SYNERGETICS AND FRACTALITY IN SCIENCE EDUCATION

Mykhaylo Mar'yan

Vladimir Seben

Nataliya Yurkovych

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Autori: Prof. Michajlo Marian, DrSc.
Dr.h.c. doc. PaedDr. Vladimír Šebeň, PhD.
Doc. Natalia Jurkovič, PhD.

Recenzenti: Prof. Oleksandr Homonnaj, DrSc.
Prof. Ivan Nebola, DrSc.

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The formation and conservation of the functional organization, its development and implementation is both the goal of the research, and its paramount stage. This concerns the problems associated to the development of materials with structural-sensitive properties and varying degrees of ordering (in the majority of cases, the most important one is the creation of the required spatial or spatial-temporal ordering). The question about the optimal structuring and organization is also topical when studying the global problems, in particular energy, ecological, educational and others, which require immense resources. In this case it is difficult to overestimate the importance of self-organization and laws of ordering in physical, technic, information systems.

The present work is dedicated to the studies on formation of the ordered structures and hyper sensibility in the different-nature systems (non-crystalline solids, materials of artificial intelligence, information and communication systems, education) by invoking the ideas of synergetics and computer modeling. In contrast to a number of known books on the problem of ordering, this book contains both mathematical background and a number of theoretical facts, concerning information technology, natural sciences. An important problem of the influence of different fields on the metastable systems is successively analyzed in many aspects, and leads to understanding of the essential importance of investigations in this direction. From this perspective, education is seen as a living organism, for which a minimum level of dissipative processes and a comprehensive information perception can be achieved. From chapter to chapter the considered tasks become more and more clear, and appropriate mathematical models of self-organizing processes are more visual. So this book may be interesting for the professionals working in this field of science, and for those readers who are just trying to understand the deep interconnections in the materials science and information objects.

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INTRODUCTION

When solving the problems concerning various fields of science ranging from physics and biology to economics and education, the formation and conservation of the functional organization, its development and self-complication is both the goal of the study and its paramount stage (Haken, 2006). The following two examples are peculiar here. The first one concerns the problems related to the development and preparation of materials with structural-sensitive properties and various ordering degrees. In the majority of cases, the most important one is the creation of the required spatial or spatial-temporal ordering. Another example is the operation of living organisms and related simulation of ordered structures in biological objects. The question about the optimal ordering and organization is also topical when studying the global problems, i.e. energy, ecological and other problems, which require immense resources (Mar'yan & Szasz, 2000). The trial-and-error method is not appropriate here. More reasonable is the way of knowledge of inherent properties of the system and the regularities of its evolution. In this case it is difficult to overestimate the importance of self-organization and ordering formation laws in physical, biological and other systems.

That is why an interdisciplinary field of science has been created, i.e. new theory of self-organization or synergetics, which explores the general principles of the formation of spatial, time and spatial-temporal structures in thermodynamically open systems of different nature away from the equilibrium state (Haken, 2006).

Thus, the first cause beneficial for the creation of synergetics was the exit out of framework of the classical (equilibrium and linear) thermodynamics and the subsequent necessity of the description of highly non-equilibrium systems.

The second cause of synergetics creation is the necessity to analyze various complicated processes by means of new mathematical methods when solving a series of scientific and technical problems (Vorontsov & Miller, 1995). One is forced to deal more frequently with non-linear phenomena where more intense external actions result in the qualitatively new behavior of the system (Nicolis & Prigogin, 1989; Yurkovych, Seben & Mar'yan, 2017).

Non-crystalline materials are here the specific example. It should be noted that the principal trends in the practical application of non-crystalline solids (i.e. vitreous and amorphous materials) have been defined clearly so far (Mott & Davis, 1979). More ample use of such solids and the quest of new areas of their application require fundamental scientific researches, which in the future will give new ideas for applied development. The main tendencies of fundamental studies of non-crystalline solids start from the analogy with the well-known structure and properties of crystalline solids and liquids, while non-crystalline solids are considered as disordered systems (Mar'yan & Khiminets, 1991; Mar'yan, Kikineshy & Szasz, 2001).

At considerable deviations of the system from the equilibrium state and under the influence of the substantial external fields the dominant role is played by synergetic effects and by the energy transformation mechanism that can be studied by means of the ideas of non-equilibrium thermodynamics (Kauffman, 1993). From this standpoint, the creation of non-crystalline solids is the self-organizing process accompanied by the formation of ordered structures on the macroscopic scale. Such an approach to non-crystalline solids is in the initial state. Hand in hand with this, it enables one to describe the formation of non-crystalline solids, their structure and the peculiarities of the interaction with the external fields based

on the unified physical principle. The solution of this problem correlates with the simulation of the vital activity of living objects (Mar'yan & Szasz, 2000).

The present work is dedicated to the studies on formation of the ordered structures and hyper sensibility in the different-nature systems (non-crystalline solids, intelligent materials, information and communication systems, education) by invoking the ideas of synergetic and computer modeling. Contrary to a number of known books on the order-disorder problem, this book contains both mathematical background and a number of experimental facts, concerning glasses, water, and bio-matter. An important problem of the influence of different fields on the metastable matter is successively analyzed in many aspects, and leads to understanding of the essential importance of investigations in this direction, especially for living objects and for the metastable matter in general.

From this perspective, education is seen as a living organism, for which it is possible to achieve a minimum level of dissipative processes and a comprehensive information perception (Yurkovych, Seben & Mar'yan, 2017; Mar'yan, Seben & Yurkovych, 2018).

Innovative teaching of physics and computer modeling of physical phenomena, as well as application of these methods by teachers, are the focus of special attention in scientific literature (Christian & Esquembre, 2007; Potter & Peck, 1989; Sladek, Pawera & Valek, 2011). However, special training of future physics teachers on numerical modeling of physical phenomena; bibliographic data in the pedagogical literature, as well as in educational practice are encountered less often (Guri-Rosenblit, 2010). For example, the curriculum of training future teachers of physics in all five Slovakian universities does not contain this subject. Students and future teachers can get acquainted with the problem of computer modeling of physical phenomena while studying special subjects such as "Digital technologies in teaching physics", "Computer Information Technologies in physics" (http://www.fpv.umb.sk/katedry/katedra-fyziky/studium/bakalarske-

studium/). A similar situation with mastering these methods is observed in other universities.

In the process of teaching physics, attention is focused on a significant amount of material and its unstructured character (Özcan, 2015; Hodson, 2014; De Cock, 2012; Fojtík, 2013), insufficient relationship and correlation with other disciplines (Hestenes, 2010; Huffman, 1997) and practical application (Reif & Heller, 1982). It points to the need for information perception in higher educational establishments, especially in teaching physics at an intuitive level, using visualization means, modern advances in programming – object-oriented programming (Guri-Rosenblit, 2010;Yurkovych, Seben & Mar'yan, 2017).

The aim of the investigation was the implementation of the educational experiment based on the positive impact of the applied measures aimed at creating the optimal object of professional competence of future physics teachers. The study objective was to determine the impact of implementing innovative approaches on the willingness and interest of future physics teachers to independently conduct computer simulations of physical phenomena (González, 2017).

The material of this book is divided into chapters so that from chapter to chapter the considered problems become more and more clear, and appropriate mathematical models of self-organizing processes – more visual. Each chapter starts with a brief, popular scientific presentation of the developed concept without a loss of strictness. In the appendix, the data, calculations and results of calculations are presented, allowing the readers possessing the necessary mathematical apparatus to evaluate the reliability and persuasiveness of arguments in favor of the mathematical models used.

Adapted to use the modern level of the latest information technologies: information exchange in the Internet network, development of mobile telecommunications and related technologies, level of abstraction and synergy of object-oriented algorithmic programming languages, formation of self-sufficient

systems - smart environment: smart home, intelligent car, smart phone. So it may be interesting for the professionals, working in this field of science, and for those readers, who just try to comprehend deep interconnections in the materials science and living objects without mathematical proving.

That is why this book will be useful for a wide community of scientists and engineers working in the fields of material science, and also for teachers of natural sciences.

Most of results outlined in this book have been obtained and developed by the authors.

I. SELF-ORGANIZING PROCESSES IN DIFFERENT-NATURE SYSTEMS

Self-organizing processes play an extremely important role in the surrounding life, i.e. in the phenomena occurring in the living and lifeless nature. One can hardly solve a variety of medical, biological, technological problems without studying such processes since the main goal of synergetics (i.e. the science which studies self-organizing systems) is to reveal the general regularities of self-organizing processes in different-nature systems (Mar'yan & Szasz, 2000).

1.1. Synergetics: principal definitions

Synergetics covers today not only various areas of science, featuring processes of self-organization in an alive and lifeless nature, but also permeates into various fields of human activity. The professor of Stuttgart University and the Director of the Institute of Theoretical Physics and Synergetics H. Haken is recognized as the author of the term "synergetics" (Haken, 1985). According to Haken, synergetics studies the behavior of the systems comprising a great number of subsystems (parts, components). In its precise sense, the term "synergetics" means the joint action, distinguishing, thus, the coordination in the functioning of the parts, reflected in the behavior of the system as a whole[1].

The advantage of synergetics just is that the systems, representing the subject of their study, and considered as a whole, can be of the most different nature and be studied by each of sciences separately (for example, by physics, biology, chemistry, mathematics, sociology, economy and so on). Each of such

[1] The predecessor of Haken's synergetics was that of the physiologist Sherington, who studied the consistent action of flexors and extensors at limb operation, as well as the synergy, i.e. junction of a man and God in a pray.

sciences studies its “own” nature of the system by its intrinsic methods and produces the results of research in its “own" language. At the existing differentiation of the science, this means in that the achievements of one science frequently become inaccessible to the attention and comprehension of the representatives of other sciences. A similar situation takes place with interfacing sciences originating from the junction of two sciences in a more or less wide frontier field (for example, in biophysics, physical chemistry and so on). So, physics studies a physical nature of the systems by physical methods, biophysics is engaged in the research of biological objects by physical methods. Therefore, contrary to the traditional areas of a science, synergetics is interested in common legitimacies of the evolution of the systems of any nature, which stipulates its generalized interdisciplinary character.

Synergetics studies a common character of regularities and dependences, not appealing to a nature of systems, by means of its specific resources, having a common character in relation to private sciences. The unity and the integrity of synergetics in studying the systems are illustrated by Fig. 1.1.1.

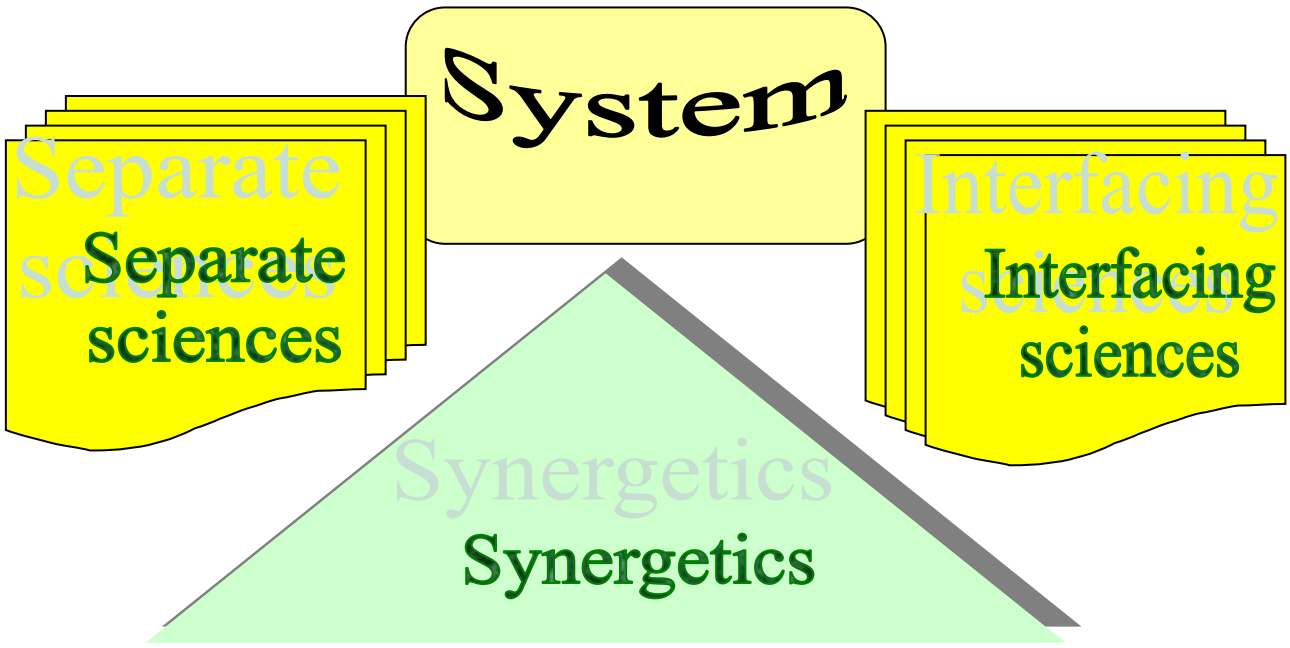


Fig. 1.1.1. Synergetics as interdisciplinary field of science.

Due to that synergetics tears away a specific nature of investigated systems, it acquires an ability to describe the formation development, by working out a common model of phenomena occurring in an organic and inorganic nature.

1.1.1. Synergetics and self-organizing processes

Synergetics appears to be a link in understanding relationship between the substance and the life. The most apparent feature of the objects of an alive nature is that they are capable of self-organization, i.e. the spontaneous formation and development of complicated structures. The necessary premise for the self-organizing effects consists in an openness of systems (energy, mass, information exchange with environment). Due to this flux from outside, the system becomes active, i.e. gaining an ability of the spontaneous formation of the structures. Apparently, the effects of self-organization cannot be an exclusive property of biological objects, and, thus, they are also observed (in simpler form) in the systems of an inorganic origin.

So, synergetics combines the studies of the system as a whole and those of its separate parts at different levels. It makes a bridge between them by two levels of description, due to their coordination, synchronization and coherence. Therefore, the system acquires the properties, not inherent in its separate parts. This circumstance has an essential importance and allows one to define synergetics as a science exploring the self-organization. Thus, the macroscopic manifestations of the processes occurring at the microscopic level arise "independently", due to self-organization, with no "guiding hand", that operates outside the system. The self-organization is born by the system itself as a result of a loss of stability of the state. Thus, self-organization is reduced to the selection among the spatially active systems, potentially possessing a great number of degrees of freedom at a small number of order parameters (variables) defining the dynamics of the whole system. A small amount of order parameters and scarce possibilities, which they reflect in

defining separate states, testify to the fact, that in compound systems only a few structures are possible and available being consistent through a combined action of the elements (Yurkovych, Seben & Mar'yan, 2017).

There are no separate control elements (units) of the system, being in charge of a certain property. The complicated structural formations in the nature are simultaneously both determinate (predictable) and stochastic (unpredictable), i.e. they exhibit a dualism of determinate and stochastic. In synergetics, there is nothing predetermined at a level of present computer program – except the structures and systems, which at a loss of stability can give rise to some new states. The system becomes unpredictable not by virtue of our ignorance, but by virtue of its non-local properties, such as complexity, non-linearity, openness, non-equilibrium. At a point of a loss of stability the new functioning mechanisms with new parameters are self-organized. It should be noted, that the parameters of the state do not disappear – they remain, but in cases related to the self-organization the system selects the order parameters itself. We obtain a sort of ready oblate information on the system. Even when the separate elements of the system have a complex internal structure, all their internal complexity is not revealed in their mutual interaction, and, from the point of view of a macro system, they function as simple enough objects with a small number of effective degrees of freedom (Mar'yan, 1998). Otherwise, no structure ordering occurs in the system.

It should be noted that it is possible to describe more or less adequately self-organizing phenomena at one level. The investigation of the phenomena between various levels is so far problematic. The chaos at one level leads to the structuration at the other level. This approach is one of the basic in synergetics. The thermal oscillations and diffusion act as the chaos at the micro level. However, for a number of self-organizing systems of organic and inorganic origin this process plays a principal role in the formation of ordering at the mezo scoping (average) level order. The chaos at one level results in the self-organization and appearance of an order parameter at the other level (spatial or temporary). The

systems behave in a chaotic manner, however at the particular stages of the process or at some characteristic moments they result in the appearance of the formations, for which the structural representation is adequate. Such structures can be considered as those of the next level with their definite functioning parameters. At the next level the ordering may arise again, and so on.

Convenient images of non-linear dynamics are the fractal structures (Mar'yan & Yurkovych, 2015), for which the description obeys the same rules with the change of spatial or temporary scales. The term "fractal structures" is widely used for the description of self-organization in the energy, mass, and information – open systems, since in this case in the non-linear dynamics tasks we do not deal with unstructured random processes, but just with the results of self-organization, i.e. the creation of complex, coherent structures (Yurkovych, Seben & Mar'yan, 2017).

Synergetics describes the birth and creation of spatially and temporally branched structure under the scripts of interchanging periods of stability and instability. At the initial stage the system, wandering in the state space, forms at certain controlling parameter values the first attractor (attractor is the steady state, to which the system tends and for which the predictability and reproducibility of the modes are peculiar). Then, skipping due to a loss of stability and fluctuations into the other domain, it forms a second attractor, and so on. Due to this the contour of the states of the system – i.e. the domain of stability, singular points, and tunnels of transitions from one domain to another – is formed. The concept of a path of self-organization of the complex system arises, being convenient to be described by the fractals. The task of synergetics consists in the search for the studies of the models of self-organizing systems, which result from the most typical assumptions, the properties of separate active elements and the laws of interaction between them.

1.1.2. Methods of the synergetics

The theory of dissipative structures, the Thom's theory of catastrophes and the theory of mappings and attractors belong to the most spread synergetic methods (see Fig. 1.1.2).

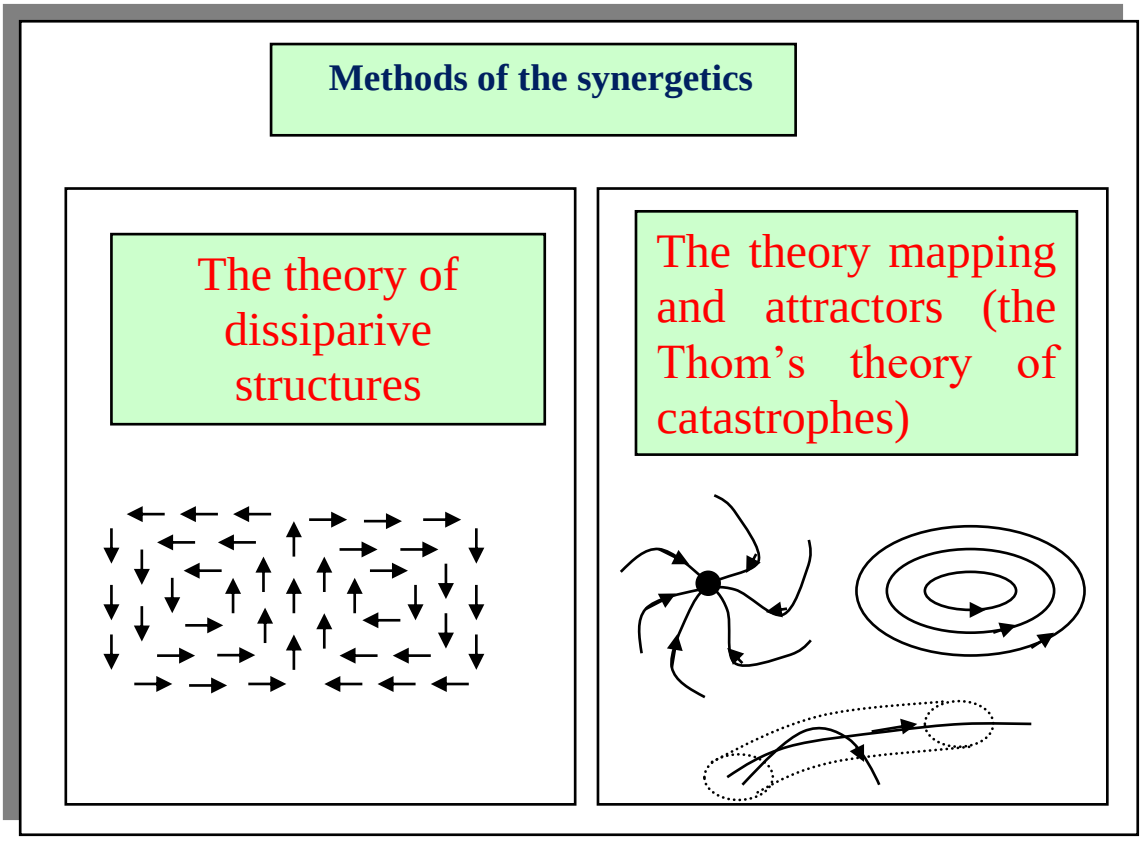


Fig. 1.1.2. Methods of synergetics.

Consider the above methods.

1.1.3. Dissipative structures: general characteristics

G. Haken (Haken, 1985) was among the first who has drawn an attention to the commonness of dissipative structure formation process with the phase

transitions in non-equilibrium systems (in ferromagnetic, ferroelectrics, superconductors, etc.). This allowed him to call the dissipative structure formation processes the non-equilibrium transitions. The latter are much more diversified than the equilibrium ones and play a prime role not only in the physical processes but also in biological and chemical processes.

The notion of dissipative structures as one of the most general notions of thermodynamics of non-equilibrium processes was first introduced by I. Prigogine (Nicolis & Prigogin, 1989). This term emphasizes the fact that these structures arise in dissipative systems during the non-equilibrium (irreversible) processes. The temporal, spatial and spatial-temporal dissipative structures are distinguished.

Note the necessary conditions for formation of the dissipative structures.

- Dissipative structures can be produced only in the open systems. In such systems, the energy influx or the matter exchange may occur compensating the losses and providing the existence of the ordered states. In this connection, the external supply of the "negative entropy" does exist together with the entropy production.
- Dissipative structures arise in the macroscopic systems comprising a large number of particles (atoms, molecules, cells, university etc.). This allows one to apply the equations for the functions averaged over the physically infinitesimal volume (the local equilibrium condition). The ordering in these systems is also of co-operative character, since a great number of objects are involved in it.
- Dissipative structures arise only in the non-linear systems described by the non-linear function.
- To admit the occurrence of dissipative structures the linear equations must allow (at certain values of parameters) the appearance of the solutions with other symmetry, for instance, the transition from the laminar flow to the turbulent one accompanied by the change in its velocity.

However, a principal difference exists between the appearance of the order via the fluctuations in the systems far from the equilibrium and that in the living systems. This difference is that in the first case we deal with the process of dissipative structure self-organization, whereas in the second case the self-regulating phenomenon occurs which provides the stability of the state of the biological system far from the equilibrium. In the first case the cause/effect relations are of a spontaneous type, while in the second case they are strictly determinate by the genetic program. So, dissipative systems are non-linear and, taking into account the necessity to be general as much as possible, we may consider them in a common mathematical model (Mar'yan, 1990; Mar'yan, 1998).

The non-linearity of the problem under study motivates the possibility of a qualitative change in solutions, which describe the behavior of the system at the continuous variation of the parameters. In this case a slight variation of the system parameters may result in a considerable change in the solutions. The simplest example of non-linear equation is an ordinary quadratic equation. We can increase continuously one of the coefficients and find that at any small increment in the vicinity of some quantity both real solutions can be produced or vanish.

The models of the turbulent motion of liquids, the ecological models and the Belousov-Zhabotinsky reactions, formation of the non-crystalline materials are the recognized examples of non-linear processes (Mar'yan, Szasz, Szendro & Kikineshy, 2005). Non-linear dynamic systems may have extremely complicated motion modes, i.e., depending on the parameters; their dynamics may be either regular or chaotic. One of the paradoxical peculiarities of the systems specified by non-linear mathematical models is the property of self-organization. In complex systems with many interacting subsystems, the qualitative peculiarities may arise being not possessed by any component. As a result, a new structure and the relevant operation appear at the macroscopic level.

1.1.4. Dissipative structures of the active medias

Based on the examples considered above, one may distinguish three types of active media elements in which self-organizing processes are observed (Mikhailov & Loskutov, 1996): bistable, multivibrating (excited) and auto oscillating elements (Fig.1.1.3).

Bistable elements have two stationary states, and may stay in each of these states for an infinitely long time. An external action may cause the transition from one state to another. To induce the transition the intensity of this action must

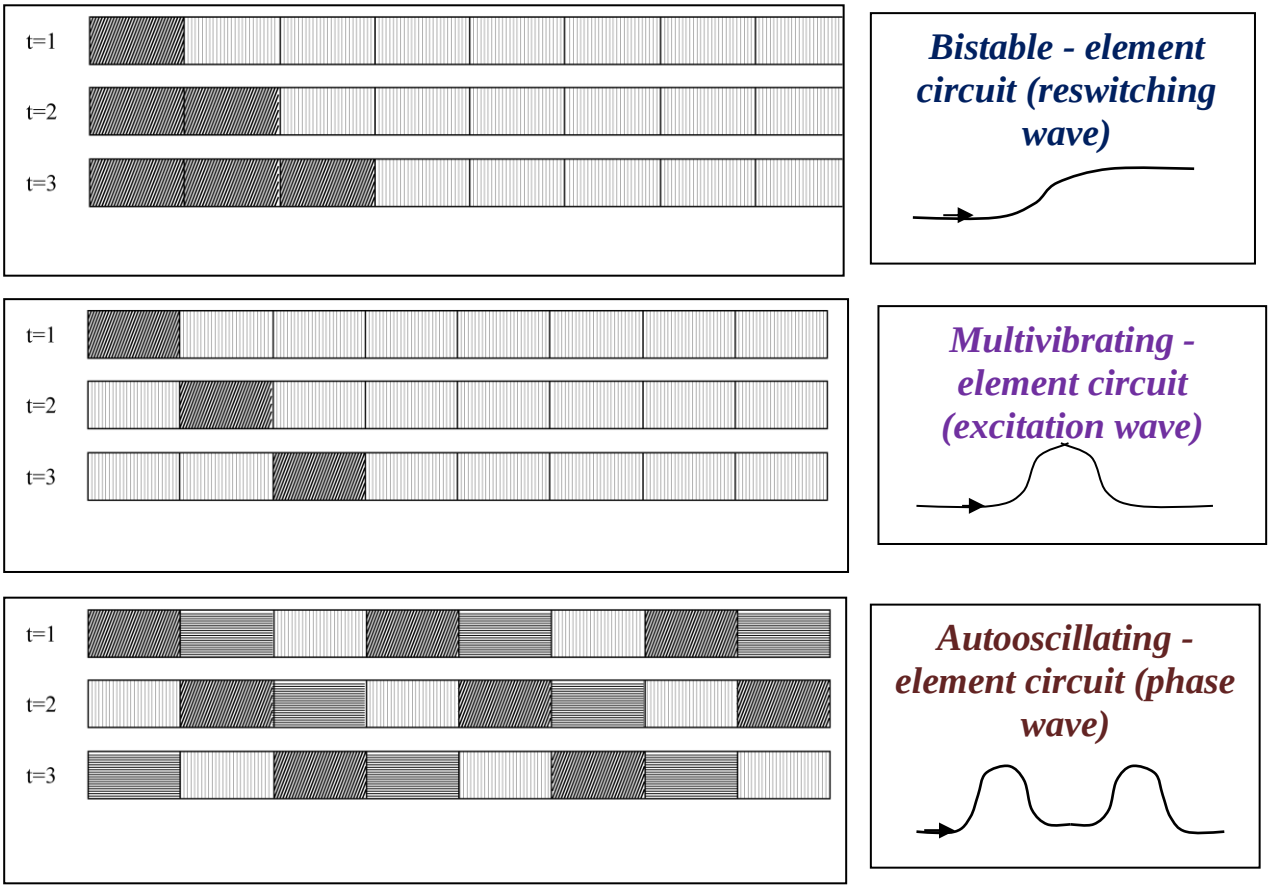


Fig. 1.1.3. Types of active media elements.

exceed a certain threshold level.

Multivibrating elements have a single distinguished rest state, which is stable with respect to comparatively weak external actions. However, such systems differ from passive ones by their response to the actions, exceeding the threshold

level. As a response to this quite intense external action, the system produces the flash of activity, i.e. a certain sequence of active transitions takes place, and only after this the system returns to the initial rest state.

Auto oscillating elements act like the *perpetum mobile*. They perform autonomously cyclic transitions via a certain group of states. An external action is able to decelerate or accelerate this cyclic movement only, but not to stop it. The examples considered illustrate the basic properties of the produced stationary structures. First of all, each of these structures is a stable formation, the form and the size of which are resumed at slight perturbations. The same distributed system can possess a huge number of different stationary non-equilibrium structures. Which one of the stationary states is realized in experiment depends on the initial conditions and external random field. For such structures, besides the local interaction, the active medium elements are involved in the long-range feedback. The properties of dissipative structures set up in the medium depend tangibly on the type of elements composing this medium, i.e. bistable, excited or auto oscillating elements (Fig. 1.1.3).

If the active medium, in which self-organizing processes are realized, consists of the bistable elements, then it comprises a family of domains with $L_{bistable}$-order dimensions in which the state of the medium is close to one of two stable states of the separate element. These domains are separated by transient L-wide layers.

If the medium comprises the multi vibrating elements, then it possesses only a homogeneous stationary rest state. In the one-dimensional case, this structure is a set of narrow L_{multi} -wide strata spaced by $\sim L$ distances. In the domains between the strata, the medium is in the state lying close to the rest one. In two-dimensional or three-dimensional cases, the dissipative structure is an aggregate of little drops (Mar'yan & Szasz, 2000).

If one separate element of the medium undergoes periodic auto oscillations, then the stationary homogeneous state of the active medium is absolutely unstable. Stationary structures are formed in it in the form of L_{auto}-long strata separated by transient layers (Fig. 1.1.3).

1.1.5. Levels formation of the dissipative structures in science education

The occurrence of dissipative structures away from the equilibrium is due to the presence of fluctuations and, therefore, it was called the "order via the fluctuations". That type of ordering is an essential approach to the conditions of the vital activities of biological objects, since the organisms are the open systems far from the equilibrium. Dissipative structures of the biological origin have been discovered at the various levels of complexity:

- at the molecular level, i.e. the variations of the substrate density during the reactions catalyzed by the ferments;
- at the cellular level, i.e. the induction-type vibrations and genome repressions described by Jacobi and Mono;
- at the organism levels (the circadian and similar rhythms);
- on the population level, i.e. the variation of a number of organisms within biogenesis. While in physic-chemical systems the feedback, similarly to autocatalysis, occurs extremely rarely, but it is a necessary condition for the biological organization in living systems (Mar'yan & Szasz, 2000).

The term "whole" in relation to the concept of dissipative structure is treated as the result together with its formation, distinguishing and combining, thus, the process of formation and the result. The dissipative structures in the objects of sciences education are not a constant notion, but are in a permanent formality.

The degree of steady integrity, which is peculiar to the dissipative structure as an organic whole at the mentioned above levels and necessary to promote the

development of the structures at the higher level of organization, is determined by a minimum of energy dissipation (Babloyantz, 1986). Let's define fundamental dissipative structures as the result of self-organization at the appropriate molecular – organism levels. A quantitative measure of each level is the intensity of interaction with the medium external wish respect to a considered level that defines the binding energy of the produced stable system. The hierarchy of levels of structural organization ("a quantum ladder") is considered as a result of a prior self-organization (Fig. 1.1.4).

One may distinguish some stages of the formation of the dissipative

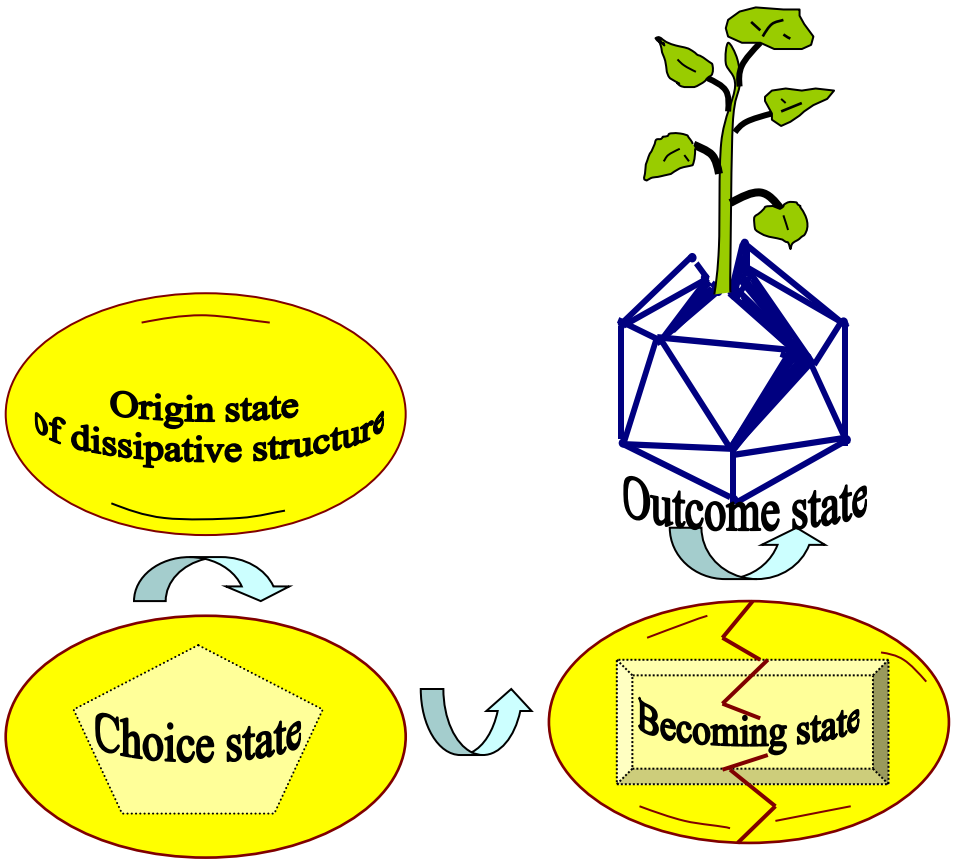


Fig. 1.1.4. Visual representation of the dissipative structure development in science education.

structure at certain levels (visually this process is illustrated in Fig. 1.1.4). The first

stage describes the initial state, which comprises different possibilities of structuring the medium in the minimized (not evident) form. In the physical aspect, this stage is associated with that initial "vacuum", the fluctuations of which are potentially uniformly distributed over the whole system (see Fig.1.1.5). The second stage is defined by a state on the verge of possible and true, in which a set of principally essential and possible, but not yet stable structures, appear to be open. The third stage is related to a choice of the possibility of structural complication up to the formation. At the fourth stage, a manifestation and implementation of the stable structures occur.

