponding phase transition.

## IV. CONCLUSION

This work is devoted to the issues of order and disorder, their relationship in nature. The problems of order and disorder are an integral part of modern natural science and occupy far from the last place in the natural sciences. Molecular physics, chemistry, mathematics and many other disciplines deal with these questions.

Ultimately, according to this work, the following can be done inng Conclusions: The law of increasing entropy is applicable only to a sufficiently large collection of particles, and for individual molecules it simply cannot be formulated. Issues related to entropy in complex systems and the law of the tendency of such systems to a state of equilibrium makes it possible to objectively perceive the processes occurring in nature and determine the possibilities of interference in these processes. The law of increasing entropy is part of the second law of thermodynamics, which is usually called the empirically obtained statement about the impossibility of building a perpetual motion machine of the second kind. In a closed system, the arrangement of molecules is determined by the case, and the most probable distribution is the distribution of molecules with complete isotropy and with a macroscopically uniform density, i.e., a perfectly random distribution. Under those external conditions in which the gas is, the most probable is disorder, that is, such a state that can be realized in the maximum number of ways. It can also be concluded that the transition of heat from a less heated body to a more heated body is a transition from disorder to order. During phase transformations, the condition of equilibrium of the two phases occurs when the possibilities of thermal motion (tendency to disorder) in one of them are compensated by greater stability (tendency to order) in the other. If the temperature rises, then the mess takes over. If the temperature drops, then the tendency to stability (to order) leads to a corresponding phase transition.

In conclusion, I would like to emphasize that the laws of probability, rules of order and disorder are an important element of this general scientific approach, covering physical, biological and social events. The main conclusion that can be drawn from all of the above is that natural systems should also be considered as complex integral systemic formations that are inextricably linked with society and technical objects. Both nature and the “nature-society” system are complex integral formations, and a change in one of the components necessarily causes a chain of changes in other components. And such interconnected sequential changes can lead to a significant change in the environment.

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