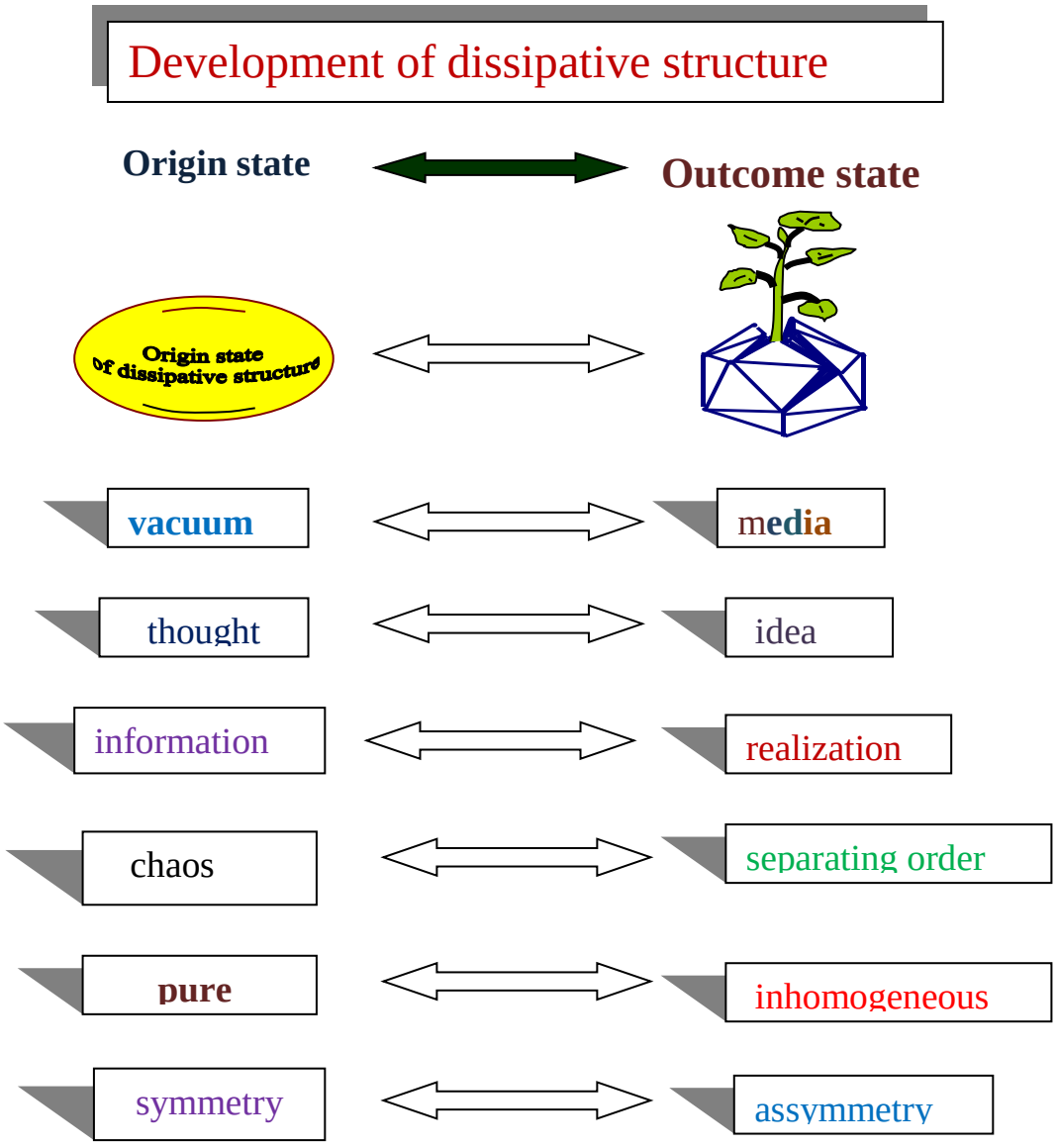


Fig. 1.1.5. Examples of the dissipative structure development in science education.

1.2. Self-organizing systems: information technology and science education

Recently much attention has been paid to the theoretical and experimental studies of self-organizing processes in various physical, chemical, biological and education systems. The processes are non-equilibrium and accompanied by the energy dissipation.

Many examples of the ordered states formation during non-equilibrium processes are known in physics. In this case the ordering may occur both in time (time dependence, e.g., the appearance of limiting cycles in auto-oscillating systems) and space (standing strata in gas discharges, the Benar's cells at the convectional movement in liquids, the transition of the laminar flow to the turbulent one in the liquid) (Nicolis & Prigogin, 1989). The formation of spatial-temporal ordered states (e.g., auto-wave processes in classic and quantum generators (lasers)) is also possible (Yurkovych, Seben & Mar'yan, 2017).

1.2.1. Information and communication systems: synergetics

The studies of self-organizing processes in condensed systems (i.e. liquids, crystals, glasses) and in information, biological objects, which receive the energy from the external sources, are characterized by a continuous energy dissipation and redistribution among active elements. When some of these elements are locally interlinked and form the distributed active medium, then the production of various stationary or time-dependent spatial structures is observed in this medium. Such fundamental notions as consistency, mutual action, ordering are the constituents of both physics and biology, sciences education, i.e. the possibility to describe the behavior of both living systems and common physical systems by using these notions is an outstanding achievement. For most cases the properties of the whole system cannot be explained on the basis of the simple superposition of the

properties of its components, since these subsystems interact with each other. In addition, the system acquires the properties, which contrast qualitatively with those of separate subsystems. Such subsystems may be atoms, molecules, cells as well as the human communities, information technology (Mar'yan & Szasz, 2000).

First of all consider the self-organizing processes in physical systems. These processes in liquid (gaseous) layers at the presence of temperature non-homogeneities are known as the Benar's heat convection (Fig. 1.2.1). The heat convection provides the basis for various phenomena observed in nature. Among them there are atmospheric and ocean circulations, which define the climate change for a short or long period. Another example is the drift of continents or, in other words, the motion of continental platforms caused by the large-scale cloak movements. Heat convection underlies the heat and matter transfer inside the Sun, which defines substantially the solar activity.

The heat convection is also related to the production of the so-called Benar's cells in the liquid layer lying between two parallel planes to which the temperature gradient ΔT is applied: $\Delta T = T_2 - T_1 > 0$.

At low temperature gradients ΔT in the system, a single state is established for which the heat transfer from the lower layer of liquid to the upper one is specific and the latter transfers the heat to the environment providing the constant T_1 (Fig. 1.2.1). The temperature, as well as density and pressure, are not homogeneous, and due to the heat conduction vary almost linearly from the warm domain (T_2) to the cold one (T_1). In this state, reached by the system in a form of a response to the external restriction, the stability dominates. When the system deviates from the equilibrium with the increase of ΔT, at certain critical value ΔT_c the bulk of liquid starts to move. This motion will not be chaotic now. The liquid is structured in a form of cells noticed first by Benar and, thus, called the Benar's cells (Fig. 1.2.1). These cells are placed along the horizontal axis, and the liquid moves sequentially clockwise (R) and counterclockwise (L) inside them.

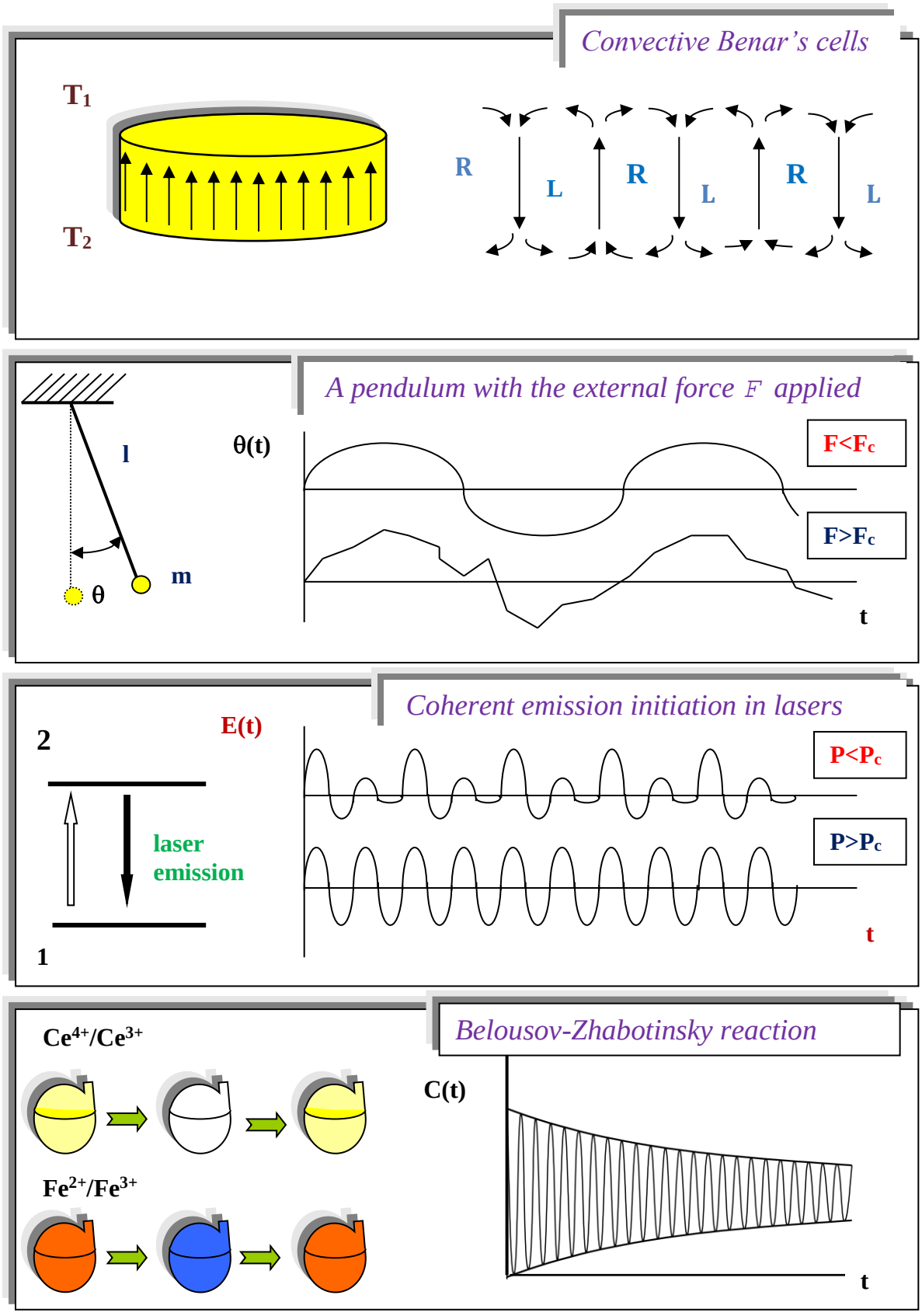


Fig. 1.2.1. Non-equilibrium self-organizing processes in the physical and chemical systems.

The qualitative explanation of this phenomenon resides in as follows. Due to the thermal expansion, the liquid is stratified, and that part of it, which is close to the bottom plane, possesses a lower density as compared to the upper layers. This causes the density gradient directed in the opposite to the gravity force direction. Evidently, such a configuration is unstable. Consider, for example, a small volume of liquid close to the bottom plane. Imagine now that this element of volume moves slightly upwards due to the perturbation. Entering a colder (and, thus, more dense) domain, the said element is a subject of the upward Archimedean force, which tries to enhance the motion. On the other hand, if the drop, which is first close to the upper plane, moves downwards, it enters the low-density domain and the resulting force of Archimedean and gravity forces will accelerate the downward movement. Therefore, in this liquid layer up- and downward fluxes may originate resulting in the cells production. The reason for which such fluxes are not observed at low ΔT is related to the stabilizing effect of the viscous liquid resulting in the initiation of internal friction forces directed against the movement. The heat conduction is also the stabilizing factor due to which the temperature difference between the displaced drop and its environment tries to escape. This, in particular, explains the occurrence of the symmetry violation and transition from the simple behavior to the complex one. The notions of ordering and consistency of the system are the specific features of such transitions. When ΔT is less than the critical value ΔT_c, the homogeneity of the liquid makes its different parts independent of each other. In contrary to this, each volume element above the threshold value ΔT_c affects the state of the other element. Such pattern implies the presence of correlations, i.e. the statistical dependence of remote parts of the system. Specific dimensions of the Benar's cells are within the millimeter region (10^{-1} cm), whereas the specific spatial scale of intermolecular forces lies within the Ångstrom region (10^{-8} cm), i.e. the Benar's cell involves almost 10^{21} molecules (Mikhailov & Loskutov, 1996). The fact that such a considerable amount of

particles may demonstrate the coherent behavior, in spite of the random thermal motion of each part, is one of the principal properties, which characterizes the occurrence of the self-consistent behavior.

A specific feature related to the Benar's cells is that this laboratory experiment is characterized by the reproducibility, i.e. at $\Delta T = \Delta T_c$ the convective pattern arises. On the other hand, the liquid is structured into the clockwise and counterclockwise-rotation cells, which are the random quantities. Thus, aside from the determinability of the occurrence of the cell structure, the direction of motion in the cells is not predictable and uncontrollable. Only the case of one or another perturbation, which dominates at the given moment, defines the motion of the liquid in the cell. Thus, a peculiar combination of the accident and definiteness is seen. This analog dualism known in biology as a manifestation of fluctuations and natural selection is revealed in physics in the quantum-mechanical approach to the description of microscopic phenomena.

As a conclusion, in the case of remoteness from equilibrium, the system can adapt itself to external restrictions in the environment by different ways. From the mathematical viewpoint, in this situation at the same values of parameters one can obtain several different solutions. Only the chance defines which one of them will be obtained. The fact that among numerous possible variants one variant has been chosen, provides a system with the historical dimensionality, i.e. a specific memory about the former events, which have happened at the critical moment and defined the influence on the evolution.

At large $\Delta T = \Delta T_c$, the most suitable for heat transfer convection regime is established in the liquid (at ΔT_c the immobile heat-conducting liquid regime becomes unstable). The convection cells form more highly-organized structure, which results from the collective motion in the liquid.

The similar self-organizing processes are also specific for the occurrence of a coherent emission (Haken, 1985). In this case the transition of atoms to the

excited state is induced by an external influence. These atoms act as a microscopic antenna (see Fig.1.2.1). At low pumping powers $P < P_c$ (P_c is the critical power value), atoms generate light packets independently of each other, and the laser is operating similarly to a common lamp (the radiation field $E(t)$ consists of separate uncorrelated packages). At $P > P_c$ powers, all the atomic antennas start to oscillate in phase and generate one giant packet of coherent laser emission. Let the dependence of the emission intensity on the pumping power be the same. The generation mode corresponds to the hypercritical cell production. The light field in a laser is generated by excited atoms. Furthermore, the field exerts an opposite effect upon the atoms: the stimulated emission arises being interfered with two factors: a permanent dissipation and fluctuations which perturb the emission process by their random action. For these reasons, the stimulated emission field in the subcritical regime is damped out. Above a certain pumping power value the amplitude begins to rise. As a rule, the dampening dies away for one mode, the amplitude of which acts as an order parameter.

Consider another example of self-organizing processes, i.e. a periodically excited pendulum. The equation of motion of the pendulum is written as (Mikhailov & Loskutov, 1996):

$$\frac{d^2\theta}{dt^2} + \gamma \frac{d\theta}{dt} + \mathrm{g}\sin(\theta) = \mathrm{F}_0 \cos(\omega_0 t),$$

where θ is a deviation angle, g is the gravitational acceleration, γ is a damping constant, ω_0 is the frequency of the external force with F_0 amplitude (the mass is taken equal to unit). A numerical solution of the equation is shown in Fig. 1.2.1. The time dependence of angle $\theta(t)$ becomes chaotic if the amplitude F of the force exceeds the threshold value F_c.

The next experimental physic-chemical system, in which the formation of spatial and temporal structures has been studied in detail, is the Belousov-

Zhabotinsky's reaction (Haken, 2006). The organic molecules (e.g. the malonic acid molecules) are oxidized by bromate ions during the catalyzation of the oxidation-reduction system (Ce^{4+},Ce^{3+}). The reagents are $Cl_2(SO_4)_3$, $NaBrO_3$, $CH_2(COOH)_2$, H_2SO_4 being involved into 18 elementary reactions (Mikhailov & Loskutov, 1996).

The generalized equations for the reagent concentration $\{C_i\}$ in the system of chemical reactions have a form of a system of non-linear 1st-order differential equations (Babloyantz, 1986):

$$\frac{dF(X,\lambda)}{dX} = F(X,\lambda),$$

where $X = (C_1, C_2, \ldots, C_k)$, $F(X,\lambda)$ is a non-linear function $\{C_i\}$, λ is an external control parameter. The variable, which possesses a chaotic behavior in the Belousov-Zhabotinsky's reaction, is the Ce^{4+} ion concentration C measured by the selective light absorption by these ions. The average time spent by the substance in the flowing reactor (Fig. 1.2.1) is an external control parameter.

1.2.2. Self-organizing processes in information technology

Among all the natural objects the biological ones are functionally and morphologically the most complex and highly organized. During the protracted period of biological evolution functioning away from the equilibrium state, they permanently receive the energy and matter flux, and preserve the memory of the forms and functions attained within this period (Yurkovych, Seben & Mar'yan, 2017).

The important balance is reached between short- and long-range effects, controlled by the energetic situation. The system always tries to realize the lowest available energy (which is the cluster (in microscopic range) with a five-fold symmetry). On the macroscopic scale it is the ordered occupation of space, which

eliminates the five-fold symmetries and therefore contradicts the microscopic requirements. This delicate balance leads to the dynamic vibrations, which can be easily frozen in by one of the forces dominating in the system. A protein, with its saturated, de-saturated states in the living process (balancing between the low-energy state at the microscopic level, which is the saturated molecule, and the low energy state required by the metabolism, which is a non-saturated state), also shows this basic dynamic construction and builds a system called life. The self-organizing builds up this dynamical equilibrium in all the organizing levels from the water-transfer through proteins and up to the organism as well. The dynamical vibration is effective for the whole living organism. It has an effect on every level of organization of the system: starting from the protein building up the total unity.

Accordingly, the system creates a balance between nutrients and end-products that breaks down the energy stored in the chemical bonds of nutrients and creates the end-products, in which the chemically stored energy is low. At the same time certain biological systems (plants) are capable of executing this process in reverse, for which they receive their energy from the solar energy and electromagnetic radiation. (This process is a fundamental conversion, which makes the nutrients available to the other life processes which are not capable of such a conversion).

The cell is the traditional object of biophysical research. Cellular biophysics processes as well as the processes of energy and information exchange typical of biological systems are also inherent in cells. The substantial non-homogeneities are also observed at the cellular level (Babloyantz, 1986).

Knowledge of the principal regularities of the formation of structures in the media open with respect to the energy and mass exchange allows one to turn to the purposive creation of distributed dynamical systems, which form one or other spatial structures. One of the principal applications in this case is the problems of digital processing of information. The use of spatial structures, not discrete signals, as the elementary unit of information processing, allows the computer efficiency in

the artificial intellect tasks to be increased drastically. There is some evidence that just the similar mechanisms underlie the human brain functioning (Mar'yan & Szasz, 2000).

As it is known, the brain is a giant network of tens of billions nervous cells (neurons) bound by the branches (dendrites and axons). The number of bindings of a single neuron may reach tens of thousands. The mechanism of the action of a separate neuron is responsible for the fact that the nervous cell may be in one of three discrete states – rest, excited and refractive (the latter corresponds to the unexcited state). The interstate transitions are controlled both by intracellular processes and electric signals coming from the other neurons through the branches. The change from the rest state to the excited one occurs in a threshold manner at almost simultaneous reception of a great number of pulsed excitation signals. The neuron spends some time in the excited state and then transits independently to the refractive state. This state features quite a high excitation threshold: the neuron almost fails to respond to the excitation signals received. After a period of time the excitation ability is restored, and the neuron relaxes to the rest state.

Thus, common physical and chemical systems may possess a complex behavior with a series of peculiarities belonging to the living systems. A question arises naturally: whether one is able to explain some of these peculiarities by the transitions induced by non-equilibrium and relevant instability mechanisms (say chemical autocatalysis).

Besides the structure of a separate nervous cell, the global aspects of brain activity, i.e. the specialization of its large areas and functional communications between these areas, are also studied relatively well. At the same time little is known about the way of information processing at the intermediate level, inside the neuron network areas involving only tens of thousands of nervous cells. The brain is quite frequently compared with a computer. In addition, it is assumed that each excitation pulse carries the unit information, while neurons play a role of logical switches completely similar to the computer elements. However, in our

opinion, the brain functioning is based on absolutely completely other principles. There is no rigid communication structure between the neurons in the brain similar to that in a computer. The reliability of separate brain elements (neurons) is considerably worse than that of the modern computer units. The damage of even those areas, which comprise quite a large amount of neurons, does not occasionally affect the efficiency of information processing in this area of a human brain. A part of neurons dies during the organism aging.

The computer network resembles the multicellular organism. After the program, i.e. the repertoire of reactions of each computer and the initial status of all of them, is being indicated, the network starts to live its own life and simulates the corresponding process. From that viewpoint one can assume that the brain stores and processes the information in images. It operates as a computer, in which the surrounding world is mapped in the spatial-temporal structures of neuron activities. An evocative simulation allows the future events and schedules of actions to be predicted. Such a mechanism of the brain operation was, probably, developed in the course of biological evolution. In animals, the basic function of the nervous system is to transform the senses prompted by the environment into a certain motional activity (Mikhailov & Loskutov, 1996).

A viewpoint that the human brain operation is based on the learning principles seems to have received recently much recognition. Consider, for instance, the possible sequence of steps expected to be performed for solving the problem of how to distinguish the triangle among all other polygons. The first step is to distinguish the lines and check whether their quite large areas are close to the straight-line sections. Then one has to choose vertices, i.e. the points where two lines cross. The next step is to create the intermediate concise image of pattern – its graph. This graph fixes only the existence of relations between the vertices independently of lengths and orientation of the lines, which realize these relations. Now, when each graph corresponds to the whole class, one has to recognize graphs, thus giving the final answer for the problem stated. Therefore, the

possibility to solve this simple task requires the creation of semantic structures – graphs. Each graph, in turn, may also be considered as a certain notion (e.g., a triangle graph) and act as the elements involved in the semantic structure of the next hierarchic level. All the necessary operations with semantic structures are executed in the brain in the analog way similarly to certain dynamical processes in the complex distributed non-linear system. The brain is like the medium where semantic structures do evolve, interact and compete with each other.

The process of development of an alive organism does not require an interference of external controlling forces, and there is a sequence of the independent acts of self-organization. Handling of this process can be carried out with the help of inappreciable effects of controlling parameters. They influence the choice of this or that path of development at the moments, when the developing structure is able to bifurcate in the presence of several possible paths of evolution in information technology (Mar'yan, Seben & Yurkovych, 2018).

The education acts as a living organism, for which there are ways of functioning that provide a coherent and complete perception of information (Yurkovych, Seben & Mar'yan, 2017). With the help of synergetics, various aspects of operation of a human organism, in particular, in medicine are researched (Mar'yan & Szasz, 2000). At normal operation of almost all the systems of vital activity, the intermediate mode between the chaos and the order (the so-called determined chaos) is characteristic. Thus, for example, for the processes of respiration, palpitation and mental equilibrium the particular measure of the chaos necessary for maintaining the health of human being is peculiar. For example, the extreme modes of heart rate (arrhythmia and excessively ordered rhythms) are dangerous and testify to its illness. Too regularly fragile heart is not able flexibly to react to varying external conditions. The health is a particular balance between the chaos and the order. The concept of dynamical illness in recognition and treatment of illnesses, and also for warning illnesses will be utilized. The

stabilization of the vital activity is reached through the instability, the stationary values of change.

How many chaos can bear a sciences education not to be ill, when are random oscillations normal, and when are they dangerous? These problems are considered with the help of synergetics and are studied in this book.

Synergetics and self-organization processes are some of the innovative approaches in the teaching of disciplines, in particular the physics, mathematics, computer modeling. This is especially significant at the present stage of the development of information technology (Chen & Lee, 2009), namely the dissemination and exchange of information using Internet, software development for mobile phones of Smartphone, Google services, which greatly expands the range of users and provides new opportunities for in-depth perception and radically new approaches in expulsion and interpretation of the laws of physics. In this context, presented the approach in the book is relevant and required.

II. DISSIPATIVE STRUCTURE FORMATION IN PHYSICS: FUNCTIONAL MATERIALS

Recently the ideas of the non-equilibrium thermodynamics predicting the possibility of the non-crystalline structure with new unique properties in strongly non-equilibrium conditions have been widely developed. In this case by the structure the method of the element organization and the spatial-temporal character of their inter correlation are meant. The dissipative structure formation in the non-crystalline materials is related to the self-organizing phenomenon. That problem is of special interest not only for physics but also for biology and chemistry in the development of artificial intelligence. Therefore we will consider it in detail.

2.1. Synergetic approach to the formation of the non-crystalline state

2.1.1. Non-crystalline condensed media: the dissipative structure

Non-crystalline solids are an extremely wide class of materials involving amorphous substances, glasses, crystals with high defect concentration, spin and magnetic glasses and biopolymer structures. The non-crystalline condensed media are much more abundant and not less important in practice than the idealized mono-crystalline structures.

By the term "non-crystalline substance" the structural disruptions are meant most frequently being manifested as the absence of the correlation of the physical quantity, which describes the present system at the distances defining the disordering scale. The non-crystalline solid state is usually considered as a metastable one, which does not correspond to the minimum of the total energy and will transit in time to the stable equilibrium state. From this standpoint the total order is the one that appears due to the non-vanishing correlation of all physical

quantities across the total volume of the system. That approach to the non-crystalline solids is in the same relation and has the same specific features as, for example, the flat picture and the real three-dimensional image. Historically, such an approach to non-crystalline materials has been realized due to the description of the initially crystalline spatially ordered solids and the attempt to extend the results for the crystals to the disordered substances. The aforementioned consideration lays the "secondary" relation to the non-crystalline materials, when the essential peculiarities of their operation are rejected. The attempts to interpret the specific properties of certain non- crystalline materials result in the development and application of numerous representations and calculation techniques. In our opinion, the situation would change drastically if the structure and properties of the condensed media were started initially just from non-crystalline materials and the crystalline media were treated as a special case of more common non-crystalline ones. In this case a host of phenomena observed in non-crystalline materials would allow one to catch the general hypotheses and models which belong to the unified approach based on the ideas of synergetics. If the studies of the solid started from non-crystalline substances, not only physics but also biology and the mathematics would achieve more success now (Mar'yan, Seben & Yurkovych, 2018).

One can formulate the following concepts of non-crystalline solid state (Mar'yan, 1998):

- substance can exist in the non-crystalline solid state in one or another form;
- non-crystalline materials are the dissipative structures formed as the method of system organization;
- non-crystalline substances are characterized by the criteria which define the domain of their stability in this state, i.e. the boundaries of the stability with respect to the control factors, which affect the system (i.e. the temperature, pressure, radiation and the rate of their variation, etc.);

- the role of non-linear modes in the formation of the non-crystalline non-equilibrium stationary system of any degree of complexity is equal and versatile;
- the main parameters, which specify the non-crystalline system, are the spatial-temporal correlation of physical quantities describing it and the life-time of the dissipative structure;
- the general regularities established for the non-crystalline state are also valid for the crystalline one.

In connection with the consideration of non-crystalline media, it is pertinent to recall the notion of the quasi-crystal as the object which is not periodic but has a long-range order. Such approach is of fundamental interest since it generalizes the definition of the crystal.

The study of peculiarities of the transition to the non-crystalline state (i.e. the dependence of the transition temperature on the control parameter as well as an anomalous increase in the structure relaxation time and thermodynamic properties in the transition region) within the framework of thermodynamic or relaxation approach in the linear approximation based on the system deviation from the equilibrium state allows only certain aspects of the present phenomenon to be explained. However, this approach fails to elucidate the whole pattern of the non-crystalline solid formation. Hand in hand with this, it is evident that the abundance and the complexity of the pattern are due to the strongly non-equilibrium character of the transition that requires the consideration of non-linear processes related to the interaction of various subsystems, i.e. the synergetic effects must be allowed (Mar'yan & Palyok,1999).

Since the non-equilibrium is the main feature of non-crystalline structures, we shall analyze the transition to the non-crystalline state by using non-equilibrium thermodynamics regularities (Haken, 2006). In accordance with this, the change in

the entropy dS during the time interval dt can be divided into the sum of two contributions:

$$dS = (dS)_i + (dS)_e \quad , \qquad (2.1.1)$$

where $(dS)_e$ is an entropy flux which exists due to the matter and energy exchange with the environment and $(dS)_i$ is the entropy production inside the system resulted from the irreversible process. It follows from the second law of thermodynamics that:

$$(dS)_i > 0, \qquad (2.1.2)$$

and the equality sign corresponds to the equilibrium state.

For isolated system $(dS)_e = 0$, and we get from (2.1.2):

$$dS = (dS)_i > 0 \quad . \qquad (2.1.3)$$

Thus, open systems differ from the isolated ones by the presence of an addendum corresponding to the exchange in the expression for the entropy variation. The $(dS)_e$ addendum has no definite sign, contrary to the $(dS)_i$ value, which never takes the negative sign. This allows one to present the transition to the non-crystalline state as the process in which the system reaches the state with the lower entropy as compared with the initial state:

$$\Delta S = \int\limits_{\substack{over \\ path}} dS < 0 \cdot$$

That state is extremely improbable from the viewpoint of the equilibrium state:

$$\Re \propto \exp\left(-\frac{E}{k_B T}\right),$$

where k_B is a Boltzmann constant, $\Re$ is the probability of the system to be found in the state with the energy E. Moreover, this state may exist very long if the system reaches the stationary state, where:

$$dS = 0 \text{ or } (dS)_e = -(dS)_i < 0. \qquad (2.1.4)$$

Consequently, if a sufficiently large negative flux of the entropy enters the system, a certain ordered configuration can be maintained in this system. Furthermore, the entropy delivery must occur in non-equilibrium conditions,

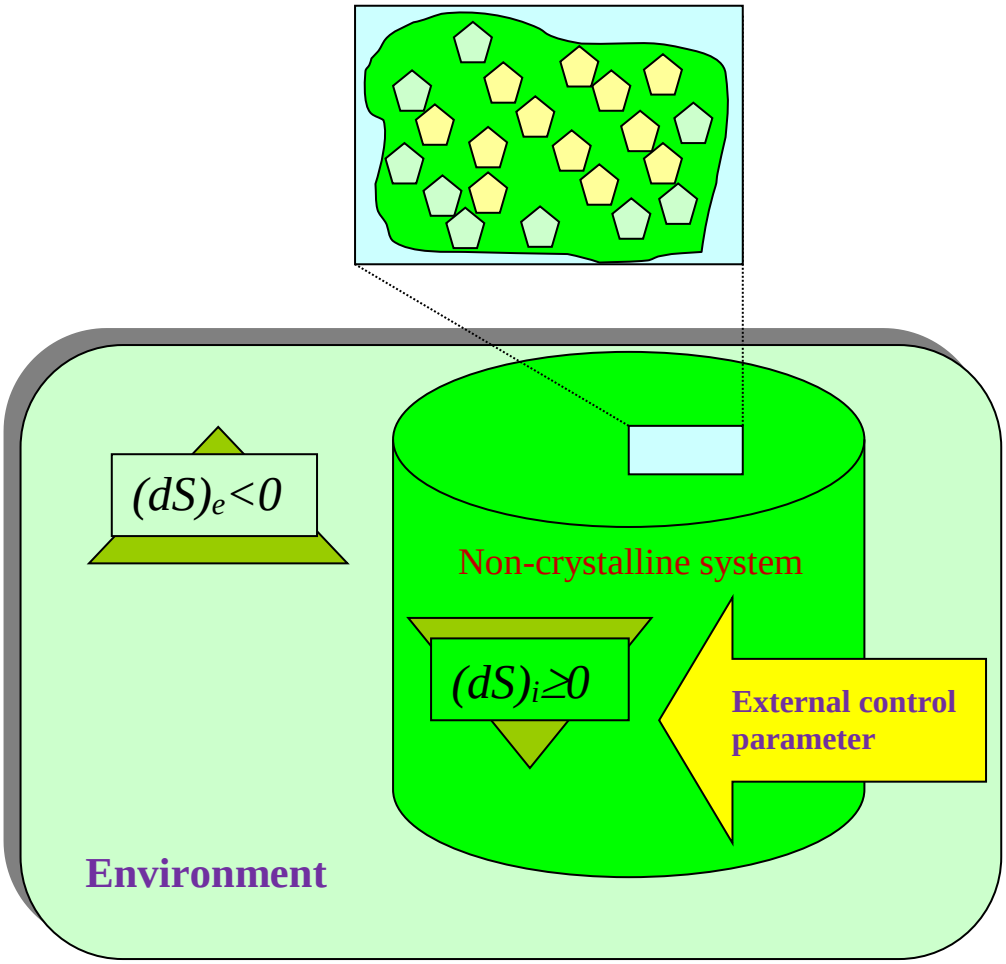


Fig.2.1.1. Formation of the non-crystalline state ($(dS)_e$ is an entropy flux which exists due to exchange a matter, energy and information with the environment and $(dS)_i$ is an entropy production inside the system).

otherwise, both $(dS)_e$ and $(dS)_i$ turn to zero. Hence the fundamentally important principle follows that the non-equilibrium can serve as the source of the order, and the self-organization of dissipative fluctuation structures is the principal phenomenon, which constitutes the basis of structural transitions in non-crystalline media (Fig. 2.1.1). Within the framework of that concept, the contradictions between thermodynamic and kinetic approaches to the non-crystalline solid formation are eliminated. Consider general regularities in the formation of the short-range and medium-range order structure in the lowly non-equilibrium (quasi-crystalline) and highly non-equilibrium (non-crystalline) solids at the melt cooling depending on the cooling rate.

2.1.2. The computer modeling of the structure

In the atomic structure of non-crystalline substances one may recognize the short-range order due to the correlation of the local physical quantities $\aleph(\vec{r})$ at the distances $L_S \le 0.1 \div 0.5$ nm and the media-range (intermediate order) due to the correlation of the parameters at the $L_M \le 0.5 \div 5.0$ nm distances. The expositions, which describe non-crystalline solid states, can be arbitrary partitioned into the following three groups (see Fig. 2.1.2).

The first group models are founded on the thermodynamic exposition of

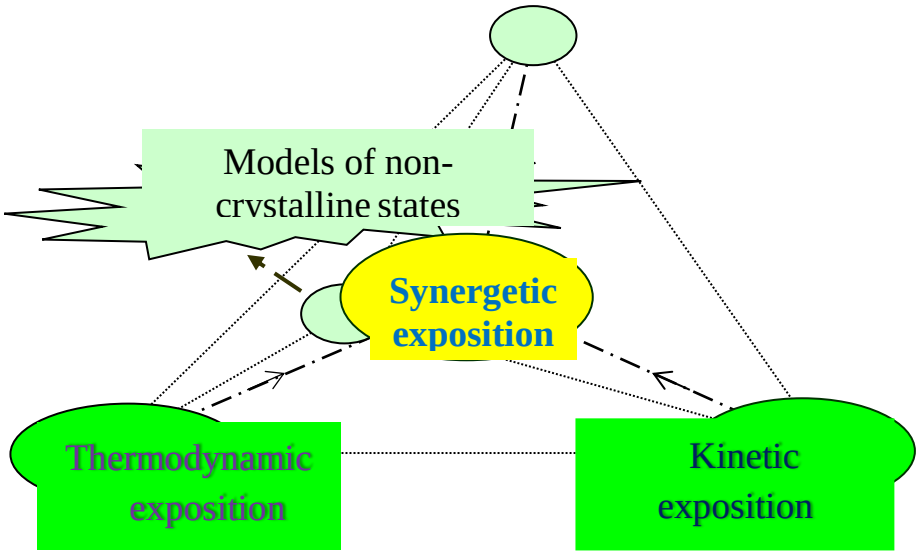


Fig.2.1.2. Expositions of the non-crystalline states.

non-crystalline skew fields. These models consider thermodynamic properties of the systems at an inappreciable removal from balanced state in view of a particular degree of disorder. The given approach well enough features a circle of appearances, which are determined by the behavior of the structural - responsive parameters, the thermodynamic functions in a transition range. Depending on the way of disorder introduction in a system, they are subdivided into the next types:

- The models obtained by introducing the structural perturbations of ideally ordered structures (crystals). This class involves the models of the micro crystallites, hot solids, dislocations and random packing. For most of them it is assumed that the structural disordering combines the local violations of short-range order as compared with the crystalline lattice matrix (violations of bond lengths and angles). Thus, for instance, the quasi-crystalline Gubanov's model assumes that the topological order in the crystalline lattice is retained. However, due to the bending and tension, it is so deformed that results in the long-range order violation at long distances (Fig. 2.1.3).The quasi-crystalline model also belongs to this class and considers the substance as the set of the crystallites, whose size is substantially large in comparison with the free path length for electrons or phonons. In this case the degree of the topological disordering is higher in the thin near-surface regions close to the crystallite boundaries, allowing one to consider the influence of the system dimension on the disordering degree (Ziman, 1977).
- The models obtained by the randomly located structural units. This class comprises the hard-sphere close-packing models (the structural models of Bernal liquids, Fig. 2.1.4). By choosing the corresponding structural units and using the evolution procedure one can simulate physically available non-crystalline structures, in particular, the metal glasses. This class also comprises the cell disordering models, when physical properties of the structural matrix

unit cells are not identical and vary in the random manner. The cell disordering is, for example, reduced to the substitution disorder in the melts or A_xB_{x-1}-like

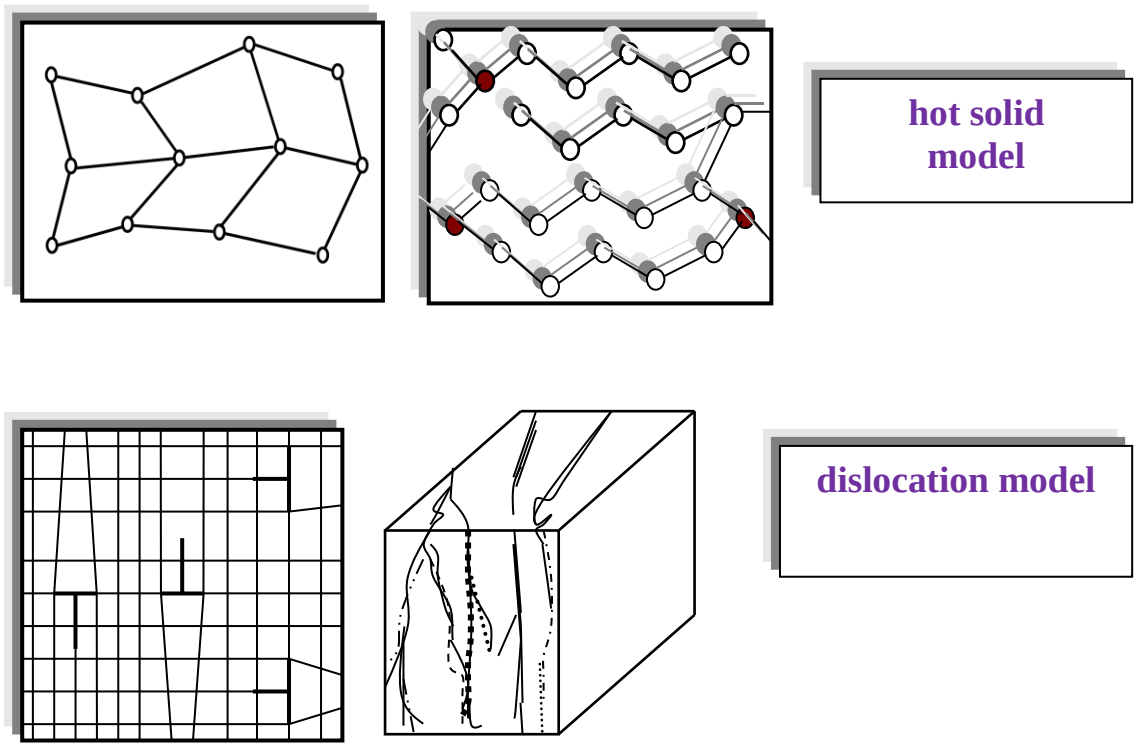


Fig. 2.1.3. The models of the non-crystalline materials.

compositions, when the regular alternation of A and B atoms and spin orientations in the lattice nodes is violated or the irregular distribution of different-type defects is observed (e.g., the vacancies, charged centers, etc.).

- The models based on the numerical simulation by the "first principles". This class considers the methods of structural models construction by means of the computer modeling using the theoretical molecular dynamics apparatus and the theory-group analysis method. Since the non-linear problems are solved analytically only in the specific cases, the computer modeling allows one to obtain a new instrument for the non-linear models studies (Fig. 2.1.4).

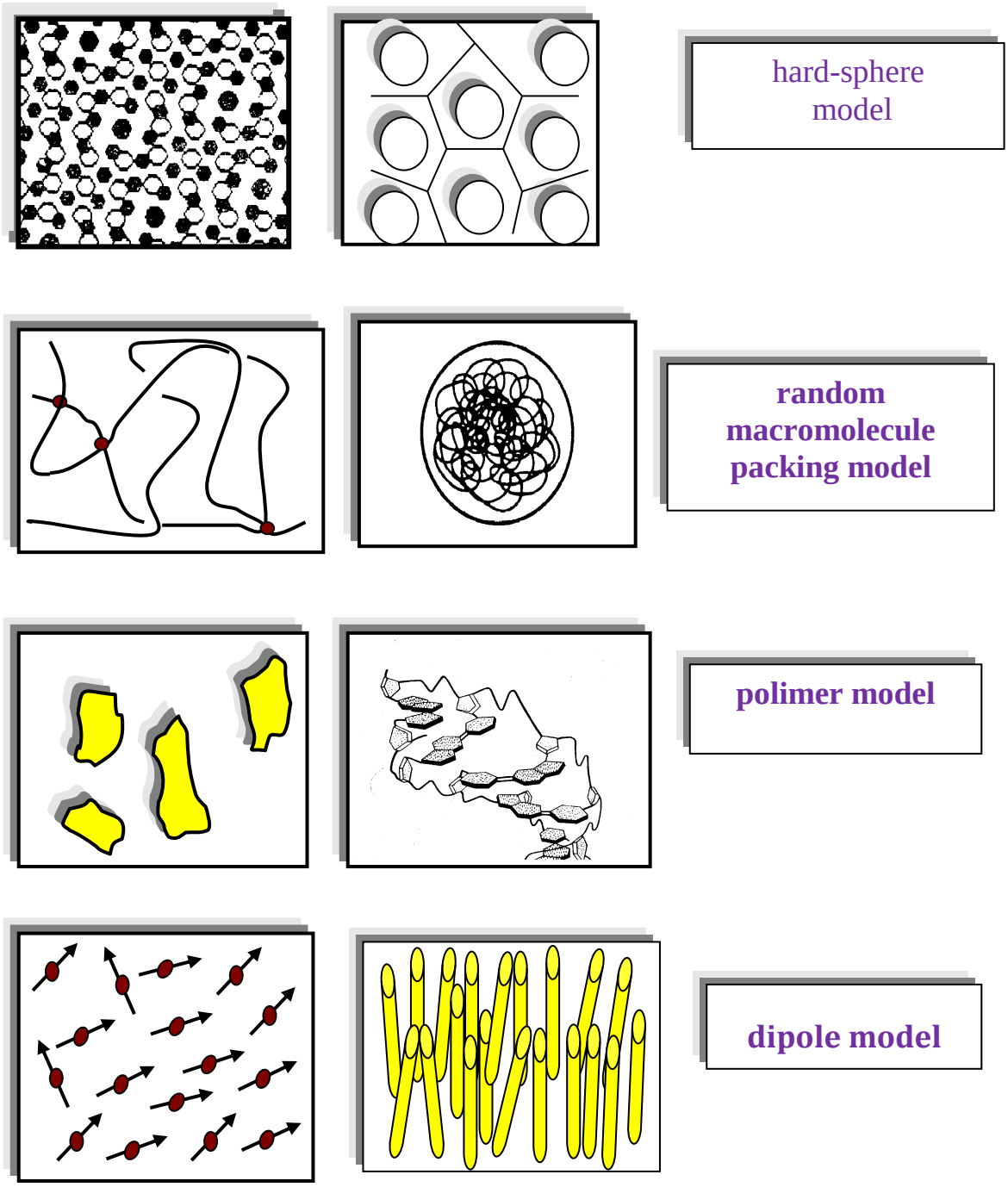


Fig. 2.1.4. The models of the non-crystalline materials.

- The continuum disordered models based on the structure less concept of solid, when the mass or potential energy distribution functions have a random and continuous character (Fig. 2.1.4). The macrostructure of the medium is ignored in this case. The Thorp's model, which considers a substance as a family of

spatial rigidity and non-rigidity domains, is one of the examples of such models. The models are obtained by the topological mapping of the set of polyhedrons, which fill the space of the higher dimension of polytypic with a preset coordination of the structure under modeling onto the 3-D Euclidean space (Ziman, 1977).

- The models based on the kinetic (relaxation) approach belong to the second group. The properties of non-crystalline media depend on the exterior factors (velocity of cooling, intensity of laser radiation), that means the presence of an interval of transition (Brodsky, 1979).

The above both concepts of exposition of non-crystalline solids reflect, at a first glance, two alternative approaches, each of them reflecting a particular circle of the experimental facts. The synergetic approach to the shaping and exposition of non-crystalline solid state enables to aggregate the indicated two concepts so that they do not exclude, but on the contrary, supplement each other. Only such an approach enables one to describe most adequately the structure and phase changes of the non-crystalline solid matter of an inorganic and organic origin that is a necessary stage at the transition from the lifeless to the alive nature. It is so because synergetics takes into account the self-consistent interaction of all factors, both thermodynamic and dynamic (Mar'yan,1998). Within the framework of a given approach non-crystalline solid states are considered as an outcome of the previous self-organization, during which the energy dissipation and transformation is observed. This part of the book will be devoted to reviewing the given approach with a reference to media of an inorganic origin.

2.2. The synergetic exposition and model of non-crystalline systems

As the temperature of the solid is elevated to the melting temperature, the concentration of point defects (of the intermodal atom (vacancy) type) or extended defects (of the dislocation type) increases sufficiently. Such defects taken

separately are not the disordered phase nuclei. However, if they are accumulated within a certain macroscopic domain, then such area of disordering corresponds to the structure inherent to the liquid-like (soft) states, i.e. it has a shearing instability, a high level of dynamic displacements and the instability related to the defect formation (Fig. 2.2.1). Hence, within the phase transformation interval along with homogeneous fluctuations (i.e. the thermal displacements of atoms) the effect of hetero-phase fluctuations increases, being the formation of the liquid-like

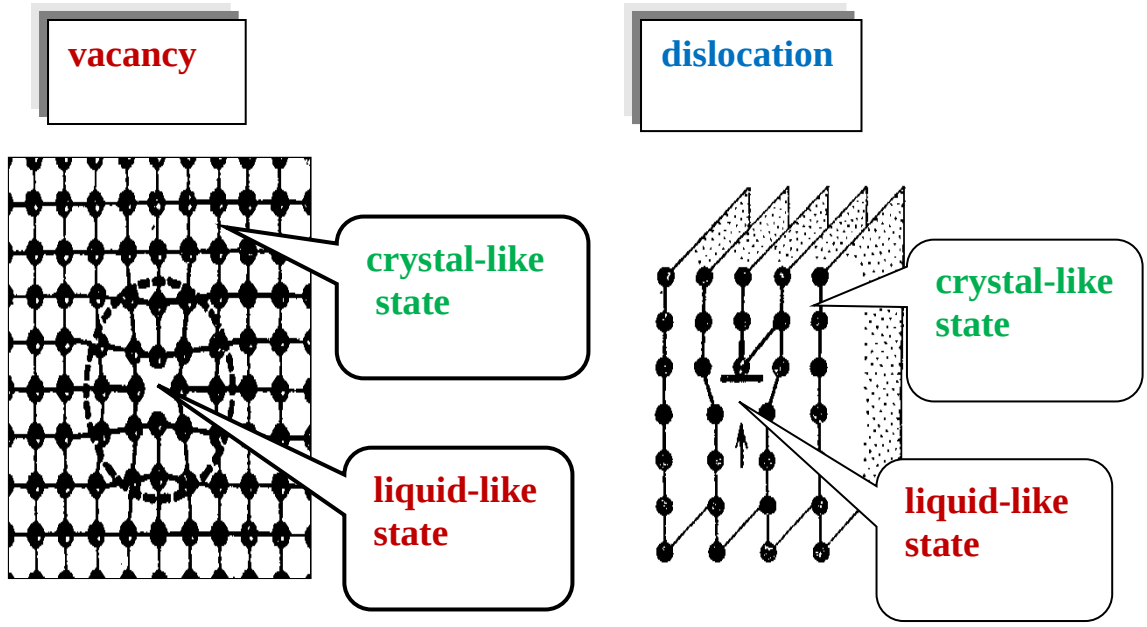


Fig. 2.2.1. Liquid-like (soft) and crystal-like (solid) states.

macroscopic domains inside the solid-phase state under study. The schematic of the potential relief of that system is shown in Fig. 2.2.2 (*f=1* denotes the solid-like localized states, while *f=2* corresponds to the liquid-like delocalized (soft) states). The "soft" states are specific structural states with an additional degree of freedom in the configurationally space. These states exist due to the spatial fluctuations of the short-range order parameters (the number and the length of the bonds, the inter-bond angles) near their average values and the formation of the defect states in the

highly non-equilibrium conditions. They are intrinsic for non-crystalline solids. Atoms in the "soft" states possess a considerable level of static displacements and,

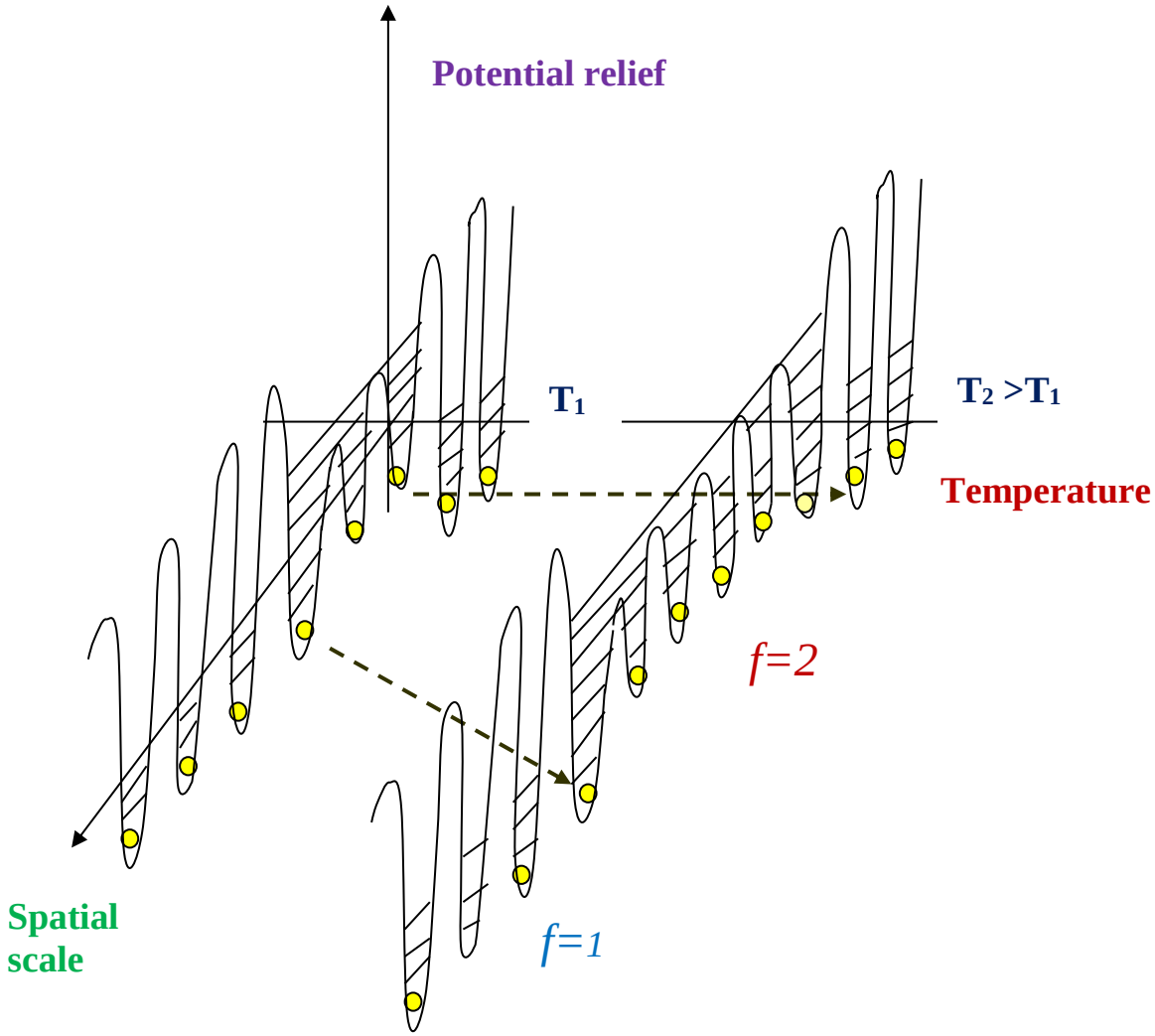


Fig. 2.2.2. Schematic representation of the potential relief of the system: f=1 – crystal-like states; f=2 – liquid-like states.

consequently, the vibrational non-harmonium and the ability to the spatial rearrangements. The bonding topology and the configurationally parameters which describe the "soft" states, are accounted for and detailed in terms of certain structural models. We shall analyze the general tendencies of the formation of the macroscopically ordered structures in the non-crystalline solids away from the

equilibrium state. Therefore, we shall use the universal characteristics of the "soft" states (Mar'yan, 1990).

2.3. Synergetics and self-organizing processes in the non-crystalline systems

2.3.1. Mathematical analysis of the instabilities

The authors (Mar'yan, Kikineshy & Szasz, 2001; Mar'yan & Yurkovych, 2016) obtained the following self-consistent system of equations with respect to the particle of atoms in soft atomic configurations $\eta = \sigma - \sigma_e$, mean square displacements $\mathrm{D}_{\mathrm{l}}^{\alpha\alpha}\left(\approx y_l\right)$ and $\mathrm{D}_{\mathrm{t}}^{\alpha\alpha}\left(\approx y_t\right)$:

$$F_1(\sigma) = -\tilde{a}_0\tilde{q}\,\eta + c\eta^2 + b\eta^3, \quad F_2(y_l) = \frac{\eta_{y_l}}{\tau_{y_l}}, \quad F_3(y_t) = \frac{\eta_{y_t}}{\tau_{y_t}},$$

$$F_1(\sigma) = \sigma\xi_P + (1-\sigma)z\left\{\frac{e^{-y_l}}{2}\left[B(y_l) - \frac{P^* e^{y_l}}{12(1-\sigma)^2}\left(\frac{r}{a_0}\right)^2\right] + \frac{G_0/V_0}{(1+2y_l)}\right\} -$$

$$z(1-\sigma)\sigma\left(1 + \frac{y_l}{4} - \frac{1}{6}\ln\frac{B(y_l)}{2}\right)A(y_l) - \tau\ln\frac{\frac{g_2}{\sigma} - 1}{\frac{g_1}{1-\sigma} - 1}, \qquad (2.3.1)$$

$$F_2(y_l) = \frac{3e^{-y_l}\tau}{8\sqrt{2}(1-\sigma)}\left[B(y_l) + \frac{P^* e^{y_l}}{6(1-\sigma)^2}\left(\frac{r}{a_0}\right)^2\right]^{-1}\left(1 + \frac{0.022(1+2y_t)^{-2}}{e^{y_l}\left[B(y_l) + \frac{P^* e^{y_l}}{6(1-\sigma)^2}\left(\frac{r}{a_0}\right)^2\right]}\right) - y_l,$$

$$F_3(y_t) = \frac{3(1+2y_t)\tau}{8(1-\sigma)e^{\frac{y_l}{2}}}\left[B(y_l) + \frac{P^* e^{y_l}}{6(1-\sigma)^2}\left(\frac{r}{a_0}\right)^2\right]^{-\frac{1}{2}} - y_t.$$

In this book, we will not dwell on complex mathematical calculations, but will analyze only the typical results of the self-organization of open systems on an example of non-crystalline materials (who wish to revise the beautiful mathematical set of Green's functions can refer to articles (Mar'yan & Szasz, 20001; Mar'yan & Yurkovych, 2015).

An illustration of the use of an iterative method for finding solutions to a self-consistent system of equations (2.3.1) in the visual programming environment Delphi is shown in Figs. 2.3.1a- 2.3.1c.

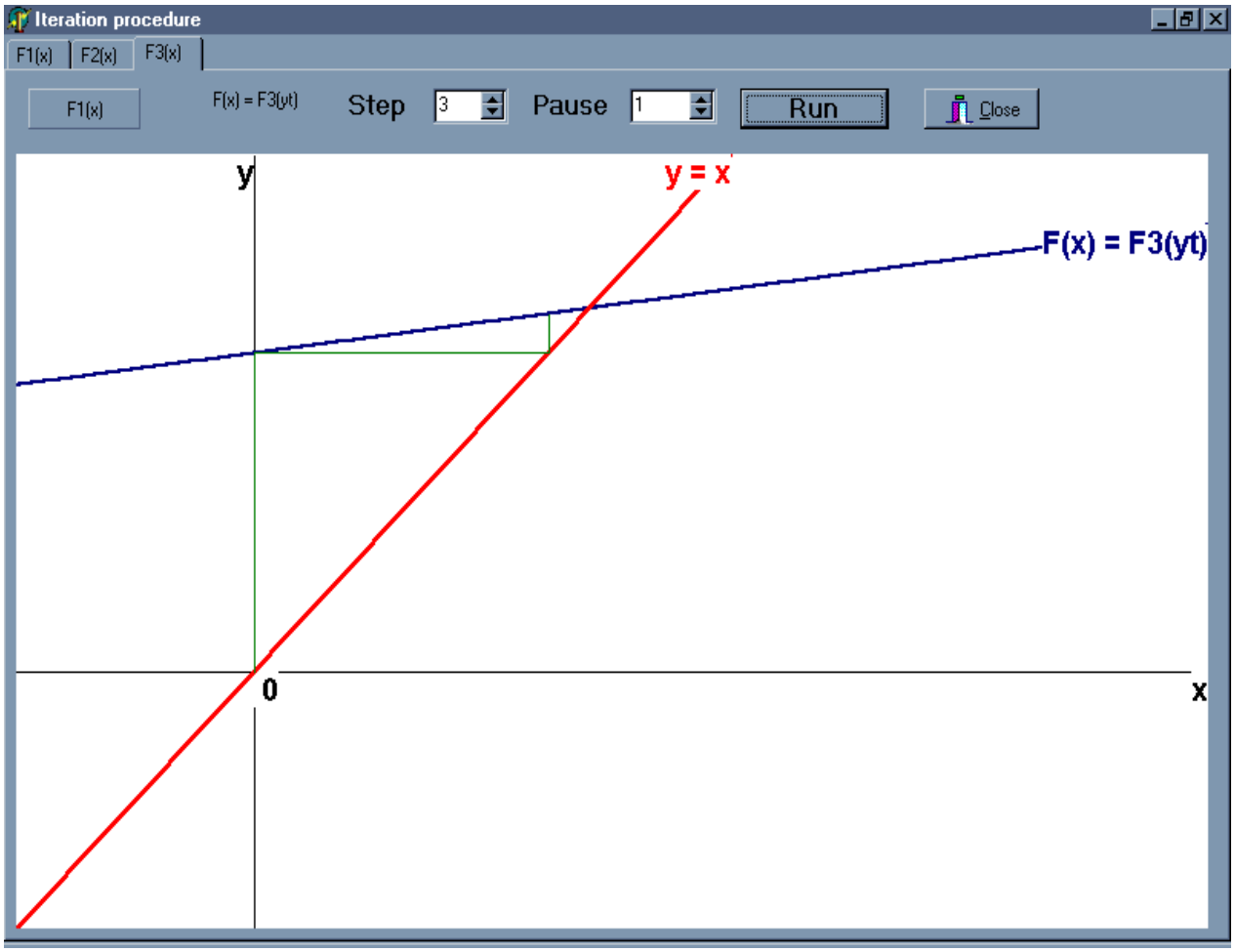


Fig. 2.3.1a. An illustration of the use of an iterative method for finding solutions to a self-consistent system of equations (2.3.1).

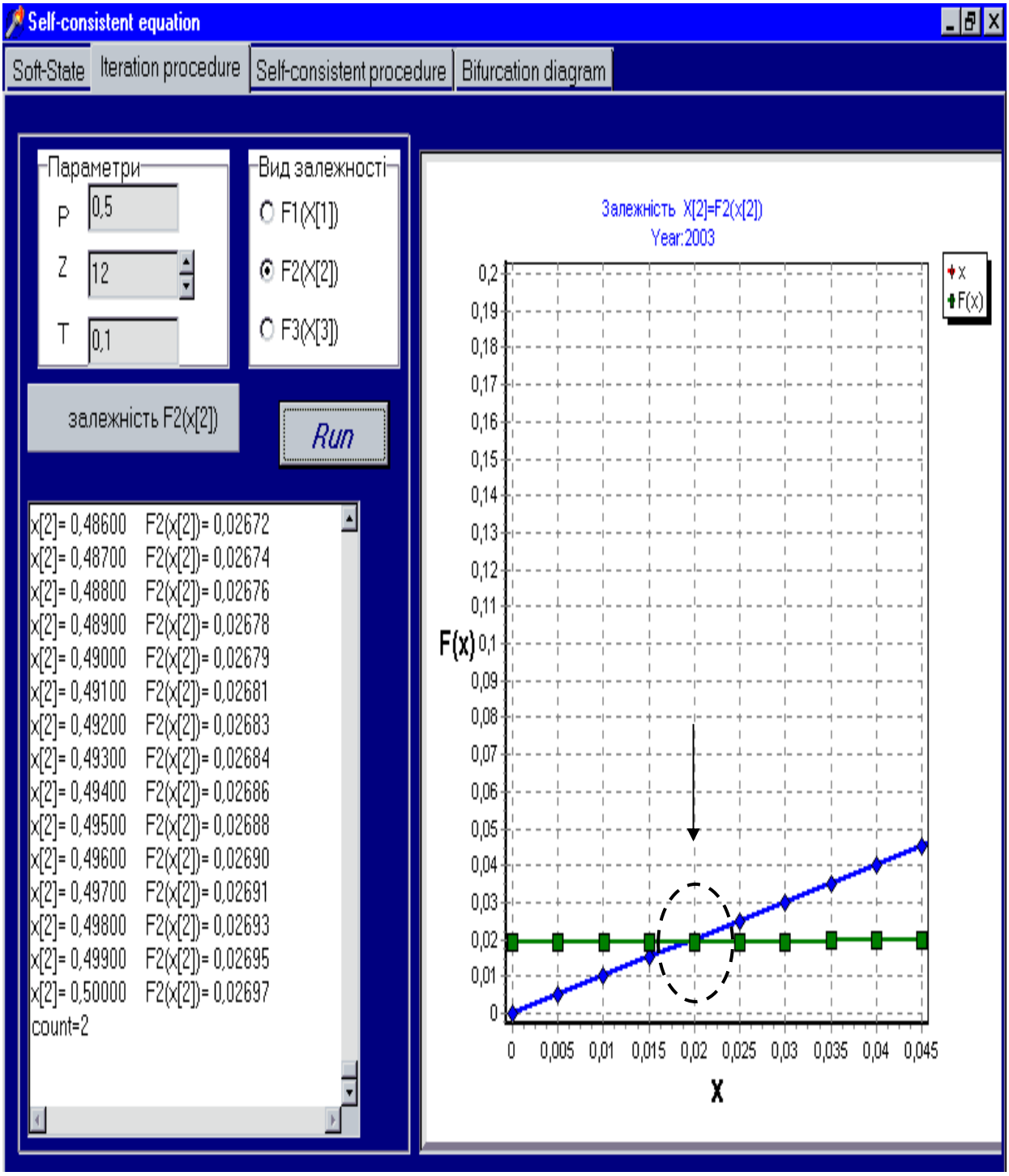


Fig. 2.3.1b. An illustration of the use of an iterative method for finding solutions to a self-consistent system of equations in the programming environment Delphi.

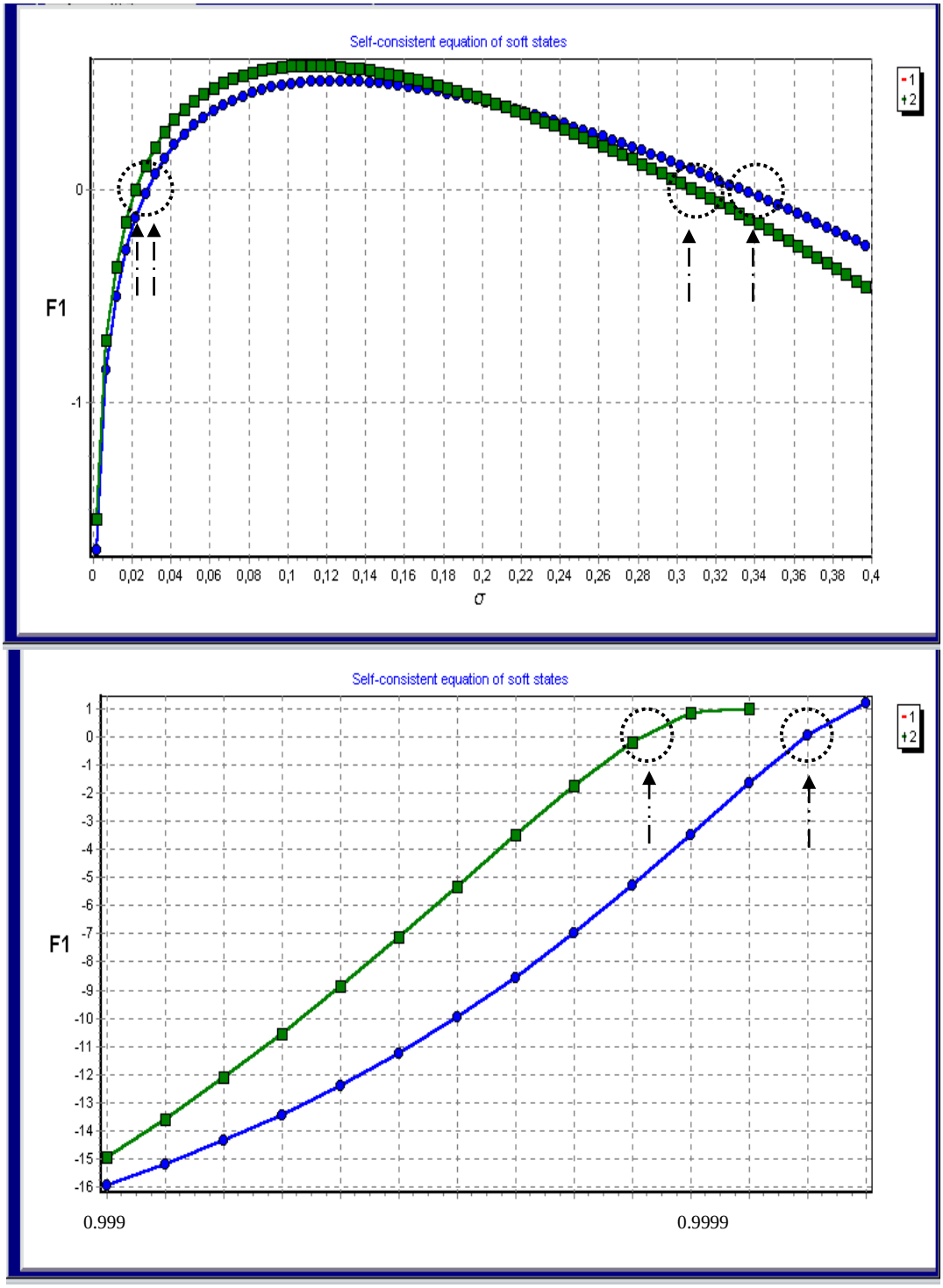


Fig. 2.3.1c. An example of finding the roots of the equation $F1(\sigma) = 0$ *by the method of dechytomy (*$\tau = 0.7,\ \ 1 - P^* = 1.0,\ \ 2 - 0.5$*).*

The results of computer simulation are shown in Fig. 2.3.2a-2.3.2b.

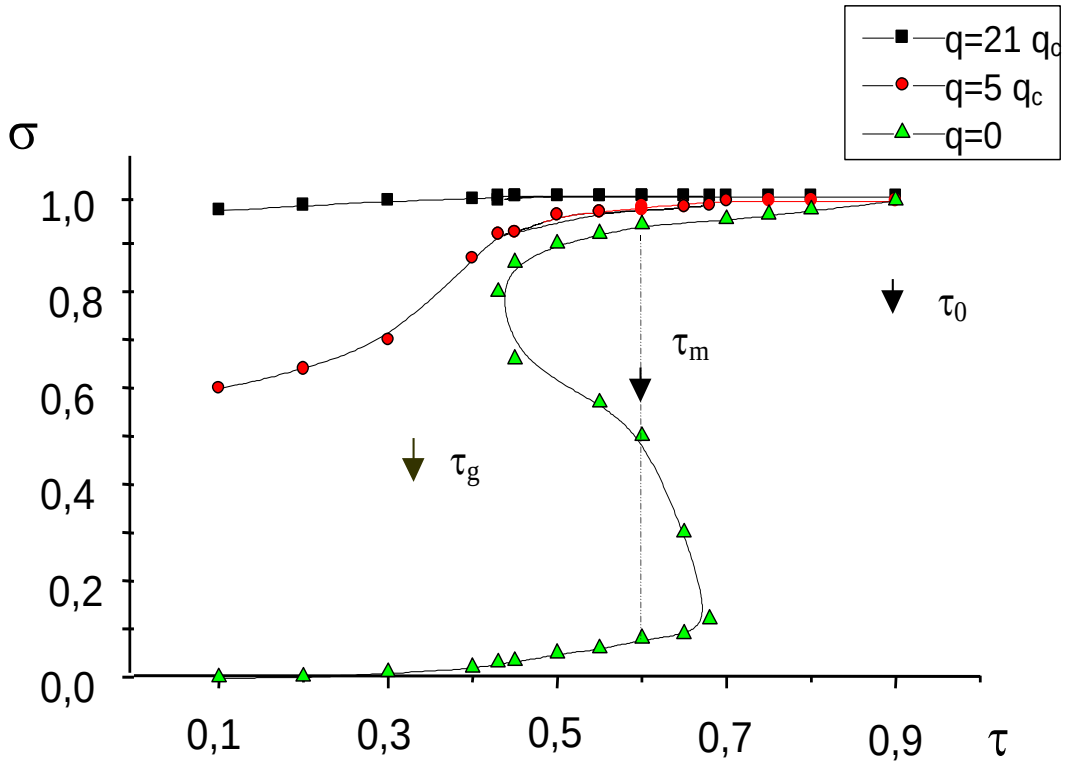


Fig. 2.3.2a. Temperature dependence of the fraction of atoms in soft configurations σ in the region of dynamic stability at different cooling rates q ($P^* = 0.5$) (Mar'yan & Yurkovych, 2016).

Now a reasonably large number of the experimental data are available allowing one to state that the structural formations of a certain chemical composition may exist within the $T < T_m$ temperature range as well as in the melt or in the non-crystalline solid. The presence of hetero-phase fluctuations is confirmed by the studies of the semiconductor melts, the viscosity coefficient and the internal friction at the verification of liquid as well as by the Mossbauer spectroscopy, Raman spectroscopy and the X-ray structural analysis data. The probability of the hetero-phase fluctuation formation and the relationship between various microscopic states are defined by the conditions of the interphase equilibrium for the equilibrium phase transformation and by the degree of deviation from the equilibrium state for highly non-equilibrium transformations (Mar'yan, 1998).

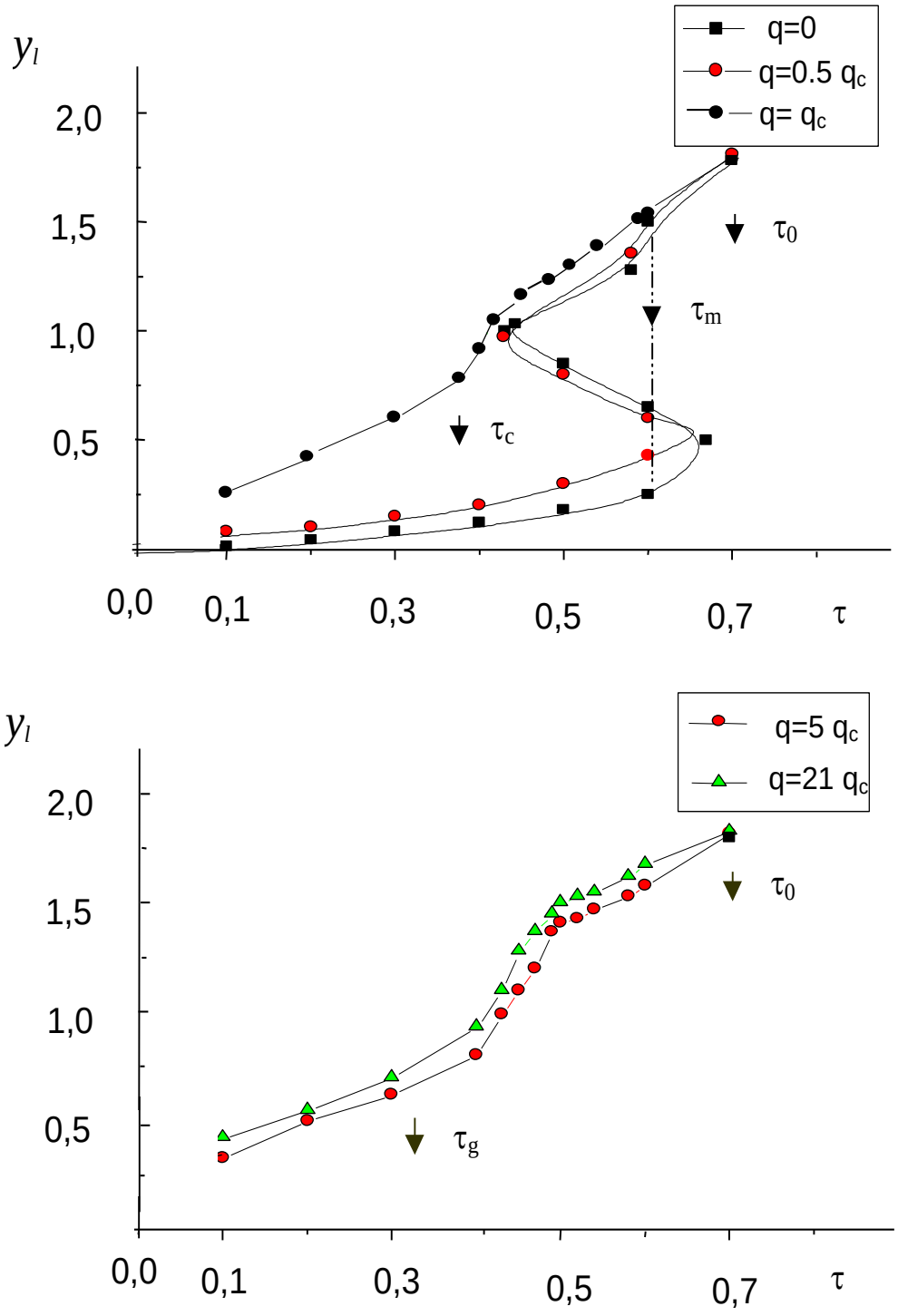


Fig. 2.3.2b. The temperature dependence of the reduced mean square displacements y_l of atoms along the communication at different cooling rates q .

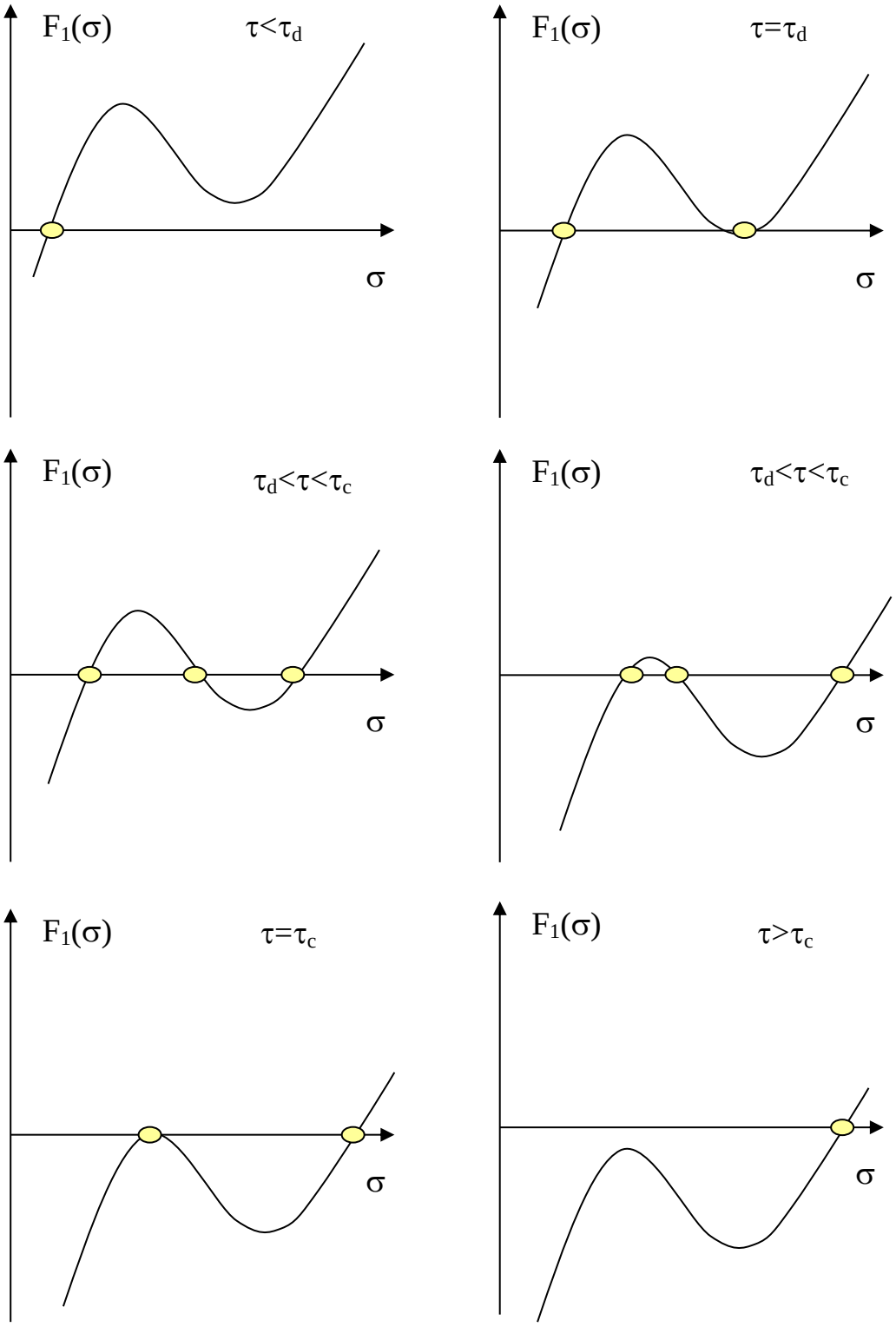


Fig. 2.3.3a. The function $F_1(\sigma)$ at different τ ($\eta=0$, $\sigma=\sigma_e$, equilibrium transformation).

The function $F_1(\sigma)$ at different temperature τ shown in Fig. 2 3.3a-2.3.3b.

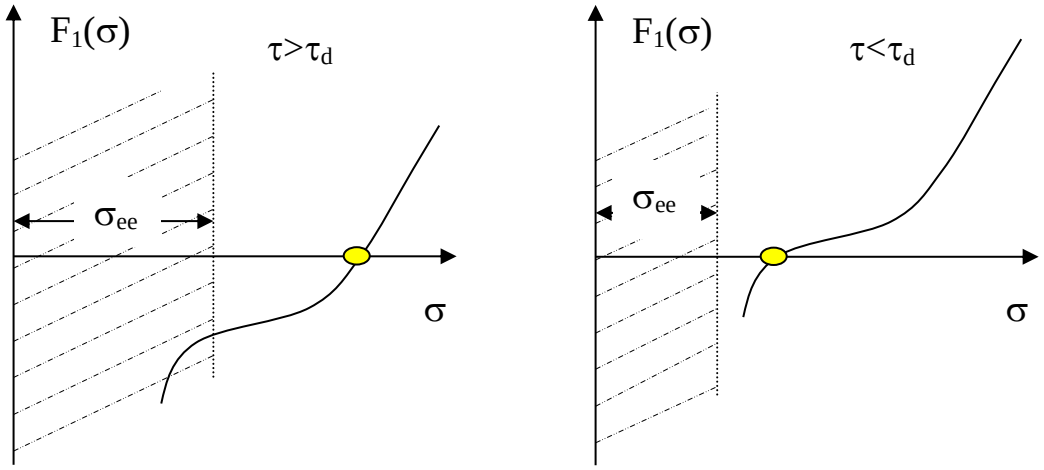


Fig. 2.3.3b. The function $F_1(\sigma)$ at different τ ($\eta \neq 0$, $\sigma > \sigma_e$, non-equilibrium transformation).

The temperature dependence of the fraction of atoms in the 'soft' states and of the mean-square displacements of atoms is presented in Fig. 2.3.4-2.3.5.

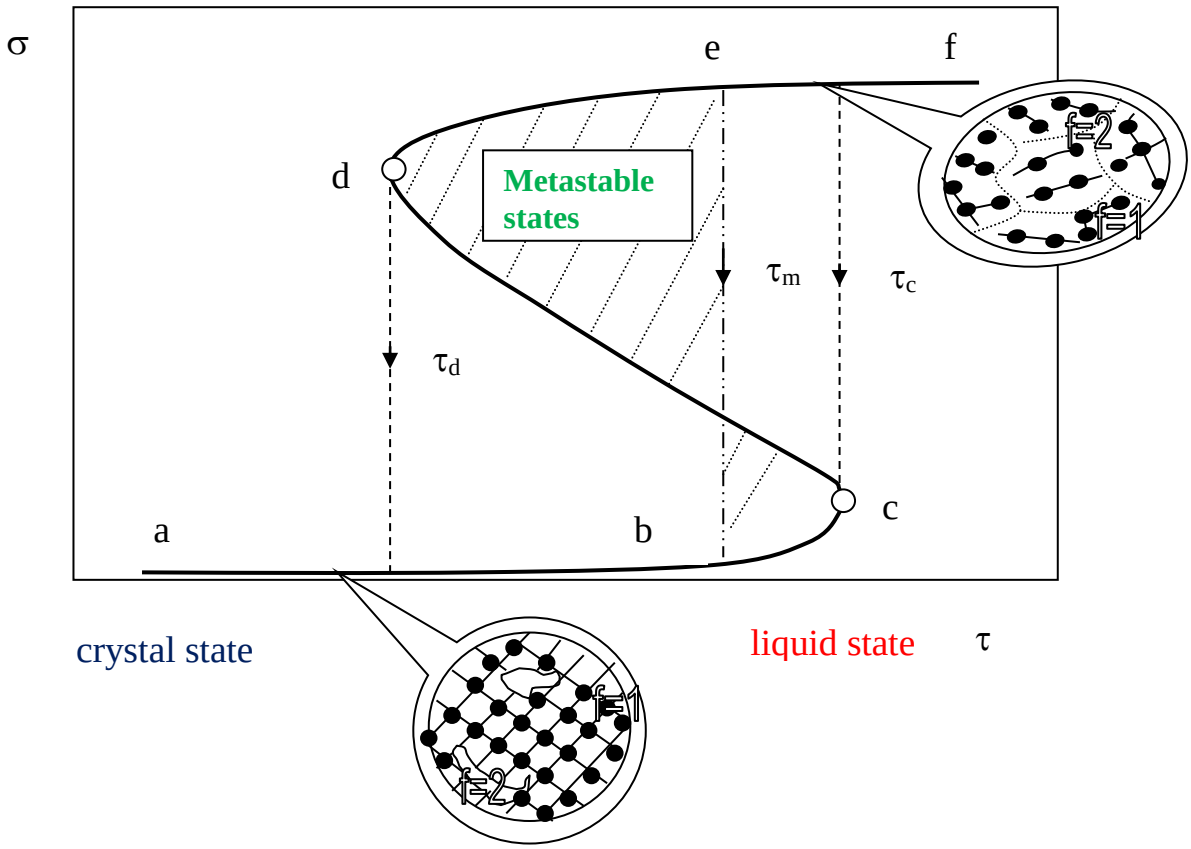


Fig. 2.3.4. The temperature dependence of the fraction of atoms in the "soft" states at $\tilde{q} = -1$.

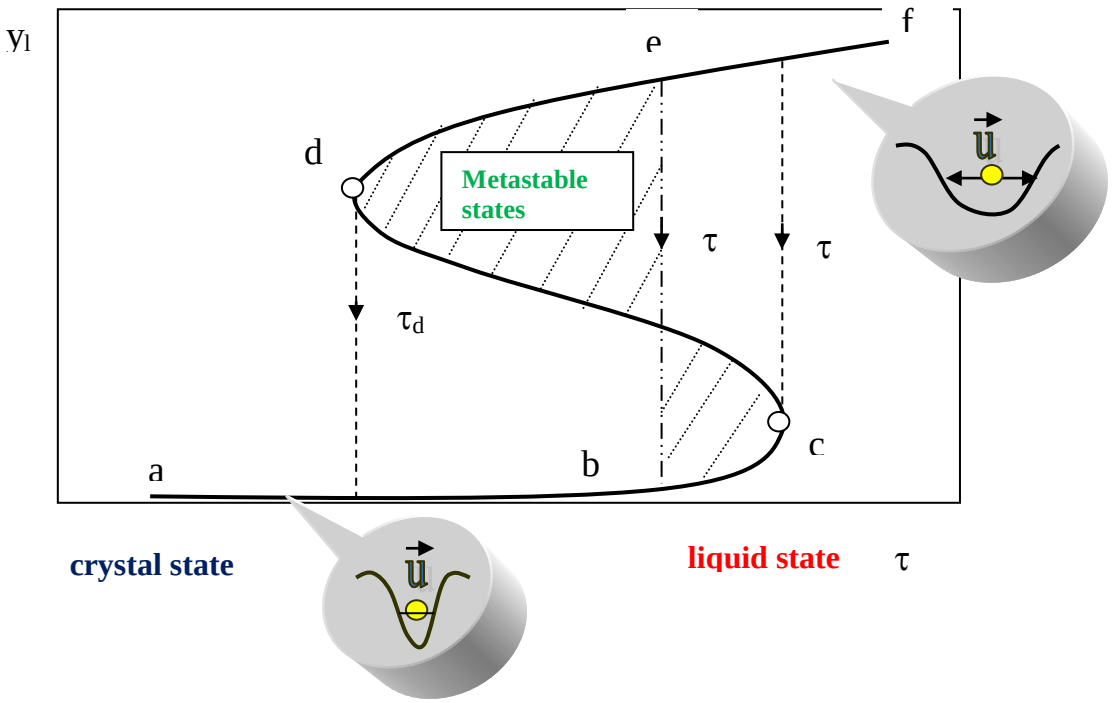


Fig. 2.3.5a. The temperature dependence of the reduced mean-square displacements y_l *at* $\tilde{q} = -1$.

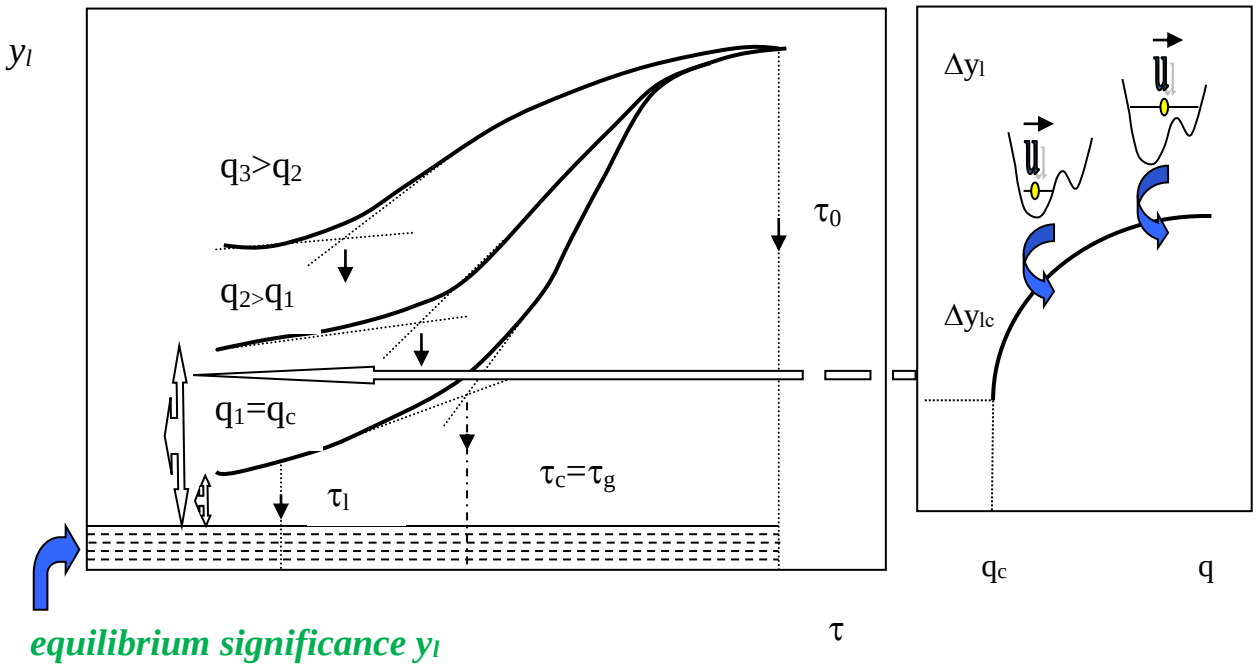


Fig.2.3.5b. The temperature dependence of the reduced mean-square atom displacements along the bond y_l *at* $q > q_c$.

Let us analyze the temperature behavior of the solutions of the system of equations (Mar'yan & Yurkovych, 2015) in highly non-equilibrium conditions, i.e. at $\tilde{q} \to \tilde{q}_c$. The temperature dependence of the fraction of atoms in the "soft" states and mean-square atom displacements have two specific domains. First of them corresponds to the system cooling at $\tilde{q} < \tilde{q}_c$, when the transition to the solid state occurs with the spasmodic increase in the elastic constants and the decrease in the fraction of atoms in the "soft" states and mean-square atom displacements. Note that the value of the leap decreases with increasing $\tilde{q}$. The second domain observed at $\tilde{q} > \tilde{q}_c$ is characterized by the continuous anomalous increase, the development of a shear rigidity of the structure and the elastic constants, as well the continuous

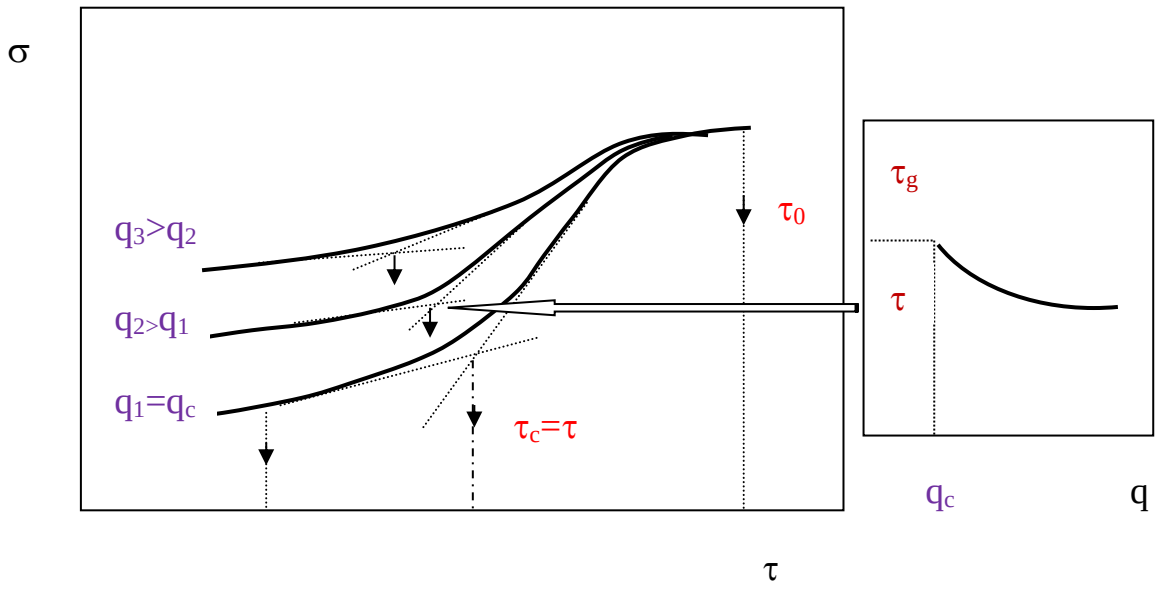


Fig.2.3.5c. The temperature dependence of the fraction of atoms in the "soft" states at $q>q_c$.

reduction of σ, y_l (see Fig. 2.3.3 - 2.3.5). Consequently, the curve at $\tilde{q} = \tilde{q}_c$ demarcates the region of the existence of metastable (i.e. the overcooled liquid) and highly non-equilibrium (non-crystalline) condensed systems. It defines the lower limit of the possible reduction of the mean-square atom displacements and

the fraction of atoms in the "soft" states in the temperature range above τ_0 at $\tilde{q} < \tilde{q}_c$ (τ_o is the temperature of synthesis, Fig. 2.3.5). The temperature τ_c in the curve $\tilde{q}_c$, at which metastable states are degenerated, is the temperature of coexistence of three states at a preset pressure, i.e. crystalline, liquid and non-crystalline states: $\left(\frac{\partial^2 \sigma}{\partial \tau^2}\right)_{\tau_c} = 0$.

2.3.2. The dissipative structure of the non-crystalline materials

The studies of the peculiarities in the behavior of the thermodynamic properties of the system in the vicinity of $\{\tau_c, q_c\}$ are of doubtless interest (point S, Fig.2.3.6a). Note that the correlated reduction of the intensity of atom vibrations and the rise of the force constants at the transition from the metastable overcooled melt to the non-crystalline solid gives evidence for the occurrence of the collective macroscopic processes at the microstructural rearrangement level at which the non-crystalline structure with the inner order parameter η is formed depending on the control parameter values $\tilde{q}$.

The order parameter used determines the degree of system deviation from the equilibrium state and correlates, in particular, with the fluctuations of system deviation from the Gaussian distribution.

The non-equilibrium stationary structure produced at $\tilde{q} > \tilde{q}_c$ results from the instability of the ground thermodynamically non-equilibrium state and arises through the self-consistent enhancement of fluctuations (the mean-square atomic displacements and the fraction of atoms in the "soft" states) which reach the macroscopic level and make a new structure stable (Mar'yan & Szazs, 2000).

That structure is a dissipative one (Fig. 2.3.6–2.3.7).

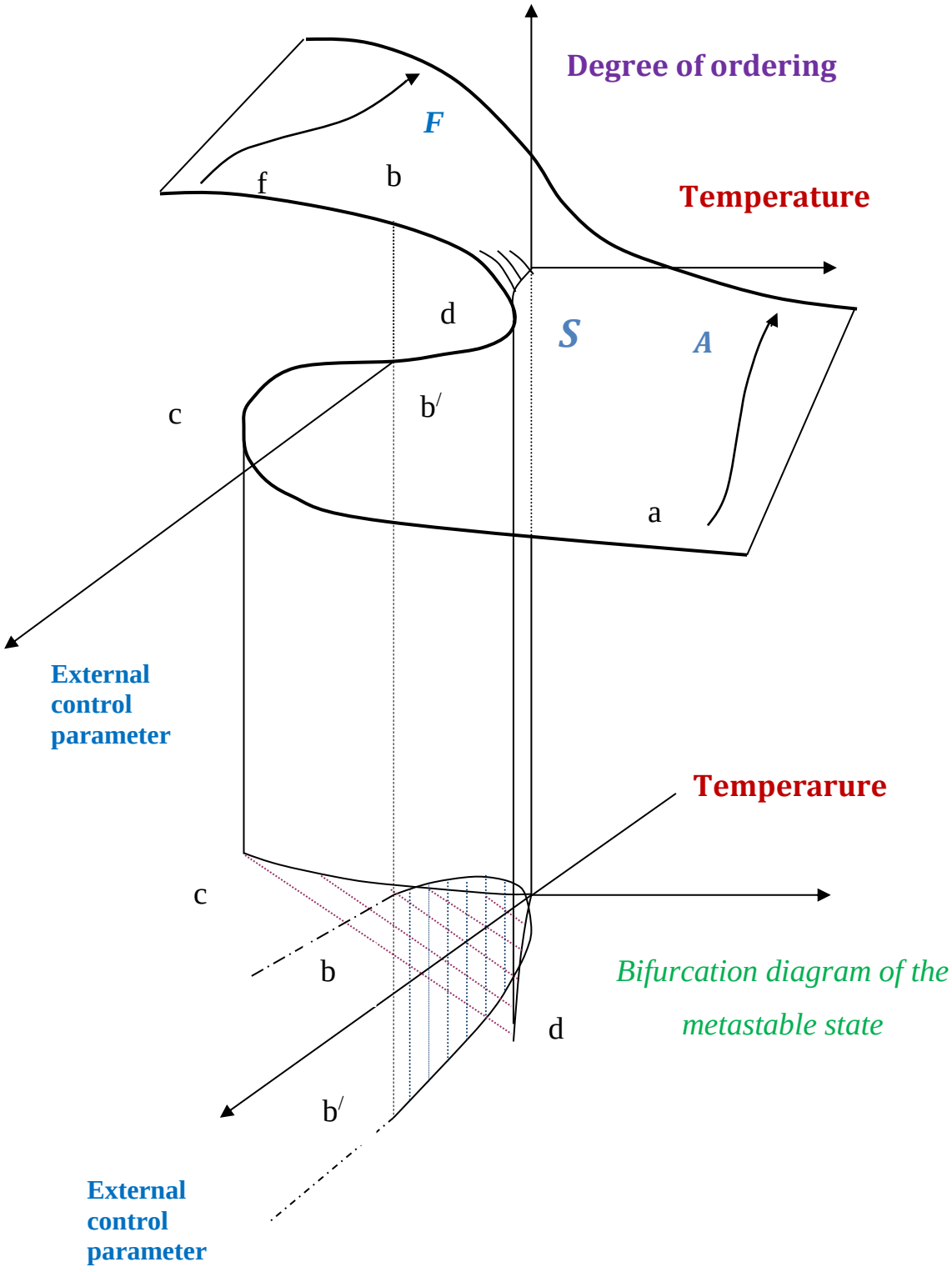


Fig. 2.3.6a. Branching of the solutions of the characteristic equation at different of the external control parameter q.

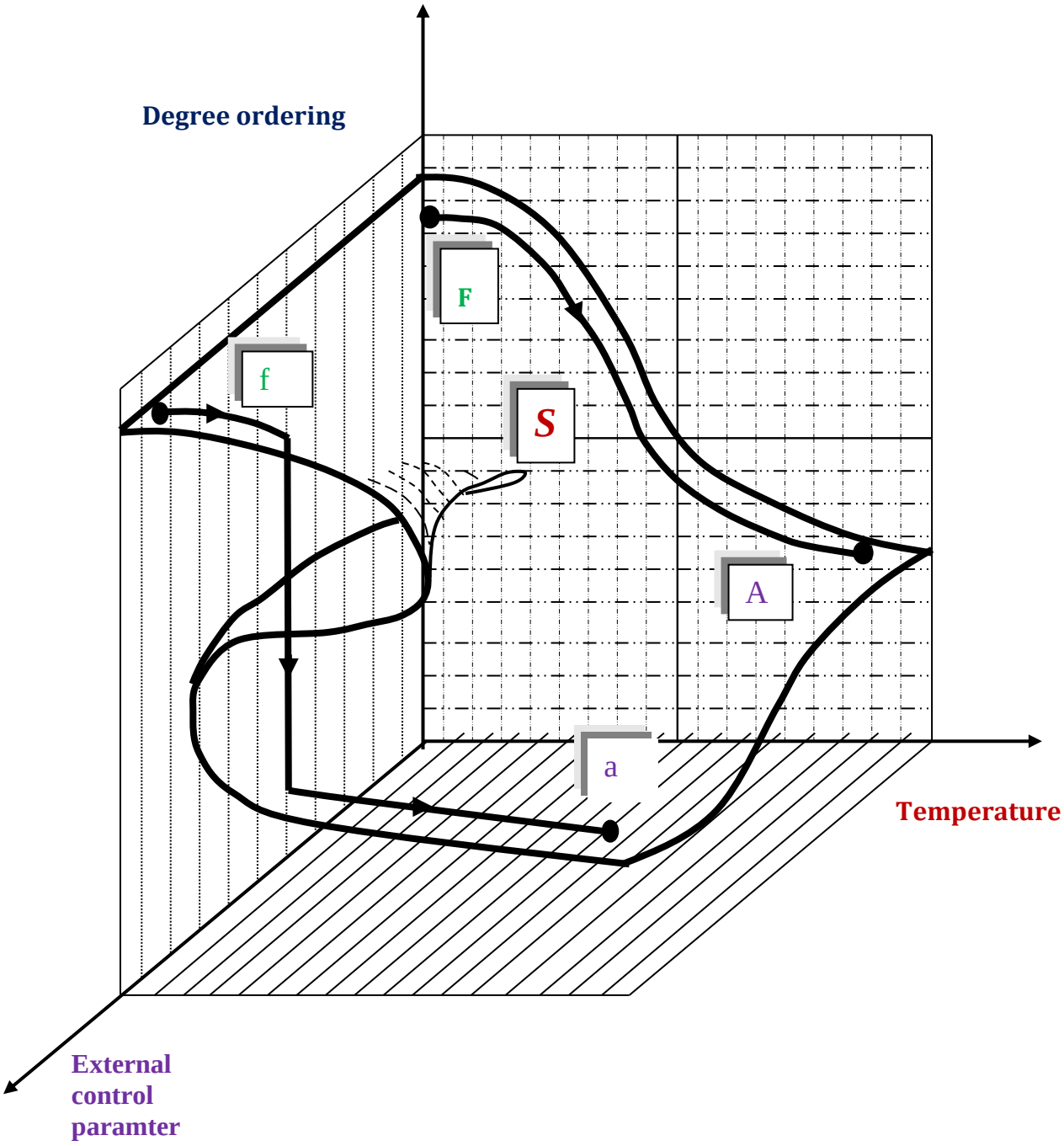


Fig.2.3.6b. Branching of the solutions of the degree ordering at different of the external control parameter q (f-a – equilibrium transition, F-A – non-equilibrium transition to the non-crystalline state).

Indeed, when the melt is cooled down under highly non-equilibrium conditions, the part of the energy of the system, which is related to the thermal motion of particles, is transformed into the macroscopically organized motion due to the

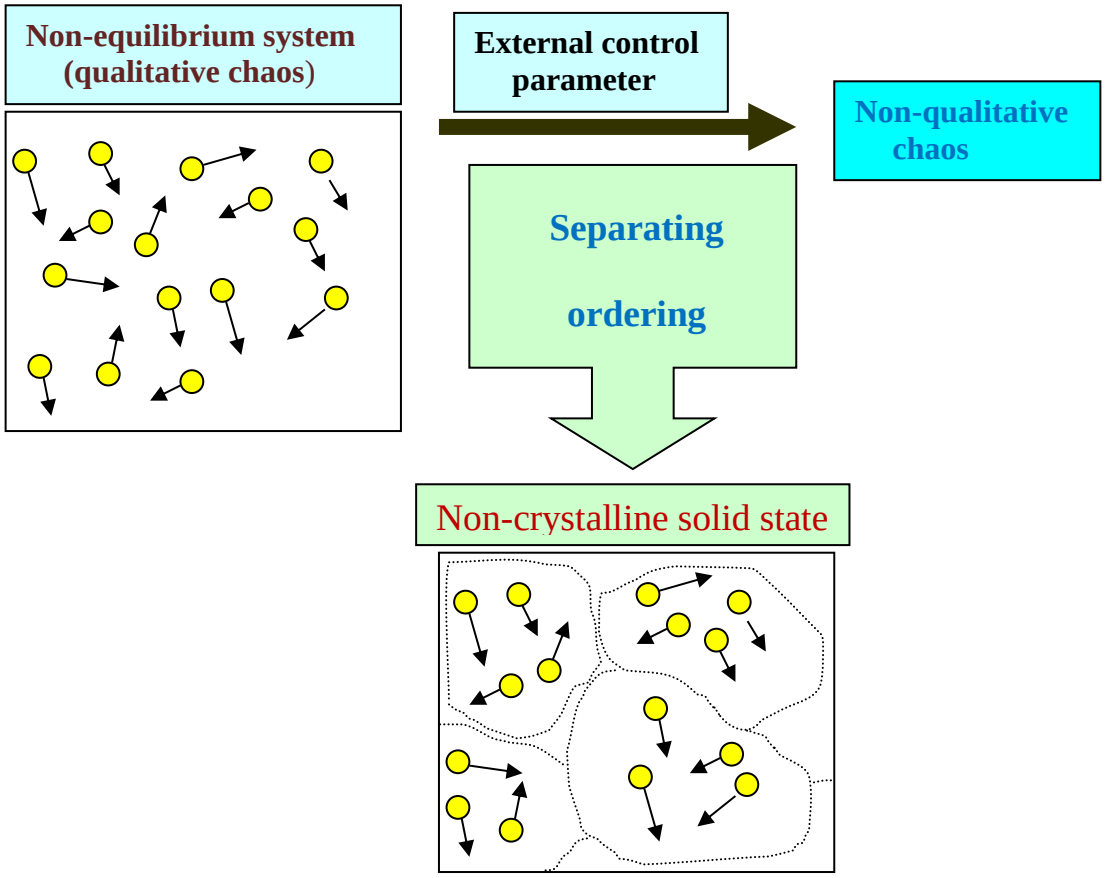


Fig. 2.3.7. Formation of the dissipative structures in the non-crystalline state.

spatial-temporal correlations at the macroscopic scale. This motion is transformed into the complicated spatial organization of the system. Such a method of organization just constitutes the dissipative structure. The dissipative structure formation in non-crystalline solids under cooling is related to the self-consistent creation of the "soft"-state domains and results from the temperature behavior of the structures under evolution towards those changes, which may promote the minimum energy dissipation and facilitate the technological process (Fig. 2.3.6–

2.3.7). The functional organization of the dissipative structure just also is

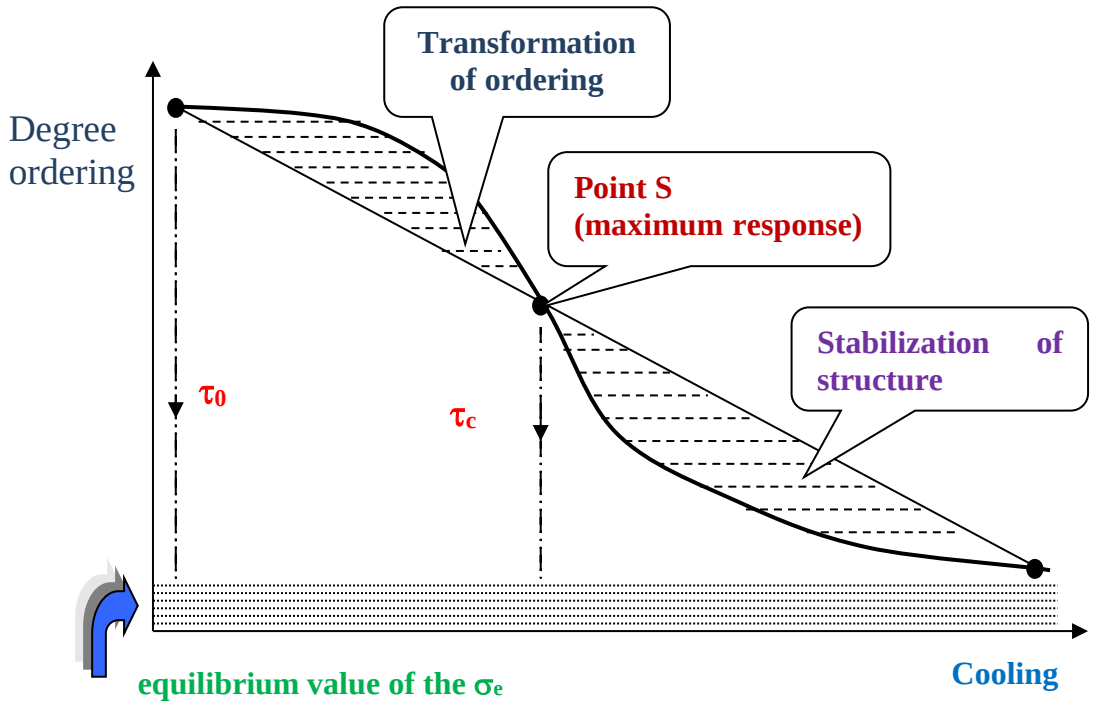


Fig. 2.3.8. The self-consistent creation of the "soft"-state domains in non-crystalline materials.

determined by the selected qualitative energy that is selected ordering from chaos. These methods are determined through external control parameters and form the appropriate types of ordering.

The value of the mean-square atom deviations from the equilibrium state for the solid produced at $\tilde{q} = -1$ is mainly due to the thermal displacements of atoms. Therefore, to determine the functional dependence of the short-range parameter fluctuations (i.e. interatomic distances, inter bond angles), related to the static displacements of atoms under cooling, on $\tilde{q}$, one may take the value of thermal displacements of particles in the system in the equilibrium state as the counting level.

As it is seen, the degree of disordering increases with $\tilde{q}$ and the region of the transition to the non-crystalline state from the overcooled liquid side. It gives a

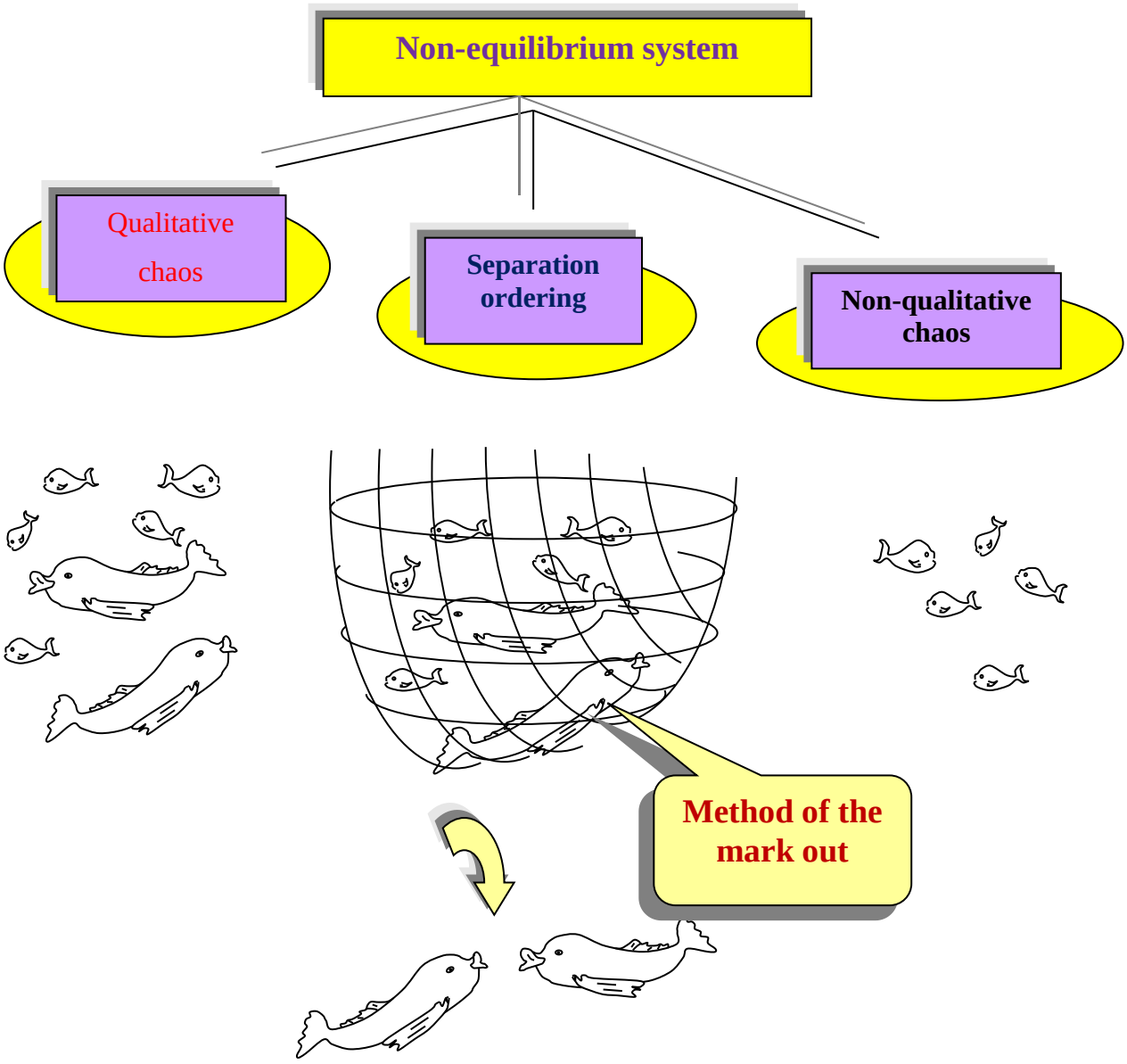


Fig. 2.3.9. Illustration of the separation and transformation of the ordering at action of the external control parameter.

way to the quasi-linear dependence for the systems in the interval of $\tilde{q}$ values under study. Therefore, those properties which are proportional to σ, y_l (e.g., the

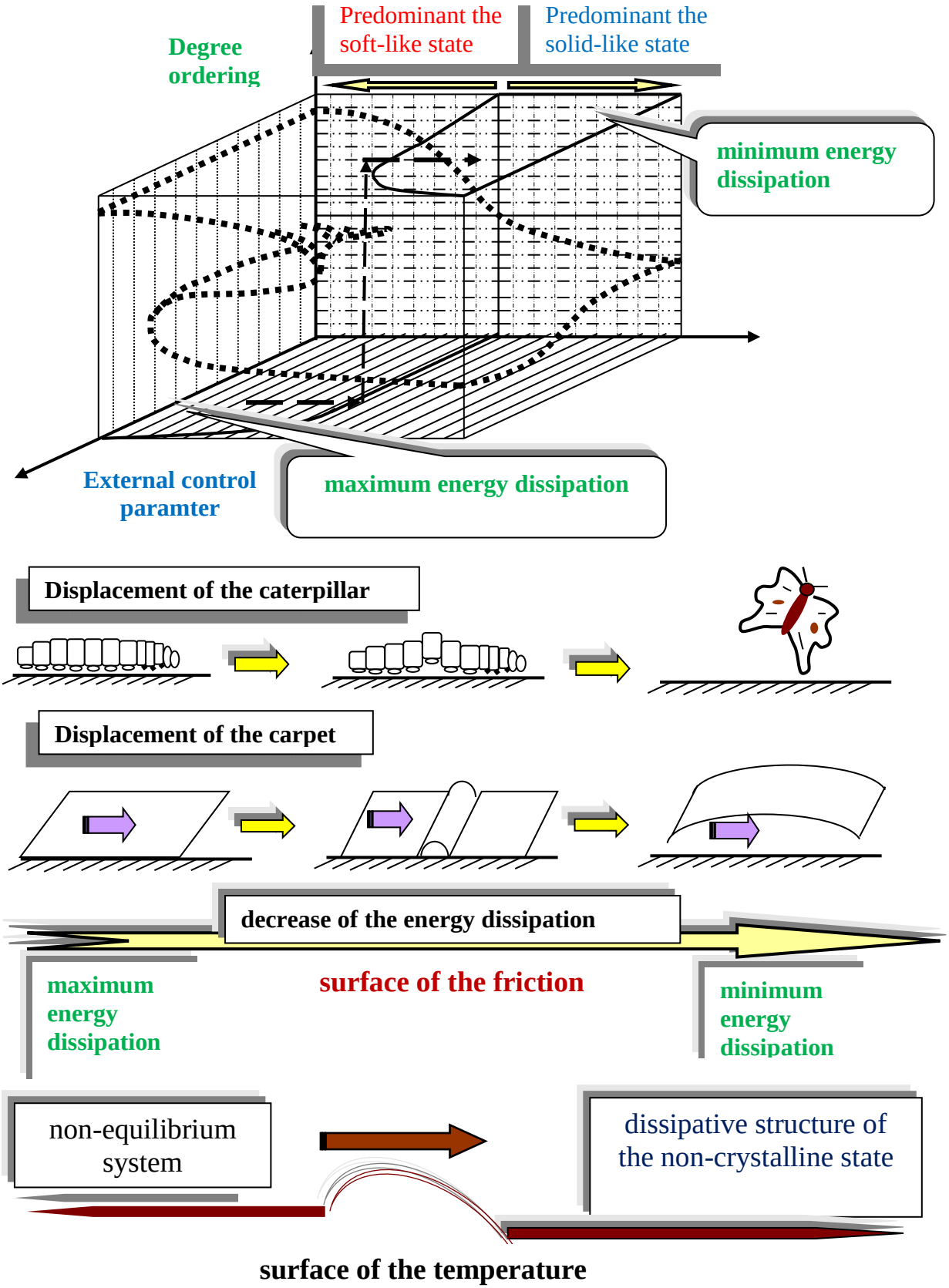


Fig. 2.3.10. Formation of the dissipative structure of the non-crystalline state.

volume of the solid), also undergo the leap at $\tau = \tau_m$, and the properties defined by

the increments $\sigma'(\tau)$, $y_l'(\tau)$, (e.g., the heat expansion coefficient and heat capacity) tend to infinity (Fig. 2.3.11).

It should be noted that the type of dependence of the disordering degree on $\tilde{q}$

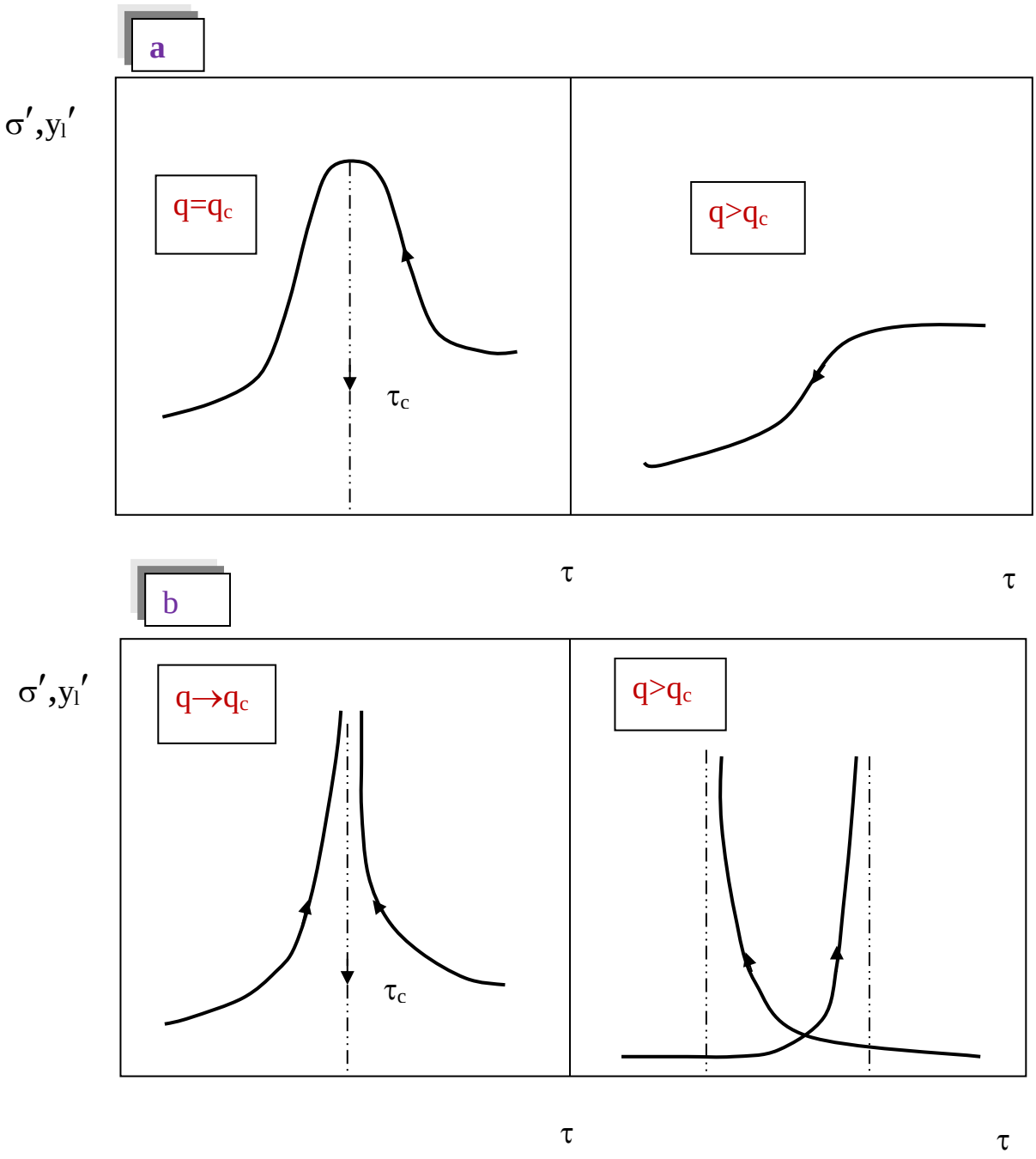


Fig.2.3.11. The temperature dependences σ',y_l' at the transition to the non-crystalline state (a - $q \geq q_c$, b - $q \leq q_c$).

in non-crystalline solids correlates with the variations of the elastic constants $\tilde{f}/f$,

$\tilde{g}/g$ at the given temperature, when they decrease with increasing $\tilde{q}$ and the structure of the material becomes more easily rearranged under the influence of the external factors. This approach allows the temperature behavior of both the microscopic and macroscopic parameters (e.g., volume) to be evaluated quantitatively for the case of cooling. The temperature dependence of the volume reduced to that of the solid at the temperature of synthesis τ_0 is plotted in Fig. 2.3.12. System cooling at low rates $\tilde{q} < \tilde{q}_c$ initiates the spasmodic reduction of v at the transition to the solid state (the volume of the solid-phase state increases slightly with $\tilde{q}$). During cooling in the $\tilde{q} > \tilde{q}_c$ conditions, which prevent the crystallization process, the volume of the solid varies continuously and the value of

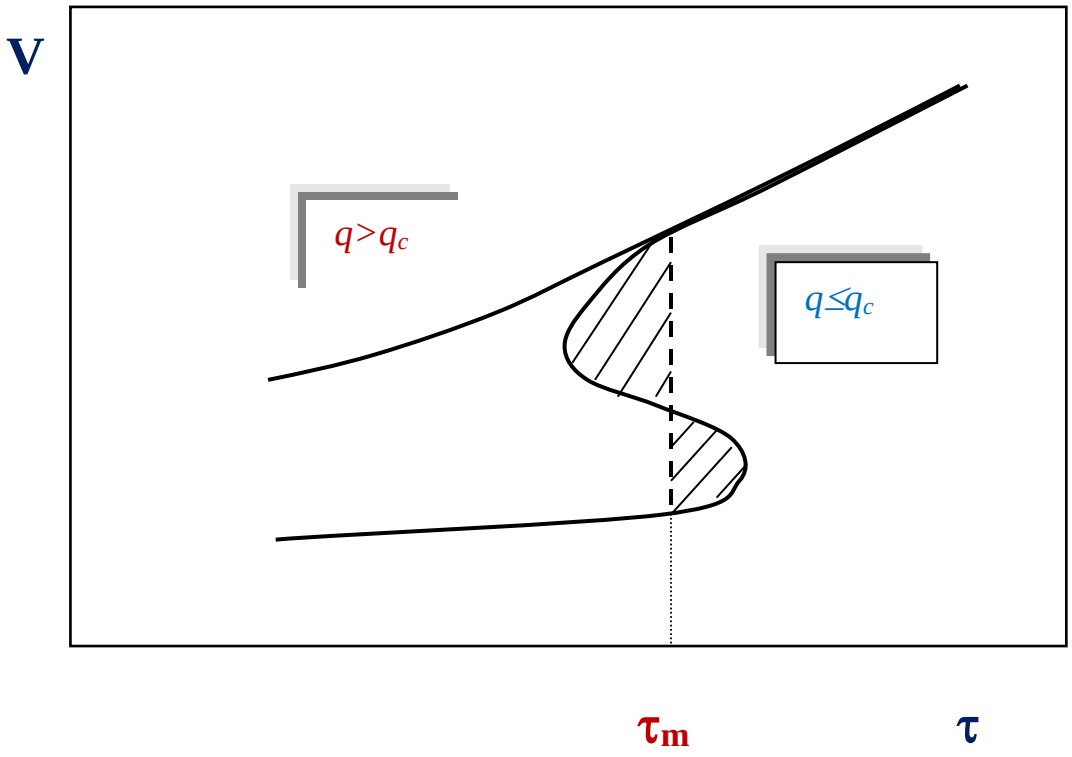


Fig.2.3.12. The temperature dependence of the volume of the non-crystalline solid.

V is determined by the cooling rate. Thus, the peculiarities of the formation of the non-equilibrium stationary state structure depending on the control parameters have been considered within the limits of the present concept.

2.3.3. Bifurcation diagram of the transition to the non-crystalline state

The transition to the non-crystalline state can be considered as the cooperative self-organized process. Indeed, the conditions of the occurrence of self-organized structures are as follows (Mar'yan & Szasz, 2000) :

- the system must be thermodynamically open, i.e. it has to exchange the energy or the matter with environment;
- the state of the system should be far from the thermodynamic equilibrium;
- the structure self-organization has a threshold nature and the behavior of subsystems forming the system must be consistent;
- the dynamical equations of the system are non-linear and stochastic.

Let us analyze how these requirements hold true in the process of non-crystalline structure formation (Mar'yan & Yurkovych, 2015):

- the technological process of melt cooling and vitreous structure formation takes place in the thermodynamically open system, which exchanges the energy with environment;
- the glass is produced in the system far away from the equilibrium state (melt). The degree of the displacement can be defined by the order parameter calculated as the deviation of a fraction of atoms in the soft configurations of the system (amplitudes of dynamic displacements or force constants) from the corresponding values for the equilibrium state;
- non-crystalline material formation has a threshold character over the dynamic displacement amplitudes and the fraction of atoms in the soft configurations; these materials are produced only at the certain control parameter values (for example, the cooling rate);

- during the glass formation the self-consistent interaction of different subsystems takes place that governs the non-linearity of the system behavior. A glass as a synergetic system offers a stochasticity, i.e. the time evolution of the system depends on the reasons not predicted with absolute accuracy;
- a non-crystalline structures produced from the melt is more ordered structure as compared with the initial (melt) state (the spatial-temporal correlation of the motion of atoms and their groups is considerably larger).

The choice of the mathematical model of the dynamical object is reduced to the construction of differential equations. The model of the non-linear dynamical system can also be constructed in a class of non-linear algebraic functions (see Appendix A). The behavior of the dynamical system in some cases is described by the first-order differential equation:

$$\frac{\partial \vec{\eta}}{\partial t} = \vec{\Phi}(\vec{\eta}),\ \vec{\eta}(0) = \vec{\eta}_0, \qquad (2.3.2)$$

where $\vec{\eta} = \{\eta_1, \eta_2, ..., \eta_n\}$ is the n-dimensional vector with the components $\eta_1, \eta_2, ..., \eta_n$, $\vec{\Phi}(\vec{\eta})$ is the non-linear function of the state. The points $\vec{\eta}_s$, for which the right side $\vec{\Phi}(\vec{\eta})$ of equation (2.3.2) equals to zero, i.e. $\vec{\Phi}(\vec{\eta}) = 0$ .The state can be both stable and unstable. The notion of the stability of the dynamic system is of great importance and may be considered as one of the basic concepts. In particular, the character of the evolution of the system from the stationary state depends considerably on the type of this state, i.e. the stable or unstable state. For the case of the unstable state, the system can be flung away from the stationary state even due to extremely small deviations from the initial state, and either the motion becomes chaotic or the system transits to the other stationary state.

The system is in the stable state $\vec{\eta}$ if even at slight deviations from it the system remains close to $\vec{\eta}_s$ for any t. In the mathematical language, this statement

is written as follows. Let the system (2.3.2) at a certain moment of time t be in the state $\vec{\eta}(t)$ close to the state: $\vec{\eta}(t)=\vec{\eta}_s(t)+\vec{\xi}(t)$, where $\vec{\xi}(t)$ is negligibly small as compared with $\vec{\xi}_s$. Let us represent solutions as: $\vec{\xi}(t)=\mathrm{A}\exp(\lambda t)$ (A is amplitude).

The eigenvalues λ of the matrix are defined from the relation:

$$\det\left|a_{jk}-\lambda\delta_{jk}\right|=0, \qquad (2.3.3)$$

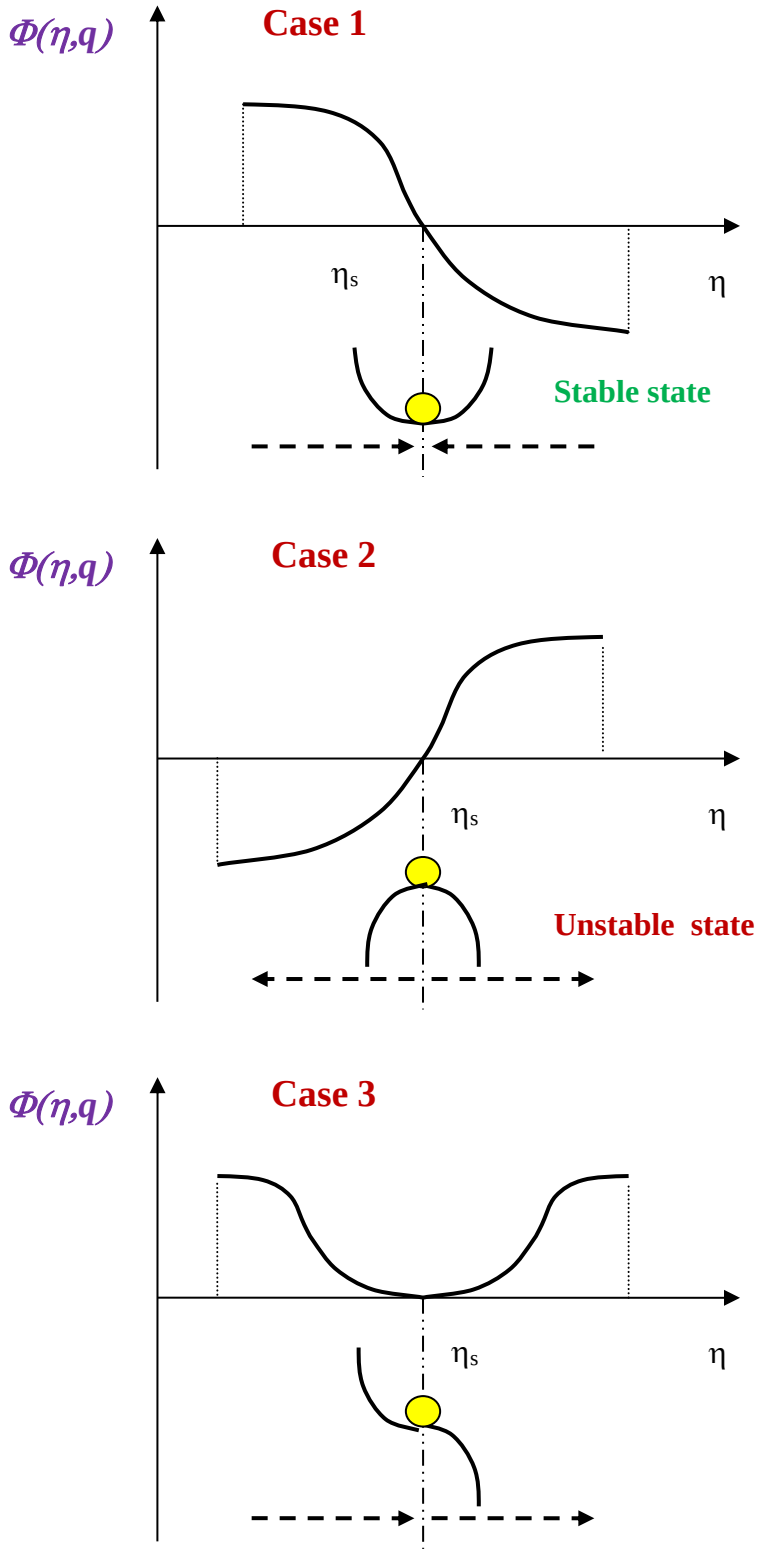
which is called the characteristic equation, where δ_{jk} is the Kronecker's symbol. The Lyuapunov's theory states that if all eigenvalues λ of the matrix $a_{jk}=\left(\partial\Phi_j/\partial\eta_k\right)_{\eta_s}$ obey the inequality: $\mathrm{Re}\,\lambda<0,$ then the state $\vec{\eta}_s$ is stable. If among all eigenvalues λ the only one exists that: $\mathrm{Re}\,\lambda>0,$ then the singular point $\vec{\eta}_s$ of the system (2.3.2) is unstable.

The behavior of $\Phi(\eta)$ close to η_s in the one-dimensional case: since $\Phi(\eta_s)=0$, three cases appear to be possible (see Fig. 2.3.13). Based on the aforementioned we shall analyze the peculiarities of the qualitative variation of the system under the control parameter (i.e. the melt cooling rate) variation. Let us rewrite the equation of motion for the order parameter η in the following form:

$$\frac{\partial\eta}{\partial t}=\Phi(\eta,\tilde{q}),\ \Phi(\eta,\tilde{q})=a_0\tilde{q}\,\eta-c\eta^2-b\eta^3. \qquad (2.3.4)$$

Here we assume that $a=a_0\tilde{q}$, and this holds in the vicinity of $\tilde{q}_c$, b and c are the constants, $\Phi(\eta,\tilde{q})$ is a non-linear function; for large $\tilde{q}$ we can use the approximation $a=a_0\arctan\left(\ln\{1+\tilde{q}\}\right)$ (Mar'yan, 1998) . The characteristic equation for the asymptotically stable stationary states has a form:

$$\overline{\Phi}(\eta,\tilde{q})=0,\ \overline{\Phi}'_\eta(\eta,\tilde{q})<0,\ \ \overline{\Phi}'_\eta(\eta,\tilde{q}) \text{ is the first derivative .} \qquad (2.3.5)$$



Function Φ(η,q) changes its sign close to η_s (from "+" to "–"). Here $\Phi'_\eta(\eta,q)<0$, i.e. the function decreases with η.

Function Φ(η,q) changes its sign close to η_s (from "–" to "+"). Here $\Phi'_\eta(\eta,q)>0$, i.e. the function increases with η.

Function Φ(η,q) does not change its sign close to η_s with increasing η. Here $\Phi'_\eta(\eta,q)=0$. This means that the illustrative point located rather close to η_s on one side will approach it, while this point being located on the other side will move away.

Fig. 2.3.13. Possible cases of the behavior of the function Φ(η,q).

The inequality in (2.3.4) is the condition for the stability of the Lyapunov's solution of equation (2.3.5). The values $\eta \geq 0$ have the physical sense for the solid-phase state, since only these values correspond to the real amplitudes of stationary solutions. From (2.3.4) it is obvious that in the $\{\eta, q\}$ plane the bifurcation diagram is transformed into a straight line $\eta = 0$ and the second-order curve:

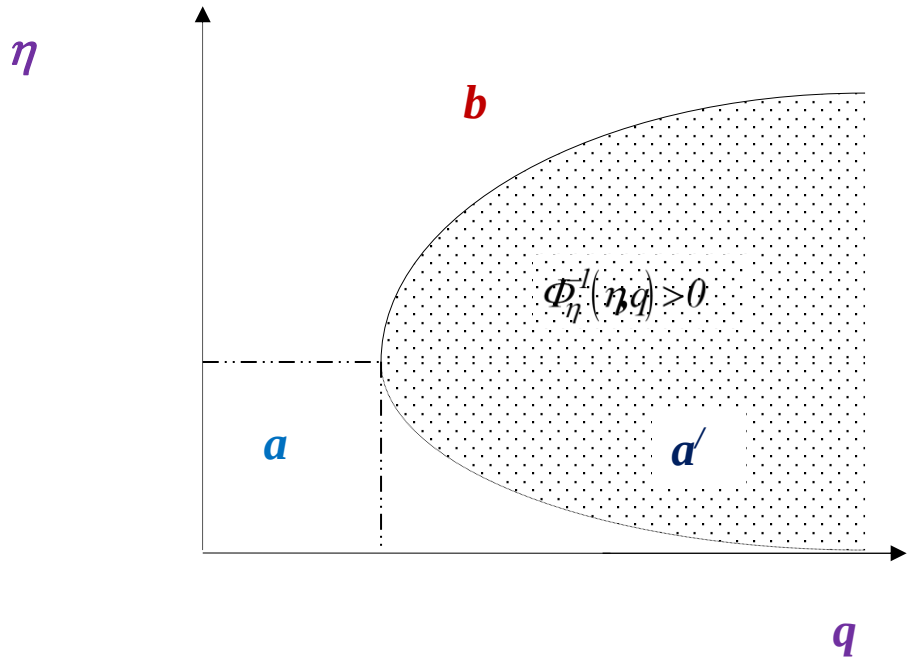


Fig.2.3.14. Branching of the solutions of the characteristic equation (a- stable part of the state; a′ - an unstable part of the equilibrium state; b- a non-equilibrium stationary state).

$$a_0\tilde{q} - c\eta - b\eta^2 = 0. \qquad (2.3.6)$$

Two bifurcation values of the parameter $\tilde{q}$ exist for the problem under consideration:

$$\tilde{q}_1 = \frac{-c^2}{4a_0 b},\ \tilde{q}_2 = 0. \qquad (2.3.7)$$

At $\tilde{q} < \tilde{q}_1$, the equation has a sole stable root $\eta = 0$ $\left(\overline{\Phi}'_\eta(\eta, \tilde{q})_{\eta=0} = a_0\tilde{q} < 0\right)$, which corresponds to the stable focus (Fig. 2.3.14). When $\tilde{q}$ passes the bifurcation value, a couple of nonzero solutions arise (the boundary cycles, whose radii are $\eta = |c| + \frac{\sqrt{c^2 + 4a_0\tilde{q}b}}{2b}$ and $\eta = |c| - \frac{\sqrt{c^2 + 4a_0\tilde{q}b}}{2b}$). One of these cycles (with larger radius, the upper branch *b*, Fig. 2.3.14) is stable $\left(\overline{\Phi}'_\eta(\eta, \tilde{q}) \le 0\right)$, whereas the second one (with smaller radius η, *b′* branch, Fig. 2.3.14) is unstable $\left(\overline{\Phi}'_\eta(\eta, \tilde{q}) > 0\right)$. The character of the singular point $\eta = 0$ is not changed in this case. A stable cycle increases with $\tilde{q}$, while an unstable one decreases. At the second value of bifurcation parameter $\tilde{q} = 0$, an unstable cycle vanishes merging with the singular point, which becomes unstable as $\tilde{q} > 0$ $\left(\overline{\Phi}'_\eta(\eta, \tilde{q})_{\eta=0} > 0\right)$.

Thus, at low melt cooling rates $(\tilde{q} < 0)$ the dynamic equation has a sole solution, which corresponds to the crystalline state asymptotically stable at $t \to \infty$. At the cooling rates above the critical velocity $(\tilde{q} > \tilde{q}_1)$ the solution that belongs to the branch *a* is bifurcated (i.e. it becomes unstable with respect to the fluctuations of dynamic displacements of atoms and the fraction of atoms in the soft configurations), and the system tends to the stationary non-crystalline state (branch *b*, Fig. 2.3.15) with the spasmodic change of the order parameter η at the microscopic level. If the melt is cooled with the rate of $\tilde{q}_1 < \tilde{q} < \tilde{q}_2$, then, to ensure the development of the system towards the non-crystalline state, one has to create a certain non-equilibrium in this system (e.g., induced by annealing or irradiation), at which the deviation of the equilibrium state η will exceed the distance from an unstable branch (Fig. 2.3.15). The result obtained, i.e. the possibility of the occurrence of at least two stable states differing in the order parameter values, η, in the non-crystalline material at the same control parameter, temperature or pressure, is a measure of the dependence of the final state of the non-equilibrium system on the method of production, i.e. on the system prehistory.

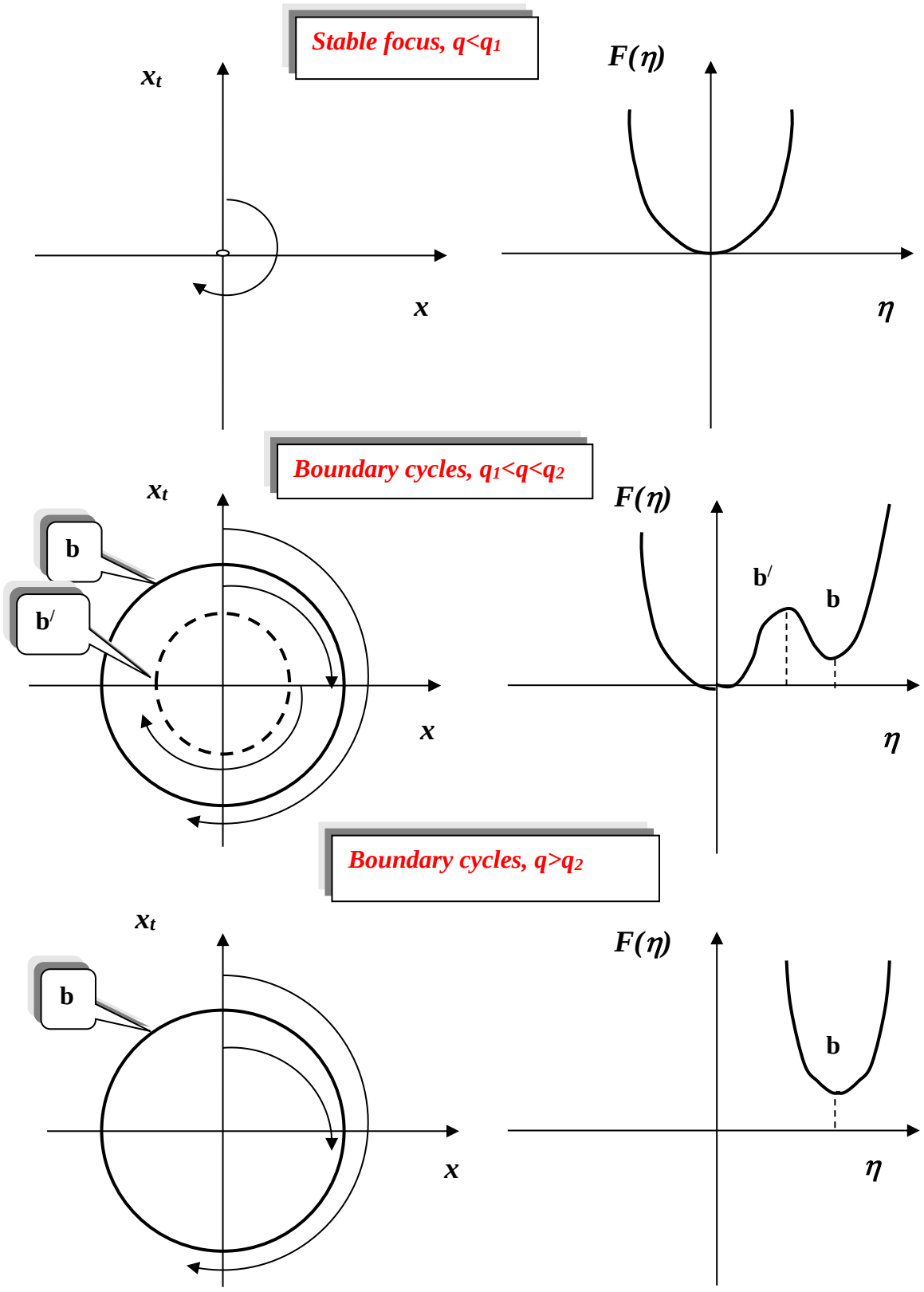


Fig. 2.3.15. Dependence of the parameter of Lyapunov's functional deviation from the equilibrium state in the vicinity of different bifurcation points.

The equation of motion for the order parameter $\partial F/\partial \eta = -\gamma\, \partial \eta/\partial t$ (γ is

constant) allows the Lyapunov's functional to be determined:

$$F(t)-F(0)=-q^2\int_0^t\left(\frac{\partial\eta}{\partial T}\right)^2 dt, \qquad (2.3.8)$$

where the allowance was made for $q=dT/dt$. The multistability phenomenon is observed, i.e. the spatial distribution of η, which corresponds to one of the minima of F, is set depending on the initial conditions and the control parameter. Typical time dependences of Lyapunov's functional at $x=\eta\cos t$, $\dot{x}=-\eta\sin t$ (t is the time) in the vicinity of the stationary solutions η are presented in Fig. 2.2.15.

Given the instability chain, the number of paths to the different states and corresponding dissipative structures increases sharply. The choice of the path is arbitrary, but the non-equilibrium system memorizes this choice. Possible bifurcation cascades and the transitions to the stationary non-equilibrium structures are shown qualitatively in Fig. 2.3.16. At $\tilde{q}<\tilde{q}_1$, only one stationary state exists for any $\tilde{q}$. For $\tilde{q}=\tilde{q}_1$ at any $\tilde{q}$, the primary bifurcation occurs, i.e. those states, which belong to the branch *a* , become unstable, whereas two other solutions (branches *b* and *b′*) appear to be possible. At $\tilde{q}<\tilde{q}_3$, the branch *b* becomes unstable and two other stable branches (*c* and *c′*) arise, and so on. That situation may occur, for instance, when the time dependence of the cooling rate is varied during the cooling process.

Consider the influence of non-locality of the system order parameter η distribution. In that case equation (2.3.8) assumes the form:

$$\frac{\partial\eta}{\partial t}=a_0\arctan(\ln(1+\tilde{q}))\eta-c\eta^2-b\eta^3+D\Delta\eta. \qquad (2.3.9)$$

Here D is the diffusion coefficient, Δ is a Laplacian which describes the diffusion-type non-locality. Equation (2.3.9) is solved in the closed confined domains with the continuous flux across the boundary, i.e. the boundary conditions are as follows:

$$\left(\frac{\partial \eta}{\partial r}\right)_{r=r_0} = 0,$$

where r is the spatial coordinate.

Let us identify the homogeneous stationary solutions of the system, $\eta_s(\tilde{q})$, with the thermodynamic branch of the system evolution in the bifurcation diagram

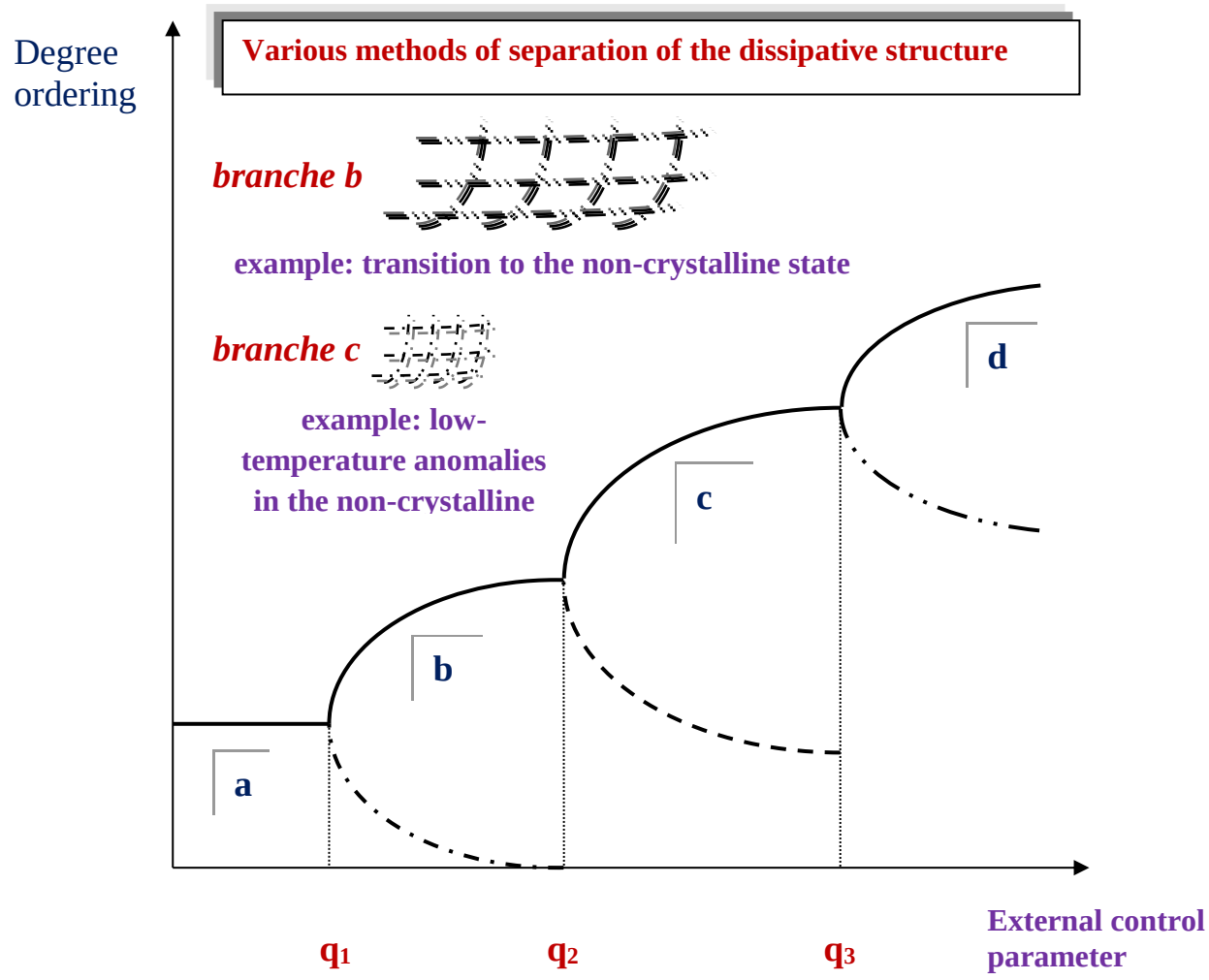


Fig. 2.3.16. The bifurcation cascade in the non-crystalline state.

(2.3.9). To clarify the stability we shall consider small perturbations of the thermodynamic branch of solutions:

$$\eta(r,t)=\eta_s+\delta\eta(r,t), \qquad (2.3.10)$$

where $\delta\eta(r,t)$ describes the deviation of the system from the homogeneous stationary state η_s due to the random fluctuations $\delta\eta(r,t)<<1$.

Let us specify $\delta\eta(r,t)$ in a form of the expansion into a Fourier series:

$$\delta\eta(r,t)=\sum_k \mathbb{A}\exp\{ikr+\lambda t\}. \qquad (2.3.11)$$

Here $\mathbb{A}$ is an amplitude of the mode with the wave-vector k and the damping decrement λ.

Substituting (2.3.10) into (2.3.11) and linearizing over the small parameter $\delta\eta(r,t)$, with the allowance made for (2.3.9), we obtain the dispersion equation which binds the decrement with the wave-vector:

$$\lambda=\lambda(k,\tilde{q}),\ \lambda(k,\tilde{q})=-a_0\arctan(\ln(1+\tilde{q}))+2c\eta_s+2b\eta_s^2-Dk^2. \qquad (2.3.12)$$

For $k^2<k_c^2=\left((-a_0\arctan(\ln(1+\tilde{q})))/D\right)$ the damping decrement is $\lambda(k,\tilde{q})>0$ indicating that the mode with the wave-vector k diverges (Mar'yan, 1998).

Let us make some essential remarks. The mathematical theory of stability of the solutions of differential equations used here starts from the Lyapunov's theory of stability. Several criteria exist being sufficient to warrant (or not warrant) the asymptotic stability of the stationary state. One of these criteria is based on the analysis of the stability over the linear approximation, while the other one starts

from the Lyapunov's function concept. The analysis of the stability over the linear approximation in the problem under consideration allows one to determine the stability (or instability) of the solutions linearized in the vicinity of the stationary state to which the homogeneous solutions η_s correspond. The instability of the solutions of the linearized equation is sufficient for the stability of the total non-linear equation. Hence it follows that one may restrict oneself to the finite-order terms in the expansion of functions $\eta(r,t)$. By virtue of the last assumption we shall confine ourselves to the infinitesimal stability, i.e. to the study of the system response to small perturbations, so that $\partial\eta/\eta_s << 1$. That restriction is unessential, since the infinitesimal stability provides the necessary condition for instability with respect to any $\eta(r,t)$. Though in this case the solution of the non-linear equation

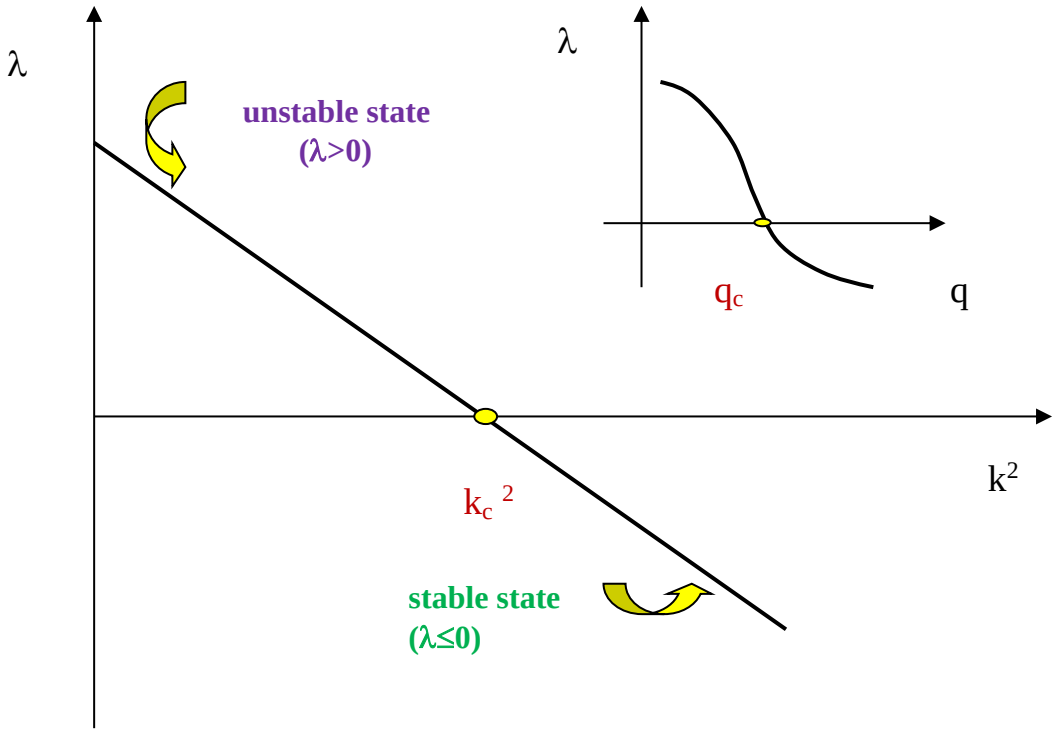


Fig. 2.3.17. The dependence of the damping decrement λ on k^2.

may also increase exponentially with time, in the presence of non-linear terms they will tend towards another stationary state with the heterogeneous distribution of domains in the "soft" states.

Beyond that point, solutions η_s remain constant on the macroscopic scale under consideration with simultaneous slow time variation on the instability development scale. The condition of the slow time variation of the $\lambda_s^{-1} \frac{\partial \lambda}{\partial t} << \lambda$ type, which is reduced to the condition of slight variation of the function λ on the scale, is imposed on the function λ_s^{-1} (an adiabatic approximation). The period and the life-time of the dissipative structure produced depend on the control parameter $\tilde{q}$. At $\tilde{q} \to \infty$, $L_c = \frac{2\pi}{k_c} \to const$ and $\tau_{life} = \frac{1}{\lambda(\tilde{q}, k)} \to const$ (see Fig. 2.3.17).

The synergetics exposition combines the studies of the non-crystalline system as a whole and those of its separate parts at different levels. It makes a bridge between them by two levels of description, due to their coordination and self-consistent determination. Therefore, the non-crystalline system acquires the properties, not inherent in its separate parts (liquid-like states, crystal-like states). Thus, the macroscopic manifestations of the processes occurring at the microscopic level arise "independently", due to self-organization (Mar'yan & Szasz, 2000). The self-organization is born by the system itself as a result of a loss of stability of the state (Fig. 2.3.16). Therefore, self-organization is reduced to the selection among the non-crystalline systems, potentially possessing a great number of degrees of freedom at a small number of order parameters η_i defining the dynamics of the whole system. A small amount of order parameters and scarce possibilities, which they reflect in defining separate states, testify to the fact, that in compound systems only a few structures are possible and available being consistent through a combined action of the elements (see Fig. 2.3.5–2.3.7).

The complicated structural formations in the non-crystalline materials are simultaneously both determinate and stochastic, i.e. they exhibit a dualism of determinate and stochastic. In synergetics exposition of the non-crystalline states, there is nothing predetermined – except the structures and systems, which at a loss of stability can give rise to some new states. The system becomes unpredictable by

virtue of its nonlocal properties, such as complexity, non-linearity, openness, non-equilibrium. At a point of a loss of stability the new functioning mechanisms with new parameters are self-organized. It should be noted, that the parameters of the state do not disappear – they remain, but in cases related to the self-organization the system selects the order parameters itself. Even when the separate elements of the system have a complex internal structure, all their internal complexity is not revealed in their mutual interaction, and, from the point of view of a macro system, they function as simple enough objects with a small number of effective degrees of freedom.

It should be noted that it is possible to describe more or less adequately self-organizing phenomena at one level. The chaos at one level (the short-range order) leads to the structuration at the other level (the media-range order). This approach is one of the basic in synergetics exposition of the non-crystalline media. The thermal oscillations and diffusion act as the chaos at the micro level. However, for the self-organizing non-crystalline systems of organic and inorganic origin this process plays a principal role in the formation of ordering at the media-range level order. The chaos at one level results in the self-organization and appearance of an order parameter at the other level (spatial or temporary). The systems behave in a chaotic manner, however at the particular stages of the process or at some characteristic moments they result in the appearance of the formations, for which the structural representation is adequate. Such structures can be considered as those of the next level with their definite functioning parameters (Mar'yan & Szasz, 2008). At the next level the ordering may arise again, and so on.

2.4. Fractal peculiarities of the non-crystalline state

A peculiarity of the simplest dynamical systems to change qualitatively the character of their motion at the transition from the regular to random at slight

variation of some external parameter is such an unusual one that all possible regularities of rearrangement occurring in this case should be clarified only by studying the fundamental properties of non-linear dynamics.

The dimensional properties of these systems create new characteristics. They have their origins in the notion of fractals inherent in a wide circle of natural objects. Fractals are used to describe the irregular forms in such physical systems as non-crystalline materials, porous solids and polymers. These systems can be called the rarefied or branched objects, and their shape is one of the most intriguing geometric properties.

The concept of fractals has been introduced first by Maldelbrot (Frame & Mandelbrot, 2002). The fractal dimensionality d_f is used as the quantitative measure of structurally of these objects. Consider first a spherical object of mass M and radius R. They are related by the following expression:

$$M(R) = R^d, \qquad (2.4.1)$$

where d is the space dimensionality, which we usually work with (the dimensionality of a straight line is $d = 1$, that for the surface is $d = 2$, etc.). For many cases we cannot be satisfied by this definition, since there exist some curves which are hard to be distinguished from the surface. The trajectory of the Brownian particle is a simple example (Fig. 2.4.1). For small intervals of investigation time, $d = 1$. At the same time the larger is the observation time, the larger is the number of trajectories filling the surface. The question arises here whether it is possible to indicate some topological characteristics of the complexity degree of the particle trajectory in the phase space. This gives us the tool which distinguishes the chaotic degree of the motion by the shape of its trajectory. This problem is especially essential in those cases, when the chaos is evoked by the regular interactions in the dynamic systems, since just in that case we meet the variety of transient states of motion from regular to stochastic (Appendix B).

The object, whose mass and size obey the relation (2.4.1), is called a compact object. In this case the scale relation for the density $\rho = M / R^d$ has a form

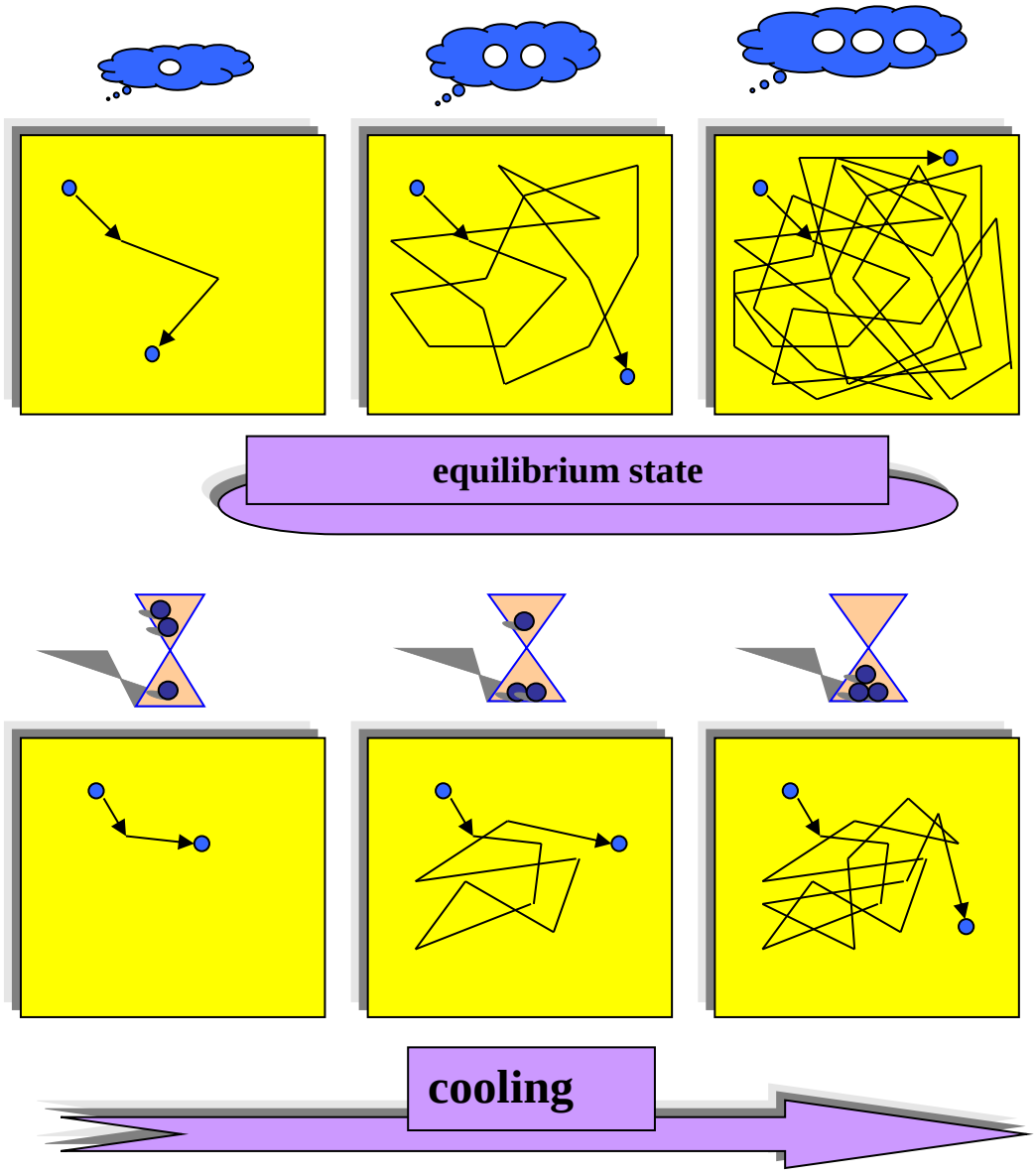


Fig. 2.4.1. Trajectory of Brownian particle and stochastic fractals.

$\rho = R^0$. The relation between mass and a specific size of the object can be defined in a more general form:

$$M(R) = R^{d_f} . \qquad (2.4.2)$$

The object is called fractal if it obeys the relation (2.4.2) with d_f, other than the space dimensionality d. In this case the density is not the same for all R and is scaled as:

$$\rho(R) = (M/R)^{d_f} = R^{d_f - d} \quad . \qquad (2.4.3)$$

Since $d_f < d$, the density decreases with size. This relation is a quantitative measure of the notion that fractals are the rarefied or branched structures. The meaning of equation (2.4.3) is that the fractal objects are self-similar, i.e. they look similarly in any spatial scale.

In case of Brownian motion at the surface the numerical analysis shows that $d_f \neq 2$, whereas $d = 1$. Thus, fractals can be regular (e.g., the Koch's curve) and stochastic (for instance, the Brownian motion trajectory, Fig. 2.4.1).

For all cases, $d_f > d$, which corresponds to a certain physical sense and just features the complication of multitudes. If this is a curve ($d = 1$), then it can be complicated by an infinite number of bindings to the point, where its fractal dimensionality reaches two for the case, when it tightly covers the finite plane, or three, if the curve fills the cube.

It should be noted that the example with Brownian motion testifies that the chaos described by the dynamical equations is essentially fractal. Its fractal character results first of all from that property of trajectories, which transforms them from regular or periodic to stochastic ones. Indeed, if the regular trajectory has a $d = 1$ dimensionality, then the local instability complicates the trajectory making it more and more cumbersome and unpredictable.

A considerable attention has been drawn recently to the studies of relaxation processes in non-crystalline condensed media. This is primarily due to the experimental fact that in numerous systems the time dependence of correlation functions $F(t)$ is governed by the Kohlrausch's exponential law:

$$F(t) = \exp(-t/\tau)^{\beta}, \quad 0 < \beta < 1. \qquad (2.4.4)$$

Parameters β and τ depend on the material and may be the functions of external variables, e.g. temperature or pressure. The relation (2.4.4) describes a number of interesting processes in disordered systems, energy transfer in condensed molecular media, electron and hole transfer in disordered semiconductors, diffusion in porous materials.

Consider the methods of simulating these objects by fractal structures taking into account both the spatial and time disorder. It should be noted that the time inhomogeneity being related, for example, to the random location of doping molecules in a matrix or with that of atoms in amorphous semiconductors, results in that the microscopic transition velocity range appears to be quite wide: the spatial disorder causes the temporal and, sometimes, energy disorder. This complicated situation cannot be described analytically. One has to develop the models like fractals considered below.

Let us analyze the space and time correlations.

Self-similarity is the basic feature of the fractals, i.e. each separate object or ensemble of objects possesses invariance with respect to the group of scale transformations. Consider the excitation damping law for the chosen donor located at the origin of coordinates due to the direct energy transfer to the defects located at the sites R with the preset structure. The relaxation function, i.e. the possibility of donor to reside in the excited state within the time interval t, is:

$$F_i(t) = \exp(-t/W(R_i)), \qquad (2.4.5)$$

where $W(R_i)$ is the relaxation rate that defines the relaxation time $\tau_i = 1/W(R_i)$. For a fixed configuration of a number of defects located at the sites R_i we have:

$$F_{\{R_i\}} = \prod_{i=1} \exp(-tW(R_i)) . \qquad (2.4.6)$$

Let us average (2.4.6) over all possible defect configurations. For the case, when the defects are located randomly and the possibility of the given site to be occupied by the defect is exactly equal to p, one may write:

$$F(t) = \prod_{i=1} (1-p) + p\exp(-tW(R_i)) , \qquad (2.4.7)$$

that for $p << 1$ gives:

$$F(t) = \exp\{-p\sum(1-\exp(-tW(R_i))\} . \qquad (2.4.8)$$

Taking into account that the site density is:

$$\rho(R) = \sum_i \delta(R - R_i) \qquad . \qquad (2.4.9)$$

We shall convert the sum into the integral:

$$F(t) = \exp\{-p\int dR\rho(R)(1-\exp(-t/W(R\ ))\} . \qquad (2.4.10)$$

If $\rho(R) = const$ and the interaction is described by the relation

$$W(R) = aR^{-s_F} , \qquad (s_F \geq 6 \text{ is the Forster constant }) \qquad (2.4.11)$$

we obtain:

$$F(t) = \exp((-t/d)^{d/s_F}) , \qquad (2.4.12)$$

(d is the space dimensionality).

Non-exponential damping results from the parallel relaxation processes and from the existence of the distance hierarchy. To generalize this result to the case of the transfer along the fractal structure with the fractal dimensionality d, one has to substitute d_f for d. For the non-crystalline matter in the synergetics approach adequate are consideration of fractal structures regular fractals and stochastic fractals.

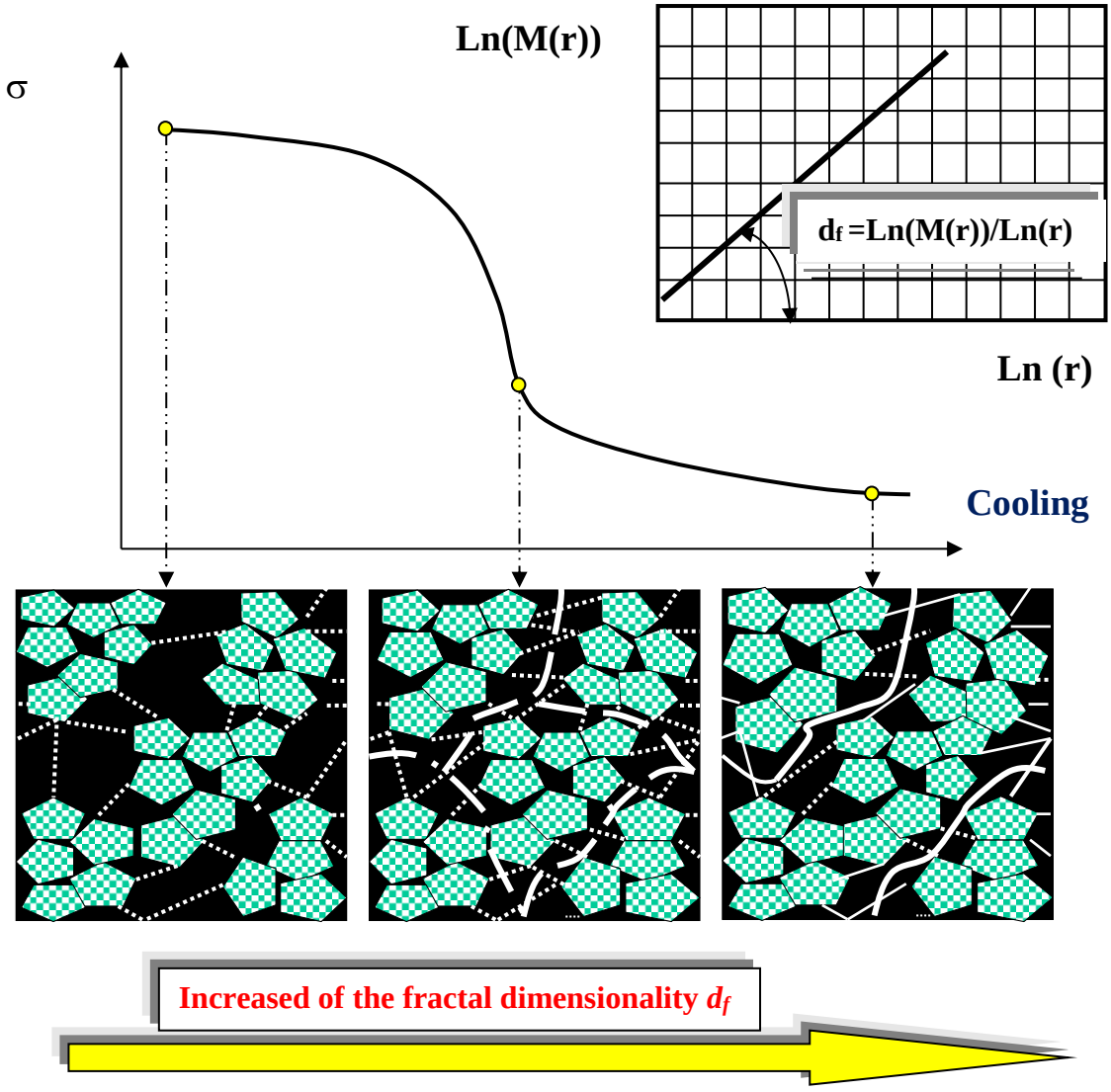


Fig. 2.4.2. The fractal dimensionality d_f at transition to the non-crystalline state.

A convenient image of non-crystalline state are the fractal structures (Fig. 2.4.2). The term "fractal structures" is widely used for the description of self-organization in the energy, mass, and information – open systems, since in this case in the non-crystalline states tasks we do not deal with unstructured random processes, but just with the results of self-organization, i.e. the formation of dissipative structures. The complicated structural formations in the non-crystalline materials are simultaneously both regular fractals and stochastic fractals, i.e. they exhibit a dualism of regular and stochastic fractals (Fig. 2.4.3). The regular fractals are shown in self-similar of “soft” states of non-crystalline materials. Stochastic fractal consists in allocation of the ordered thermal displacements during effect of external control parameters at formation of the non-crystalline materials.

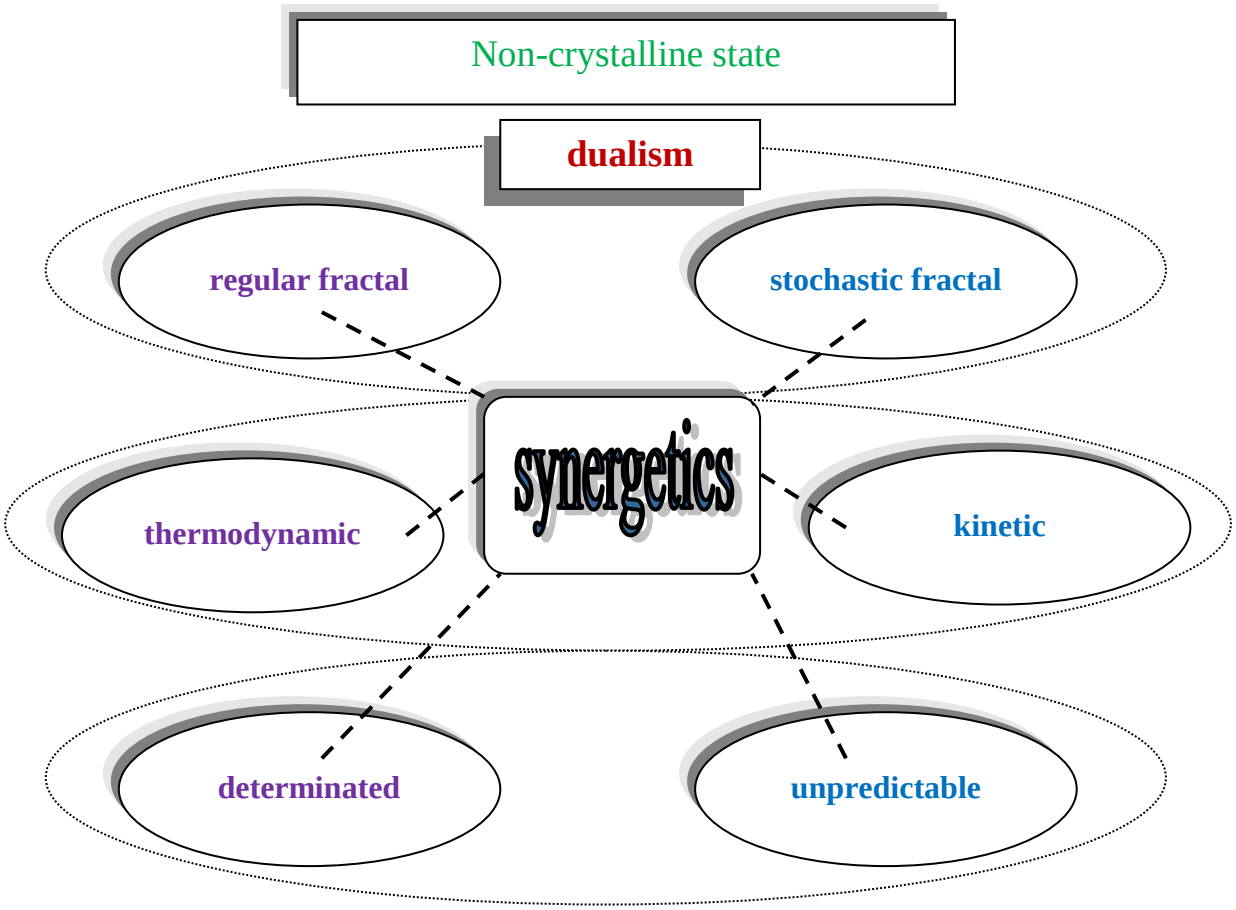


Fig. 2.4.3. Demonstration of the synergetics in the non-crystalline state.

III. FRACTAL APPROACH AND COMPUTER MODELING TO TEACHING NATURAL SCIENCES

In Section 2, we analyzed the peculiarities of the formation of dissipative structures in the non-crystalline states, the different levels of ordering and the transition between them in the flow of energy and information. The uniqueness and beauty of synergetics manifests itself in the integrity of the results obtained and the possibility of their application to radically new areas, in particular, information technologies, teaching of educational sciences. In this section, we will focus our attention on this particular branch of branching out, their bifurcation and stability, synergy and fractality in the teaching of natural sciences. As we shall see in the synergetics there are no void and contradictions, division - the functions and actions are finally functioning and open, creating a symbiosis of knowledge and practical implementation.

The present chapter considered and appraises the fractal approach to teaching physics, mathematics and technics using computer modeling in the environment of the object-oriented programming, Delphi. It manifests the formation of a fractal structure and the corresponding iteration, reflecting the integrity and spontaneity of information perception. The chapter elaborates the iteration of the fractal structure on the example of studying physics sections, “Geometric optics,” and “Wave optics”. Each iteration (section of physics) is characterized by a synergy - adding new iteration provides a qualitative perception of the information. The possibility of using this approach in other sections of physics, and research fields related to physics has been demonstrated.

Innovative teaching of physics and computer modeling of natural phenomena, as well as the application of these methods by teachers, are the focus of special attention in scientific literature (Christian & Esquembre, 2007; Potter &

Peck,1989; Sladek, Pawera & Valek, 2011). However, special training of future physics teachers on numerical modeling of physical phenomena; bibliographic data in the pedagogical literature, as well as in educational practice are encountered less often. For example, the curriculum of training future teachers of physics in all five Slovakian universities does not contain this subject. Students and future teachers can get acquainted with the problem of computer modeling of physical phenomena while studying special subjects such as “Digital technologies in teaching physics”, “Computer Information Technologies in physics” (http://www.fpv.umb.sk/katedry/katedra-fyziky/studium/bakalarske-studium/). A similar situation with mastering these methods is observed in other universities.

In the process of teaching physics, attention is focused on a significant amount of material and its unstructured character (Özcan, 2015; Hodson, 2014; De Cock, 2012; Fojtík, 2013), insufficient relationship and correlation with other disciplines (Hestenes, 2010; Huffman, 1997) and practical application (Reif & Heller, 1982). It points to the need for information perception in higher educational establishments, especially in teaching physics at an intuitive level, using visualization means, modern advances in programming – object-oriented programming.

The aim of which the investigation was the implementation of the educational experiment based on the positive impact of the applied measures aimed at creating the optimal object of professional competence of future physics teachers. The study objective was to determine the impact of implementing innovative approaches on the willingness and interest of future physics teachers to independently conduct computer simulations of physical phenomena.

3.1. Investigation methodology: methods used

There is a relationship between the different branches of physics and among its very sections that can be demonstrated using a fractal approach (Mar’yan &

Yurkovych, 2015). This means that in teaching one of the sections (subsections), an algorithm can be determined that is produced and realized in the following sections and, thus, a complex structure is formed while maintaining the integrity of material perception using computer modeling. This approach is tested in teaching electromagnetic phenomena in the sections of physics, “geometrical optics,” and “wave optics.”

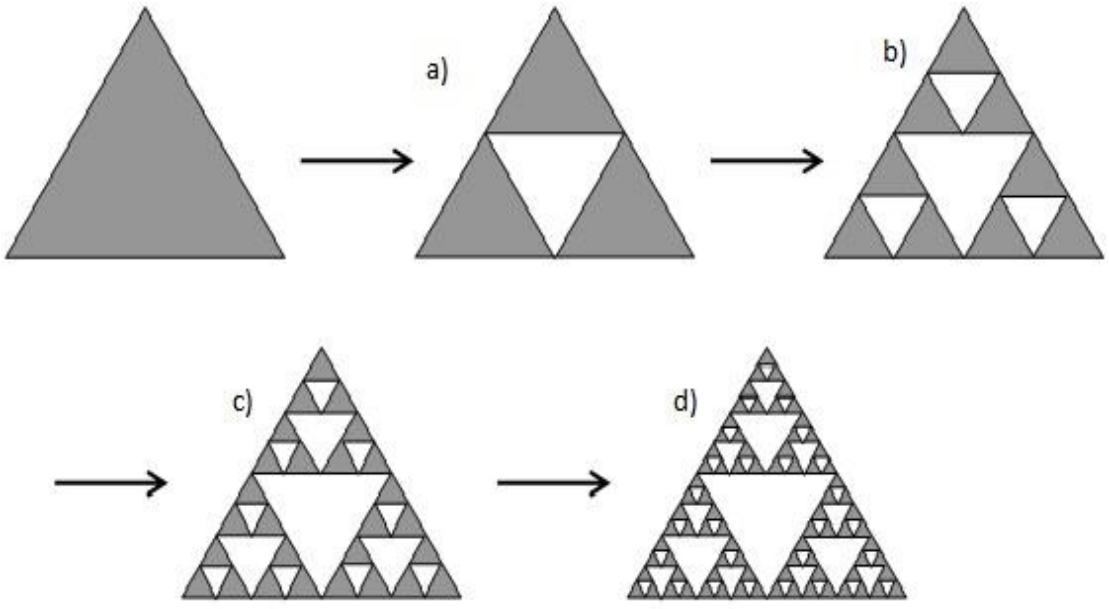


Fig. 3.1.1. Fractal — the Sierpinsky’s carpet (Falconer, 2003).

A fractal is a branched or dispersed structure, whose dimension is different from that of an integer (Falconer, 2003). There are geometric, algebraic and stochastic fractals (Frame & Mandelbrot, 2002), applied in various fields of physics in modeling of non-linear processes, such as turbulent fluid flow, diffusion processes, plasma, porous materials (Shuster, 1984; Haken, 1985). One of the properties of fractals is self-similarity on spatial and temporal scales, which predetermines the usage of one algorithm in the formation of complex structures with a minimum dissipation of energy (Nicolis & Prigogin, 1989; Haken, 2006; Mar’yan & Yurkovych, 2015; Mar’yan & Yurkovych, 2016). This may be illustrated by the so-

called Sierpinsky's carpet in Fig. 3.1.1. The Sierpinsky's carpet is a line that has an infinite length and confines the finite area (see Appendix B).

This line is the self-similar, i.e., composed of three parts that are similar to the entire curve as a whole with the ratio of similarity one to two, and fractal dimension $d_f = 1.5849$ (Falconer, 2003) (Fig. 3.1.1).

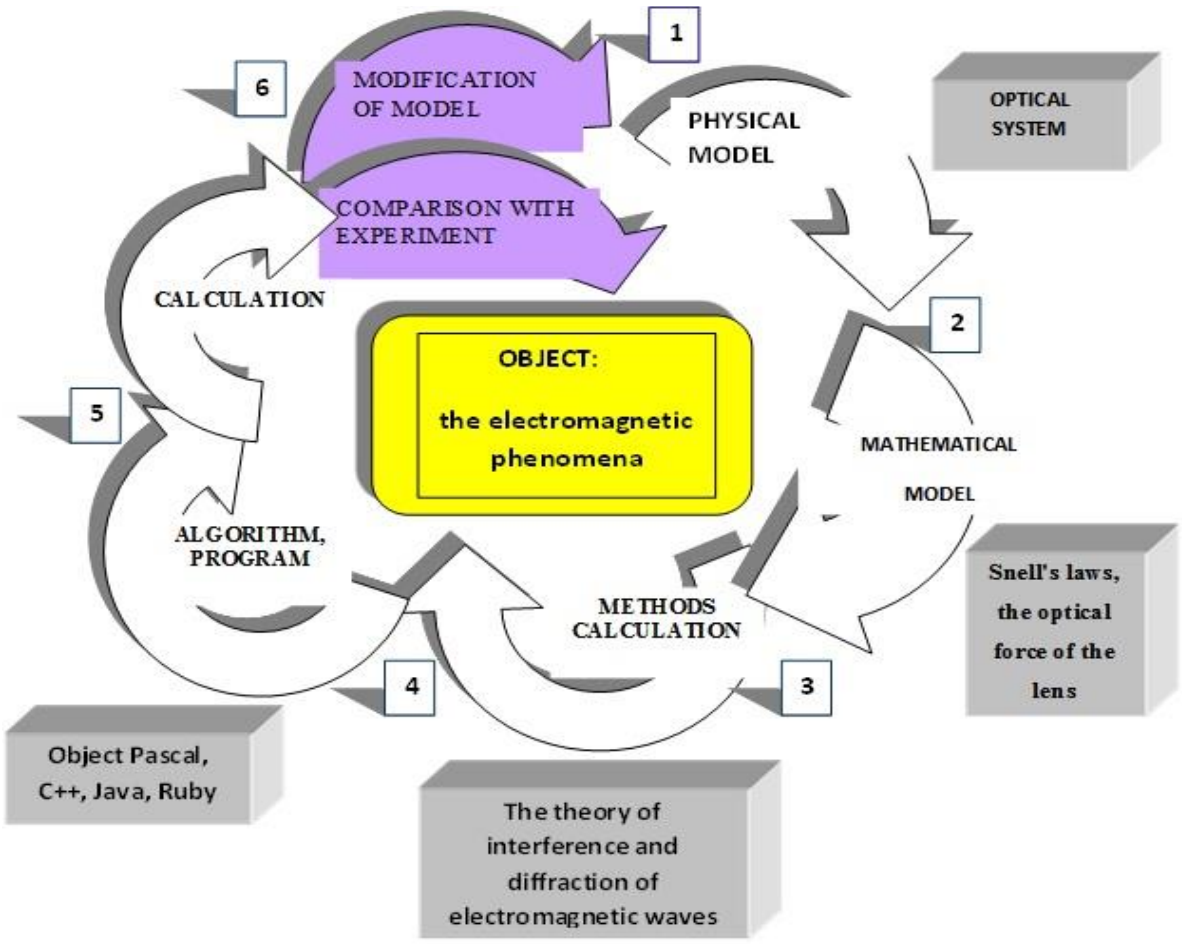


Fig. 3.1.2. The example of computer simulation for electromagnetic phenomena.

Computer simulation has become a creative means of solving applied scientific and technical problems of physics, but at the same time it is equally

important in the educational process, along with cognitive, informational technologies that are powerful (Fig. 3.1.2).

The assimilation of computer simulation opens enormous opportunities for using modern technologies in their scientific and educational activities for the implementation of interdisciplinary connections in computer science, mathematics, physics and other subjects. It involves a detailed analysis of the physical phenomenon or process, the construction of the physical model (abstraction from minor effects, the choice of laws that describe the corresponding processes), the creation of a mathematical model, the implementation of its means of information technology, conducting relevant calculations and analysis of the results. The application of computer modeling, as shown in Fig. 3.1.2, provides for the iteration and "formation" of the model in a loop: 1-physical model, 2-mathematical model, 3-calculation methods, 4-algorithm and model calculation program, 5-testing conduct and model research, 6-comparison of calculation results with experimental data and subsequent refinement of the model. This cycle repeats the necessary number of times, approaching the real object (phenomenon). Consider each of the stages of computer simulation (Fig. 3.1.2). The first stage is the physical model. The physical model for electromagnetic phenomena is a model of electromagnetic waves and environments in which they propagate. The second and third stages are mathematical models and methods of their calculation. Fourth - the use of modern algorithmic programming languages Object Pascal, C ++, Java, Ruby. The fifth and sixth stages - the testing and debugging of the program, the calculation and comparison with the optical experiment (Yurkovych, Seben & Mar'yan, 2017).

In the process of teaching physics, attention is focused on a significant amount of material and its unstructured character, insufficient relationship and correlation with other disciplines.

However, internally, there is a relationship between the different branches of physics and among its very sections that can be demonstrated using a fractal approach (Mar'yan & Yurkovych, 2015, Yurkovych, Seben & Mar'yan, 2017).

This means that in teaching one of the sections (subsections), an algorithm can be determined that is produced and realized in the following sections and, thus, a complex structure is formed while maintaining the integrity of material perception using computer modeling. This approach is tested in teaching electromagnetic phenomena in the sections of physics, "geometrical optics," and "wave optics". It applies the environment of the visual programming, Delphi - Embarcadero RAD Studio XE8, and the algorithmic programming language, Object Pascal, which is built on the principles of Object-Oriented Programming and the latest information technologies—RAD (rapid application development), VCL (visual component library), DLL (dynamically linked libraries), OLE (object linking and embedding) (Sugden, 2009; Bucknall, 2001; Yurkovych, Seben & Mar'yan, 2017).

3.2. Process and the results of solving the issue: fractal structure.

The first iteration. *The laws of reflection and refraction of light (the Law of Snelius)*. This is analogous to the first iteration of the fractal—the Sierpinsky's carpet in Fig.3.1.1a. The algorithm contains the features of computer modeling of the light propagation process at the interface of two environments, and is further used for the following phenomena (steps), forming a more complex but internally self-sufficient fractal structure.

In the course of the lecture students consider the basic laws of geometrical optics and types of light reflection: mirror (parallel light rays remain parallel after reflection (smooth even surfaces) and diffuse (parallel rays after reflection are scattered in all directions (rough uneven surfaces) with the immediate transition to computer modeling. The laws of geometric optics: 1) the law of rectilinear propagation of light - in a homogeneous transparent medium light travels rectilinearly; 2) the law of independence of light rays propagation – light rays which are distributed in space do not influence each other at the intersection; 3) the law of reversibility of light rays – if light propagates from point 1 to point 2, then,

it propagates according to the same path in the opposite direction from point 2 to point 1; 4) the law of light reflection - the incident ray, the reflected ray and the perpendicular set in the point of incidence lie in the same plane; wherein the angle of incidence α equals the angle of reflection β: α=β.

After consideration of these laws in the environment of visual programming Delphi - Embarcadero RAD Studio XE8, the students create the interface (Fig. 3.2.1): the following components are used (Bucknall, 2001): MainMenu – formation of the main menu (Mirror reflection, Diffusion reflection, Snell's law, Illustration), Label – labels to describe the panels of entering the output values, Edit – data fields, PaintBox – output of graphic image of mirrored and diffuse reflection). The example of program code in Object Pascal is given in Appendix C (Yurkovych, Seben & Mar'yan, 2017).

Students have the opportunity to directly modify the parameters of the optical system (angle of incidence α, refractive index n, the factors of reflectivity and diffuseness), means of visualization of the rays in Delphi environment (colors of the incident and reflected rays, types of lines) and become active self-sufficient participants in conducting computer experiment in Fig 3.2.1. It is important to develop the algorithm of information perception by students on the intuitive level that will be used and developed further in later iterations (lectures) (Yurkovych, Seben & Mar'yan, 2017). It is important, however, that the laws of optics are not perceived separately, not standardized as reports of forced execution and duplication, but they come to life through synergy and principles of object-oriented programming of computer simulation: encapsulation (self-sufficiency), inheritance (creation of a new), polymorphism (distribution in new environments). Students get the opportunity to be self-sufficient, to create a radically new, to perceive different environments (physical environment, programming environment, information environment), which become not passive (as in the traditional approach), but active - complementary, interpenetrating. It also determines the ability of accumulation and spontaneity in other areas of knowledge, including

economics, information technology, mathematics, engineering, and others. That is, the tandem "student-teacher" is filled with activity, ability to develop and rich functioning. This is not an over-saturation with inadequate information, namely the spontaneous, self-organized acquisition and receipt of information objects through the formation of an appropriate fractal structure.

This iteration, this step is essential for the further functioning of the complex structure of the student-teacher and the transition to a new level of perception of information, to the formation of a unique branched structured system.

The new and full-fledged value is also acquired by information technologies of computer modeling : RAD (rapid application development) - creative approach and development, VCL (visual component library) - visualization of the laws of physics with preservation of their information integrity of perception, DLL (dynamically linked libraries) – dynamic perception of information. The change and interpenetration of information environments, OLE (object linking and embedding), is a transition between different environments with a minimum energy dissipation, synergistically (Mar'yan & Szasz, 2000).

The concept of object-oriented programming implies that the basis for managing the implementation of the program is the transmission of messages to objects. Therefore, information objects are defined in conjunction with the messages they must respond to when executing the program. This is the main difference between object-oriented programming from procedural programming, where separate data structures are passed into procedures (functions) as parameters. Thus, object-oriented programming consists of information objects - individual pieces of code that interact with each other through certain interfaces (Mar’yan, Seben & Yurkovysh, 2018).

This shows the perfect implementation of synergy - the complementarity of information objects. This also manifests itself in the main difference between the approach proposed and adapted in this book to the teaching of natural sciences (see also section 2).

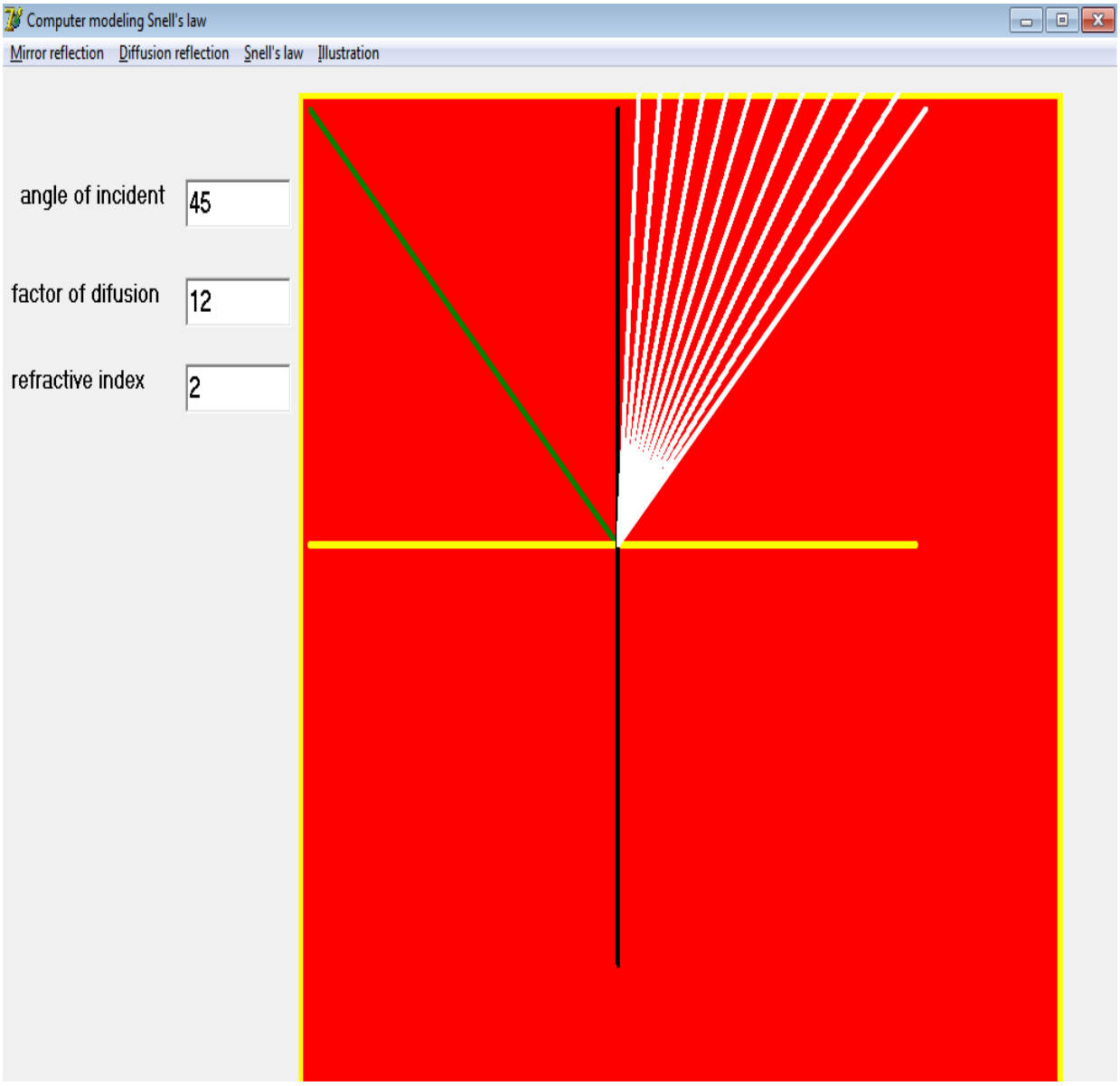


Fig. 3.2.1. The visual interface of modeling the laws of light reflection and refraction in the Delphi environment ***(****Yurkovych, Seben & Mar'yan, 2017).*

The second iteration. *Total internal light reflection in Fig. 3.2.2.* This is analogous to the second iteration of the fractal—the Sierpinsky's carpet in Fig.3.1.1b. It is important to note that the formation of this and subsequent iterations retain the "algorithm" of the fractal structure incorporated for the

previous iteration that ensures the integrity, self-sufficiency and localization of perception.

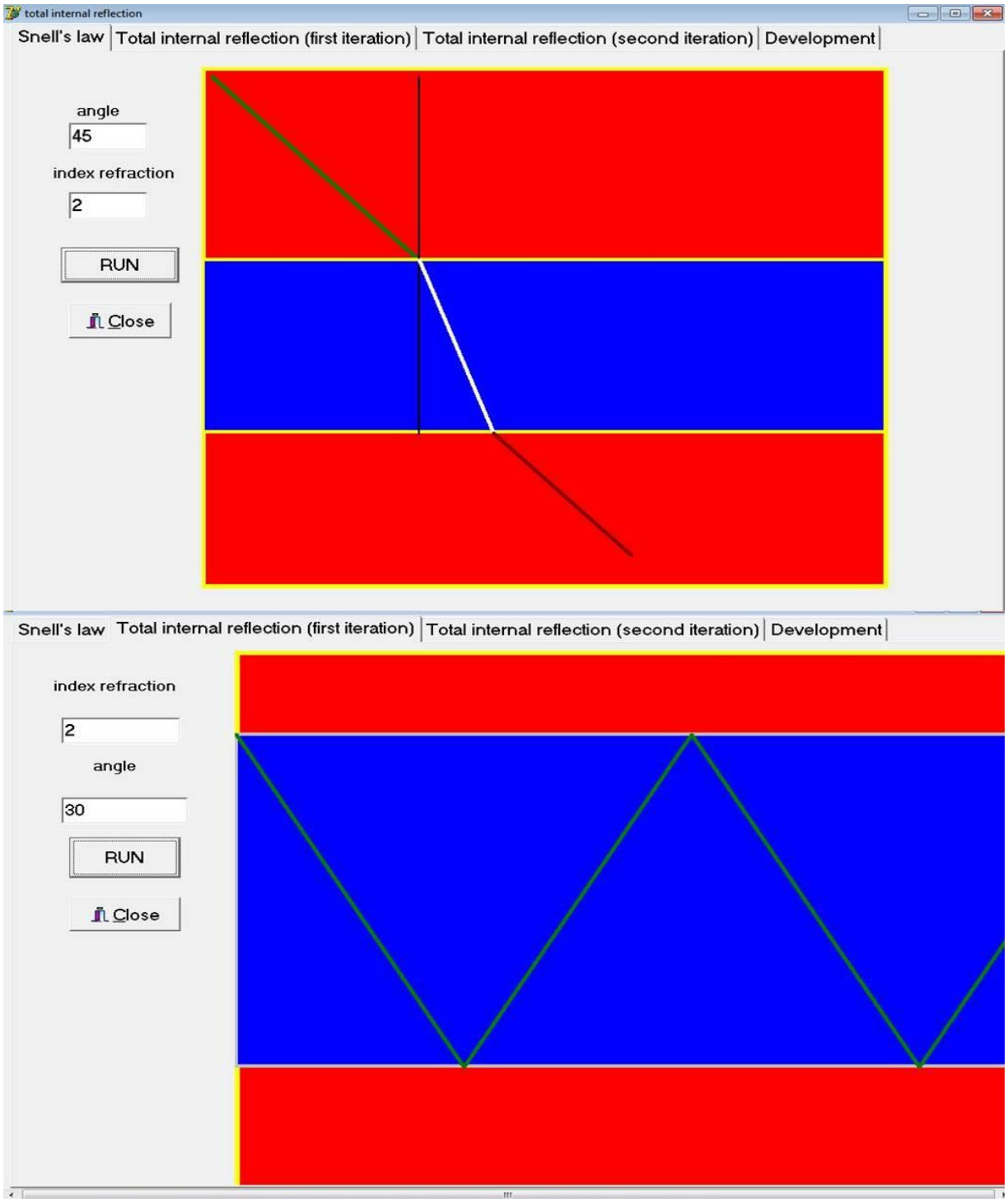


Fig. 3.2.2. The visual interface of computer modeling of the total internal reflection phenomenon (Yurkovych, Seben & Mar'yan, 2017).

It is important to use computer modeling (Gould & Tobochnik, 1988; Yurkovych, Seben & Mar'yan, 2017), which determines the cross-cutting nature and the spontaneity of the material presentation, the features of object-oriented programming languages developed on the principles of encapsulation, inheritance and polymorphism (Bucknall, 2000; Cantu, 2008; Mar'yan, Seben & Yurkovych, 2018). Because of this, each iteration makes use of the properties of the previous one, and, at the same time, it must contain new information (property, method)—in this case, the possibility of directional light propagation.

Tentatively the laws of refraction are formulated as follows: 1) incident ray, refracted ray and the perpendicular at the point of incidence lie in the same plane; 2) the ratio of the sine of the incidence angle α and the sine of the refraction angle β is constant for two separated environments:

$$\frac{sin\alpha}{sin\beta} = \frac{v_1}{v_2} = n_{21},$$

where v_1 is the speed of light in the first environment; v_2 - the speed of light in the second environment; n_{21} - the relative index of light refraction in the second environment relative to the first one. Since $n_1 = \frac{c}{v_1}$, $n_2 = \frac{c}{v_2}$, where c - the speed of light in vacuum, then

$$n_{21} = \frac{v_2}{v_1} = \frac{n_2}{n_1}.$$

(The example of the Snell's law record for students is given in Appendix D).

The law of light refraction allows us to explain an interesting and practically important phenomenon of total internal light reflection. If we increase the angle of incidence α, then, reaching the limit values of the angle α_0 (let us call it the angle of total internal reflection), angle $\beta = 90°$. At this angle of incidence and bigger angles, the refracted ray cannot penetrate into the second environment but is reflected - the total internal reflection of light occurs.

If $\alpha = \alpha_0$, then $\beta = 90^o$ and $\frac{sin\alpha}{sin\beta} = \frac{1}{n}$, sin 90º = 1 then $\alpha_0 = arcsin\frac{1}{n}$ is the marginal angle of the total internal reflection.

The illustration of the refraction laws and total internal reflection in Delphi environment are depicted in Fig. 3.2.2. Students get the opportunity to change the parameters of the optical environments, to observe the ray propagation in real time under total internal reflection.

The third iteration. *Determination of light transmittance of a thin film taking into account multiple reflections and using the methods of approximation in Fig. 3.2.3*. It is analogous to the third iteration in Fig. 3.1.1c.

Students are introduced to the concept of light absorption - the phenomenon of the reduction of light wave energy during its propagation in the substance as a result of conversing wave energy into other forms of energy. In particular, the absorption of light in the substance is described by Bouguer's law:

$$I = I_0 e^{-\alpha z} \quad , \qquad (3.2.1)$$

where I_0 and I the intensity of a flat monochromatic light wave at the input and output of the layer of the absorbing substance with the thickness z, α is the absorption coefficient depending on wavelength of light, the chemical nature and state of the substance. The transmittance ratio of T light shows which part of the light flux falling on the object under study passes through it, without being absorbed:

$$T = \frac{\Phi}{\Phi_0} = \frac{I - I_T}{I_0 - I_T} \cdot 100 \, . \qquad (3.2.2)$$

The optical density of the D substance describes the degree of absorption of monochromatic radiation and is described by the ratio:

$$D = \lg \frac{1}{T} = \lg \frac{I - I_T}{I_0 - I_T} \cdot 100 \, . \qquad (3.2.3)$$

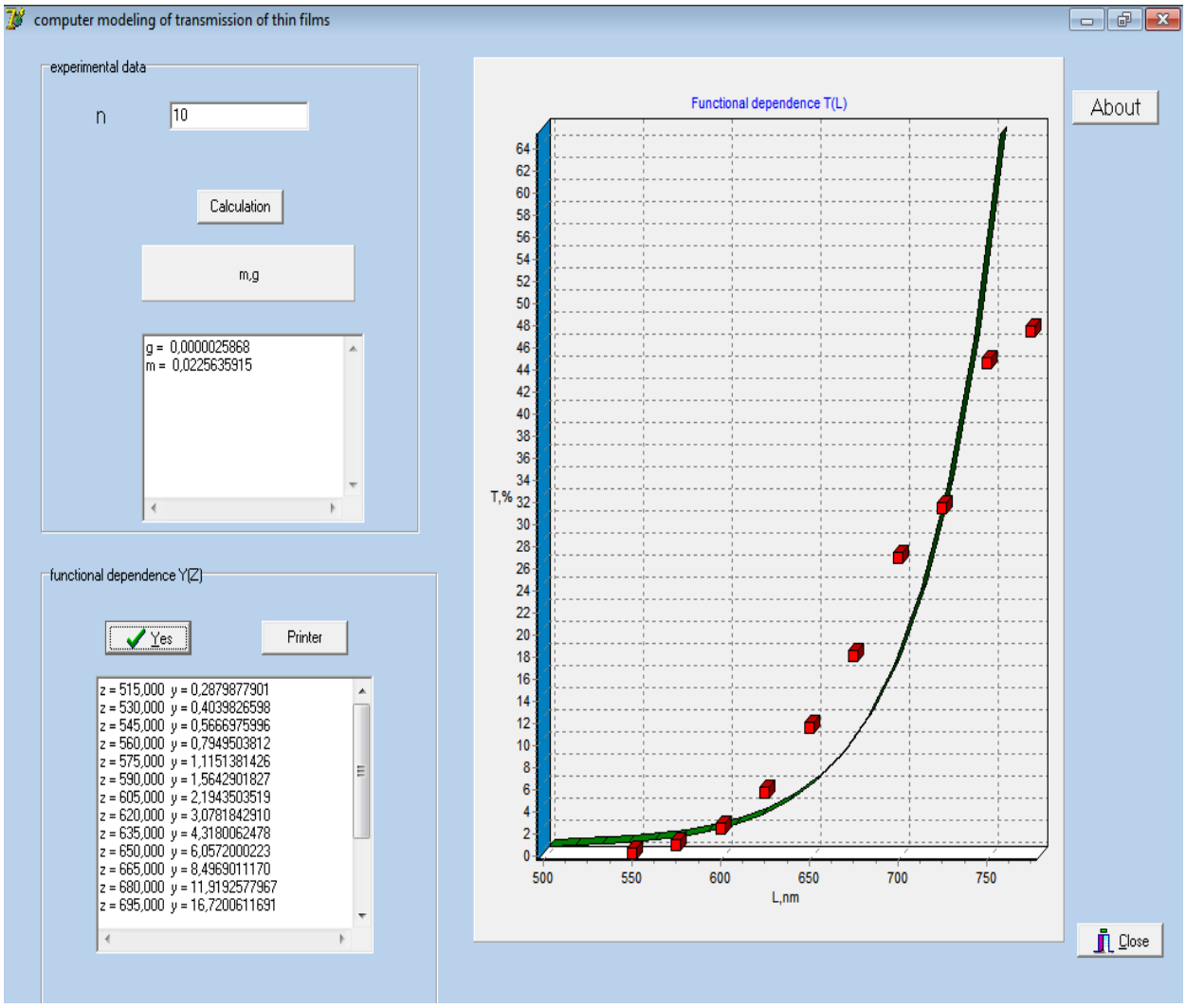


Fig. 3.2.3. Visual interface of two parametric approximation of light transmittance in the Delphi environment (Yurkovych, Seben & Mar'yan, 2017).

According to the Bouguer's law, the transmittance ratio exponentially decreases depending on the thickness of the sample z (layer of the substance):

$$T = \exp(-\alpha z), \qquad (3.2.4)$$

and the optical density depends on the thickness of the sample linearly:

$$D = \alpha \cdot z \cdot lge = 0.43 \cdot \alpha \cdot z\ , \qquad (3.2.5)$$

i.e., the optical density of the substance is directly proportional to the thickness of the layer.

To experimentally obtain dependences of transmittance upon the wavelength in the visible region of the spectrum, the students carried out the two-parametric approximation method (Hestenes, 2010). The two-parametric dependence has been considered (Appendix E):

$$y = ge^{mz}, \qquad (3.2.6)$$

Where m, g variation parameters which are determined in the process of computer modeling (Fig. 3.2.3).

Therefore, arising out of (3.2.6), it is possible to calculate the values of the vibrational parameters m, g , which correspond to the experimental dependencies of transmittance on the thickness of the sample (see formula (3.2.1): $y = \frac{1}{I}$, $g = \frac{1}{I_0}$, $m = \alpha$). The visual interface of the calculation program in Delphi environment is given in Fig. 3.2.3 (components Button, GroupBox, Edit, Label, Panel, Memo, Chart, and provide them with the necessary properties including the series type with the help of Object Inspector (Yurkovych, Seben & Mar'yan, 2017)). The qualitative difference of this iteration consists in transmission to obtaining the analytical dependence and its graphical visualization. However, there remains the inherent in previous iterations algorithm of structuring teaching material and enhancing students' attention, involving them in the formation of the fractal structure (Mar'yan & Yurkovych, 2015; Scerri, 2016).

The fourth iteration. *Modeling of the optical characteristics of the positive and negative lenses in Fig.3.2.4 is analogous to the fourth iteration in Fig.3.1.1d.*

In order to perform the fourth iteration of the fractal structure the students have been familiarized with some methods of determining the focal distances of condensing lenses taking into account the position of the principal planes and the refractive index of the lens material. In optics, a lens is a transparent for light

body limited by two surfaces. A straight line passing through the centers of the spherical surfaces of the lens is called its main optical axis. The distance between the peaks of the surfaces of the lens is its thickness. Lenses, whose thickness is sufficiently small compared with the radii of curvature of their surfaces, are called thin lenses. This condition is not fulfilled for thick lenses.

The lens can be considered as a system of two refracting surfaces. The system preserving the homo centrism of beams and the image turns out to be is strictly geometric similar to the object, is called a perfect optical system. As the theory proves, the images of objects using an ideal optical system can be constructed without a detailed study of the rays inside the system. It is only necessary to know the focal length and the position of the principal planes.

The main planes of perfect optical systems are called conjugate planes, the linear increase of which is equal to $\varepsilon=+1$. The principal planes coincide in a thin lens and their intersection with the optical axis produces the optical center. The main planes of the lens may be located inside the lens and outside of it depending on the shape of the lens. The rays, parallel to the main optical axis, being refracted in the condensing lens, intersect at a point lying on the optical axis and is called the principal focus of the lens. There exists the main front focus F and rear main focus F'. Distances from the principal planes to the main foci are called the focal distances. According to the rule of signs for the condensing lens $f<0, f'>0$, for the disperse one – $f>0$, $f'<0$. The optical power of a thick lens can be calculated by the formula:

$$\Phi = \frac{1}{f'} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) + \frac{d(n-1)^2}{n \cdot R_1 R_2} \quad ,$$

where f' is the back focal distance of the lens, R_1 and R_2 are the radii of the refractive surfaces curvature, n is the refractive index of the lens material, d is the thickness of the lens. In the process of using computer modeling (Gould & Tobochnik, 1988) there exists a significant influence of graphical tools for data visualization (building various types of graphs for a single analytical dependences,

that is, one and the same analytical dependence is observed by students at different visual foci) in Fig. 3.2.4.

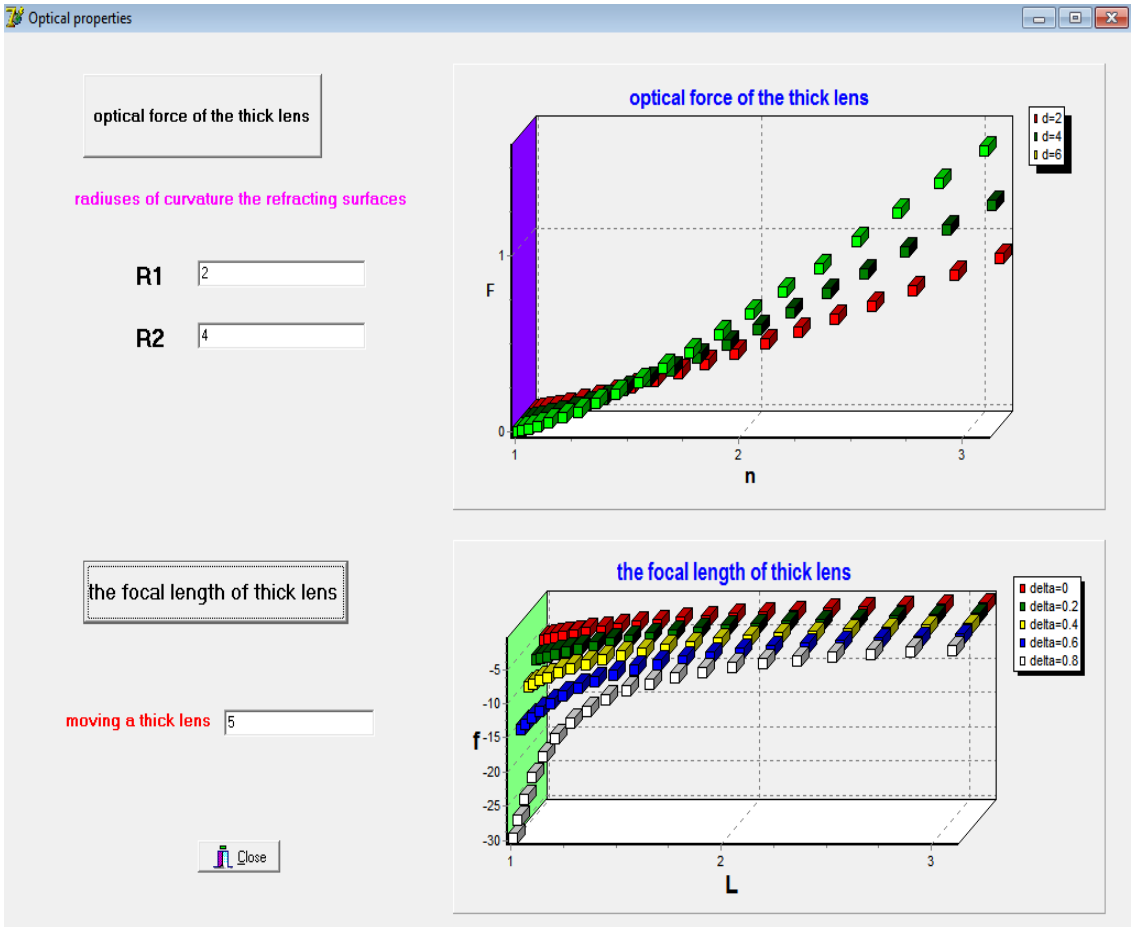


Fig. 3.2.4. The visual interface of modeling optical parameters (optical power and focal distance) of a thick lens (Yurkovych, Seben & Mar'yan, 2017).

The fifth iteration. *Practical application of the given physical phenomena in Fig.3.2.5.*

It should be noted that the fractal structure has a fractional dimension, completely filling in the corresponding space (Mar'yan & Yurkovych, 2015). The practical application itself is analogous to the fifth iteration in Fig. 3.1.1 and reproduces the integrity and development of the section of physics, "geometric optics." (Mar'yan, Kikineshy & Mishak, 1993; Mar'yan, Kurik, Kikineshy, Watson & Szasz, 1999; Young & Freedman, 2003).

To create the interface of the program in Fig. 3.2.5, students were asked to use the object Image in Delphi environment (properties of Picture and Stretch of the object Image (Yurkovych, Seben & Mar'yan, 2017)).

The students got acquainted with the technical product — optical fiber consisting of an optical fiber waveguide, protective coatings and marking colored membrane. The optical fiber waveguide is the physical medium of transporting an optical signal and consists of a core and membrane having different values of refractive indices. It is emphasized that owing to the phenomenon of total internal reflection there is the possibility to transport optical signals (light) generated by the source. The types of optical fiber have been considered in Fig. 3.2.5: single mode fiber; multimode fiber; gradient fiber; a polarization-stable fiber; photonic crystal fiber.

The next part of the practical application is the process of accommodation light rays by the lenses in Fig. 3.2.5. The eye undergoes the process of accommodation not so much by the change of curvature of the eye-lens, but rather by the influence on the shape of the eyeball by external muscles that surround it. Let us provide some simplified explanation for the students to understand what is being described. Comparing the structure of the eye with the device of the camera has become a common matter in ophthalmology.

If we draw the analogy between the structure of the eye and the device camera, the role of the lens in the eye is performed by the transparent elastic formation having the shape of a biconcave lens, i.e. the eye-lens. It is emphasized that the light rays reflected from an object enter the eye and, passing through the lens, are focused on the retina. The retina is an analogue of the photosensitive film in the camera – there is a thin membrane that lines the inner surface of the eye in Fig. 3.2.5.

Each iteration (section of physics) is characterized by a synergy - adding new iteration provides a qualitative perception of the information (without a mechanical outside introduction of the division according to themes), the

formation of the integrity in which the student becomes an active participant (Haken, 2006; Mar'yan & Yurkovych, 2015). This synergy creates a unique fractal structure, capable of development and functioning (Mar'yan & Yurkovych, 2016).

The iteration discussed above can be complemented and developed, in particular by involvement of learning using the testing tools (Hodson, 2014), the exchange of information using the Internet (Mieke De Cock, 2012), that is, the process generates and allows an infinite number of steps, which is essential for fractal structures (Frame & Mandelbrot, 2002).

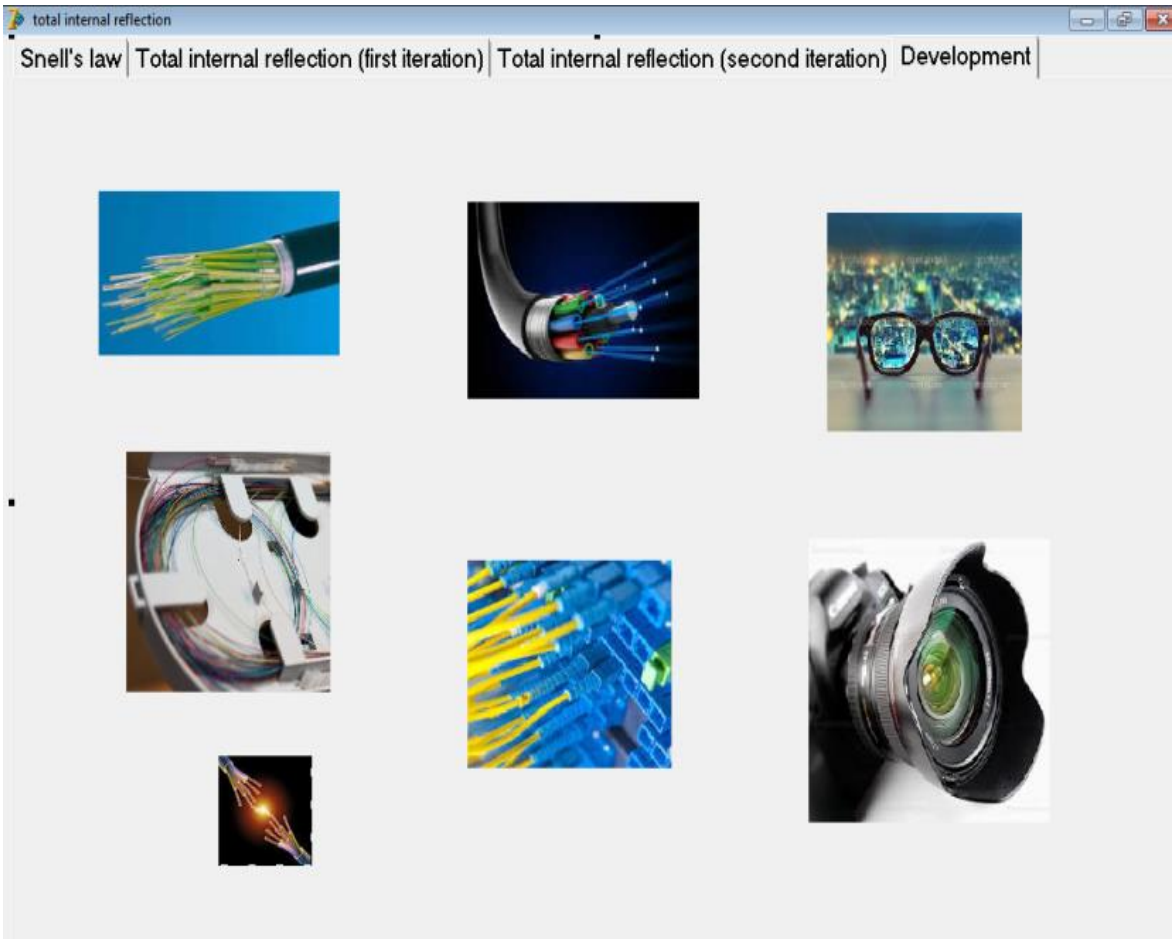


Fig. 3.2.5. Practical use of the phenomenon of total internal reflection in fiber-optic communication lines and optical lenses.

Based on the presented approach of the joint synergistic usage of lectures on physics and computer modeling, the fractal structure (table 3.2.1) is formed on an intuitive level (Sherin, 2006). Functioning of this structure is manifested in the transition to the presence of students' self-sufficiency, involving the use of creative approach and the desire to apply the obtained information in radically new areas (Young & Freedman, 2003). For example, the phenomenon of total internal reflection along with the classical perception of physics as a process of dissemination of information (Informatics), preparing a hamburger (cooking), the Belousov-Zhabotinsky reaction with the formation of dissipative structures (chemistry), dancing rhythms (music).

Table 3.2.1. The formation of the fractal structure of information perception.

Steps	**Levels of information perception**
The first step	Physics
The second step	Physics and computer modeling
The third step	The intuitive perception of information by students and the formation of the fractal structure
The fourth step	The hyper sensibility and distribution of fractal structure in the integrated environment
The five step	The formation of an integrated fractal structure

The resulting fractal structure is qualitatively manifested in the table 3.2.2 (Yurkovych, Seben & Mar'yan, 2017).

Table 3.2.2. Fractal structure in the study of physics sections "Geometric optics", "Wave optics".

Iterations	**Objects**
The first iteration	Computer modeling the laws of light reflection and refraction
The second iteration	Computer modeling the laws of light reflection and the total internal reflection phenomenon = { Synergy of integration in the Delphi environment }
The third iteration	Computer modeling the laws of light reflection, the total internal reflection phenomenon and two parametric approximation of light transmittance = { Synergy of integration in the Delphi environment }
The fourth iteration	Computer modeling the laws of light reflection, the total internal reflection phenomenon, two parametric approximation of light transmittance and the modeling optical parameters of a thick lens = {Synergy of integration in the Delphi environment }
The fifth iteration	Computer modeling the laws of light reflection, the total internal reflection phenomenon, two parametric approximation of light transmittance, the modeling optical parameters of a thick lens and practical use of the phenomenon of total internal reflection in fiber-optic communication lines and optical lenses ={Synergy of integration in the Delphi environment}

3.3. Results of research: discussion and conclusions

Thus, a fractal structure in teaching one of the sections of physics, "geometrical optics," is formed (it can be easily spread to other branches of physics). The advantages of this approach are obvious: the corresponding physics section is perceived as a single unit without the mechanical separation into its component parts; and the possibility of forming branched structures according to a single algorithm that can be extended to other branches of physics, while maintaining the integrity (fractality) at the level of several sections (Breslyn & Mcginnis, 2012; Kuo, Hull, Gupta & Elby, 2013).

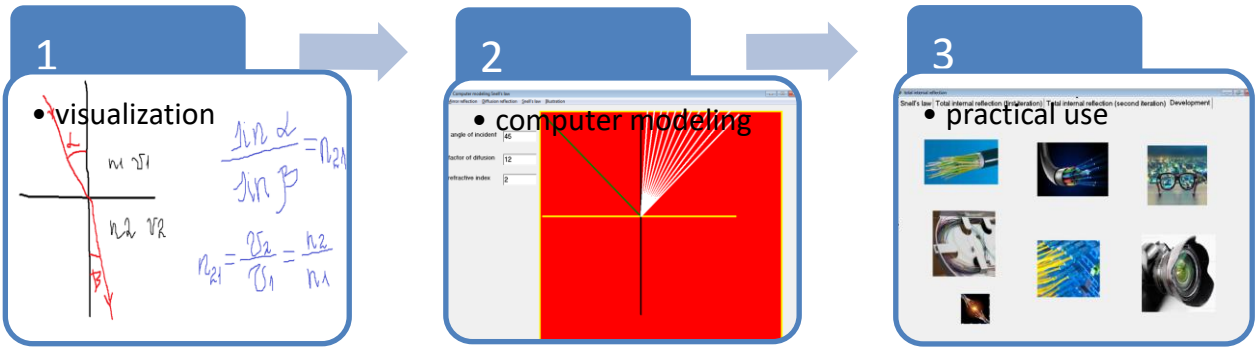


Fig. 3.3.1. An example of one of the branches of the fractal structure.

The given approach is also used in the formation of a fractal structure, which is implemented, in particular, in the transition from geometrical to wave optics. Moreover, the iterations analyzed above, iterations 1–5 in Fig. 3.2.1–3.2.5, are considered as the first iteration of a new fractal structure formation (an example of

one of the branches of a fractal structure see Fig. 3.3.1, 3.3.2). It should be noted that unlike the classical approach, which is based on the assimilation of a certain amount of material (Özcan, 2015; Hodson, 2014), the fractal connections reflect the internal structure of the sections (Mar'yan & Yurkovych, 2015; Mar'yan & Yurkovych, 2016) that are assigned spontaneously. In computer modeling, along with the use of the algorithmic programming language, Object Pascal, other object-oriented languages such as C++, Java, and Ruby, can be used.

The offered fractal approach of teaching physics has been a probated in the Uzhgorod National University (Uzhgorod, Ukraine), the Faculty of Physics, Department of solid-state electronics & information security and University of Presov (Presov, Slovakia), the Faculty of Humanities & Natural Sciences, Department of Physics, Mathematics & Techniques for students in the third course—the future physics teachers for the physics sections "Geometric optics", and "Wave optics".

During these classes, the activation of students, and in-depth perception of the material have been noted. In our opinion, the adoption and usage of the methodological approach of modeling physical phenomena and processes by future teachers of physics is very useful (Windschitl, 2004). It creates space for the expansion and implementation of the key competencies in the field of targeted and effective use of information and communications technology in school physics experiments (Luft, 2001; Lotter, Harwood & Bonner, 2007; Schwartz & Lederman, 2008).

So, the fractal approach to teaching physics using computer modeling in object-oriented programming, Delphi, has been substantiated (Fig. 3.3.3). The formation of a fractal structure has been established and the iteration has been determined, which reflect the integrity and spontaneity of presenting information. The lectures for students of Prešov University in Slovakia and Uzhgorod National University in Ukraine with the use of a fractal approach in teaching physics

sections “Geometric optics”, “Wave optics”, and computer modeling have been conducted.

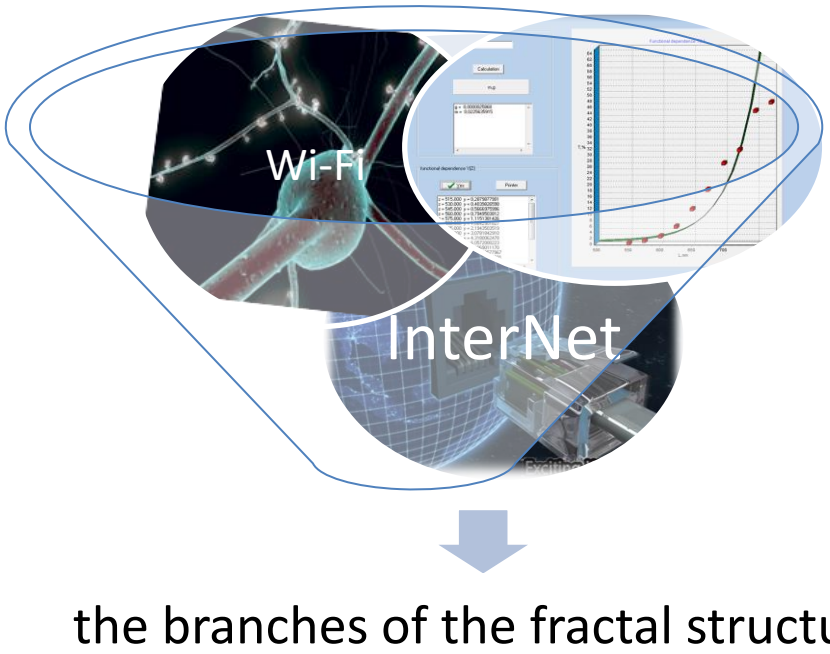


Fig. 3.3.2. An example of element for the branches of the fractal structure (attraction of telecommunications Wi-Fi and network Internet).

Presents synergetics and fractality approash in this book identify and attract to use the modern level of the latest information technologies: information exchange in the Internet network, development of mobile telecommunications and related technologies, level of abstraction and synergy of object-oriented algorithmic programming languages, formation of the self-sufficient systems - smart home, intelligent car, smart phone (Chen & Lee, 2009). They provide an opportunity to implement a reasonable lecture, a reasonable audience, a sensible conference with the direct embodiment of ideas and development (Fig. 3.3.2-3.3.3).

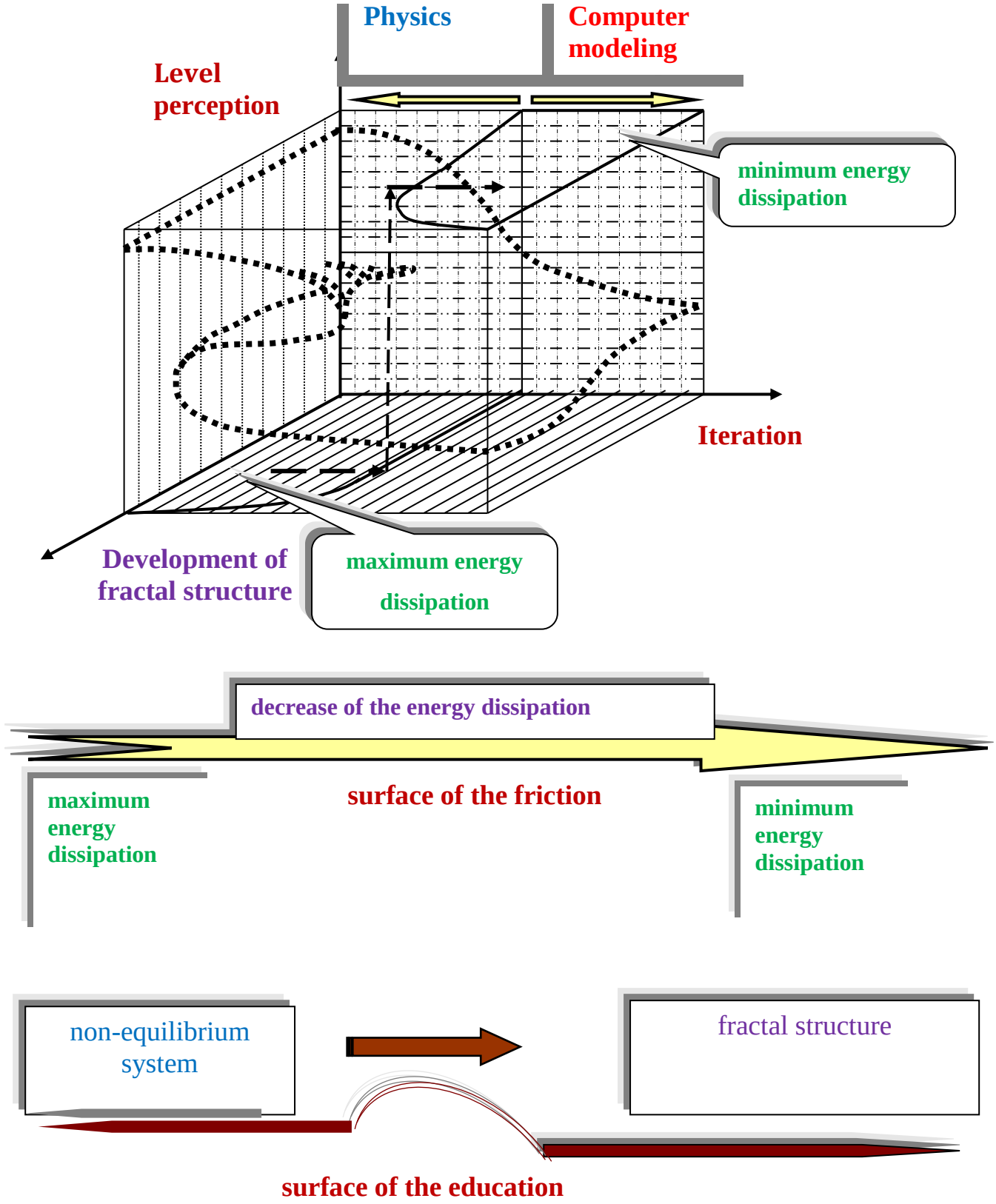


Fig. 3.3.3. Formation of the dissipative fractal structure in the teaching physics.

At the present stage in the process of mastering the sciences and technologies in the higher education establishments, universities considerable attention is mainly focused on a significant amount of material and its unstructured nature, insufficient interconnection and correlation with other disciplines and their practical application (Balanov & Janson, 2009). This indicates to the need for the presentation and perception of information on an intuitive level, using visualization tools, modern advances in information technology, especially computer modeling and object-oriented programming (Fig. 3.3.4). There is a relationship between the different branches of the education, science, technology and their very sections that

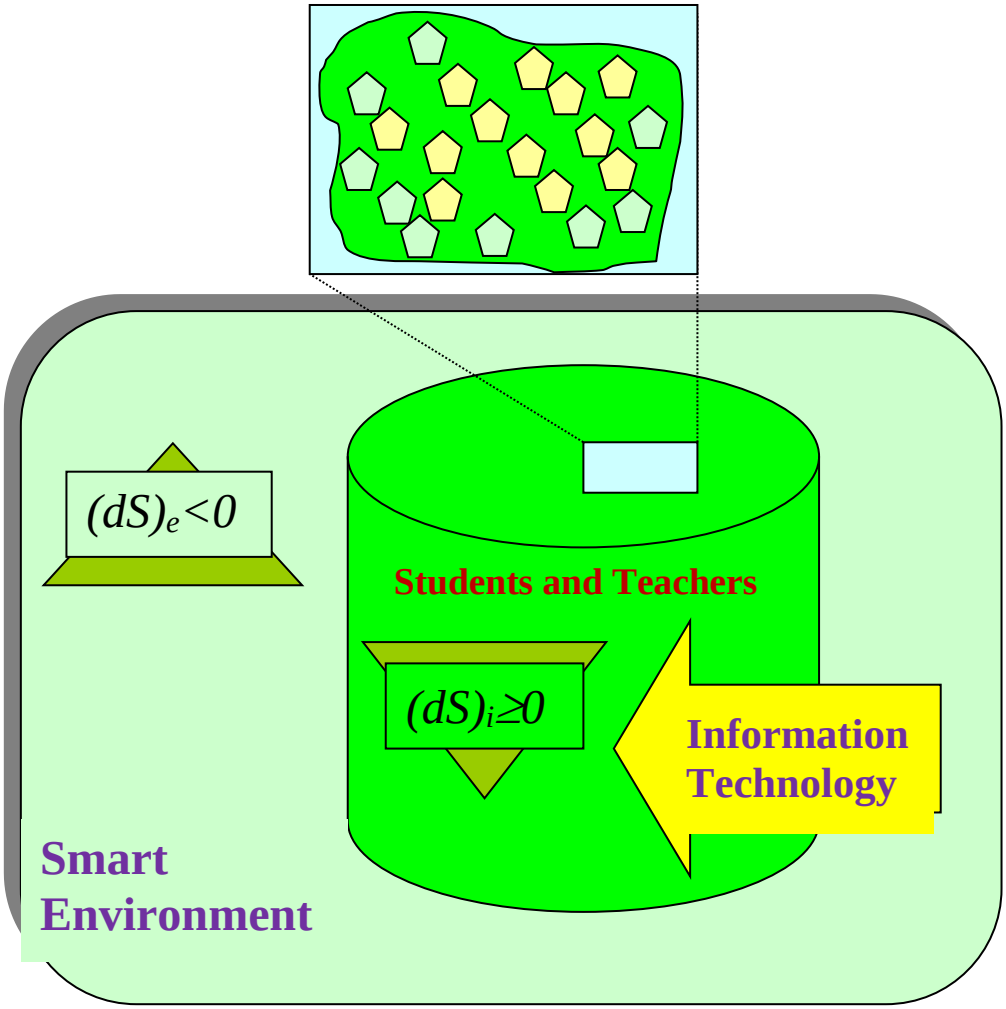


Fig.3.3.4. Synergetic of the fractal structure ($(dS)_e$ is an entropy flux which exists due to exchange the energy and information with the environment and $(dS)_i$ is an entropy production inside the system).

can be demonstrated using a fractal approach. This means that in teaching one of the sections (subsections), an algorithm can be determined that is produced and realized in the following sections and, thus, a complex structure is formed while maintaining the integrity of material perception using computer modeling. It is important to note that the formation of this and subsequent iterations retain the "algorithm" of the fractal structure incorporated for the previous iteration that ensures the self-sufficiency and localization of perception. Use is essential of the computer modeling, which determines the cross-cutting nature and the spontaneity of the material presentation, the features of object-oriented programming languages developed on the principles of encapsulation, inheritance and polymorphism. Because of this, each iteration makes use of the properties of the previous one, and, at the same time, it must contain new information (property, method).

The iterations of the fractal structure on the example of studying physics sections, "Geometric optics" and "Wave optic" elaborated. Each iteration (section of physics) is characterized by a synergy - adding new iteration provides a qualitative perception of the new information. The possibility of using this approach in other sections of physics, and research fields related to physics has been demonstrated. It manifests the formation of a fractal structure and the corresponding iterations, reflecting the integrity and spontaneity of information perception. Based on the proposed synergistic approach to the use of subject areas of knowledge and computer modeling, the fractal structure is formed on an intuitive level. The functioning of this structure manifests itself in a qualitative transition to self-sufficiency of students, which involves the use of a creative approach and the desire to apply the received information in radically new fields.

This section is adapted for the general public: scientists, teaching in high schools, teachers, and students.

IV. SYNERGETICS OF THE INDUCED INSTABILITIES AND ORDERED STRUCTURE FORMATION

The studies of the dissipative structures and self-organization processes in the systems different nature are presented. The formation of ordered structures is substantiated and investigated. The ability to control the types and levels of structuring is shown. Directions of application of these data in cyber systems are established.

4.1. Production of ordered structures: the feedback mechanism

At presence significant deviations from state equilibrium or significant external fields crucial role in shaping the ordering, creation and storage of functional organizations are implemented synergistic effects and mechanisms of energy transformation, which can be explored using the ideas of self-organization and symbolic dynamics (Mar'yan & Szasz, 2008; Guri-Rosenblit, 2010). This approach makes it possible, based on the only one integrated information principle, to describe both the formation of non-crystalline materials, their structure and the peculiarities of interaction with external factors in the presence of self-organization processes, as well as the implementation of the different ways of ordering that determine the appropriate types of structuring on spatial and temporal scales. One of the unique features of these structures is hypersensitivity - an integrated, holistic perception of information, which is especially significant in the development of cyber systems (Mar'yan & Szasz, 2008).

In this work the theoretical studies of the dissipative structures and self-organization processes in the transition to a non-crystalline state, the action of

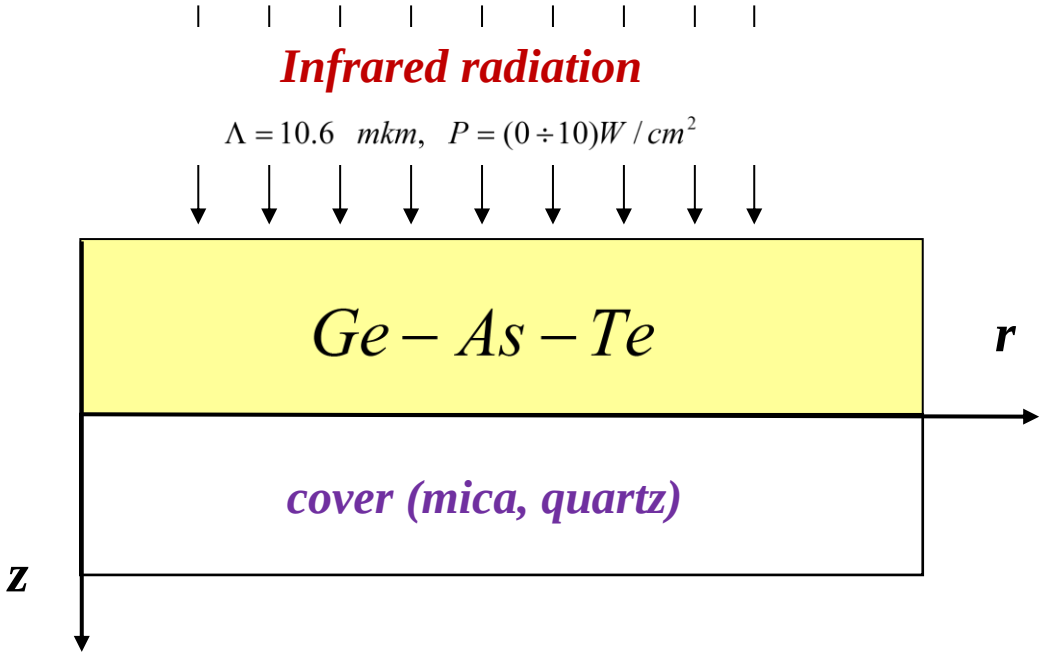


Fig. 4.1.1. Thermo-induced transformations in amorphous condensates $Ge - As - Te$ under the influence of infrared radiation.

external fields (electromagnetic radiation, temperature field) in the non-crystalline materials of systems $As - S(Se)$, $Ge - As - Te$ are presented. In particular, studies of the model of thermal instabilities and the formation of dissipative ordered structures of non-crystalline semiconductors under the action of continuous infrared radiation (wavelength is $\Lambda = 10.6\ \ mkm$, power is $P = (3 \div 5)\ \ W/cm^2$ and duration of exposure is $t_p = (1 \div 30)\ \ s$) are given and comparing with experimental data. The application of these structures in cyber systems is analyzed.

Radiation with Gaussian's distribution on the beam cross section normally falls to the surface layer axially z and totally absorbed in the substrate (Fig. 4.1.1). The dynamics of temperature T change on the surface of the amorphous layer and the substrate which describes a system of the non-linear differential equations taking into account the process heat generation, its distribution and heat transfer to the substrate and the thin film amorphous layer are considered:

$$\rho C\frac{\partial T}{\partial t}=div(\chi gradT)+W(T)-Q(T), \qquad (4.1.1)$$

$$\rho_a C_a\frac{\partial T}{\partial t}=div(\chi_a gradT)+Q(T)-Q_a(T).$$

Here C, ρ and χ are the heat capacity, density and thermal conductivity of the substrate respectively; $W(T)=\gamma UP\exp(-\gamma z)f(t)$ is the laser heat source; $\gamma=\gamma_0\exp\{-\alpha_a T_a/T\}$ is the absorption coefficient, α_a and T_a are parameters of the absorption capacity of the substrate; U is the optical transmission of the amorphous layer at the wavelength $\Lambda=10.6$*мкм*; $f(t)=1$ in $t\le t_p$ and $f(t)=0$ in $t>t_p$; $Q(T)=\int_{T_0}^{T}\eta_h(T)\frac{S_0}{V}dT=\eta_h(T-T_0)/d_\gamma$ is the heat exchange with amorphous layer (η_h is the heat transfer constant, T_0 is the temperature before irradiation, $V=s_0 d_\gamma$ is effective volume of the absorption radiation, d_γ is effective depth of radiation penetration in the substrate); C_a, ρ_a and χ_a are heat capacity, density and thermal conductivity of the amorphous layer, respectively; $Q_a(T)=L_a\rho_a f_a$ is the quantity of heat that is absorbed during the crystallization of the amorphous layer, L_a is the heat of crystallization, $f_a=\upsilon\exp(-\upsilon\cdot t_p)$ is the proportion of crystallized volume per unit of time, which is determined by the Johnson-Mel-Abraham equation $\upsilon=\upsilon_0\exp(E_a/k_BT)$, E_a is the activation energy of crystallization.

Initial and boundary conditions are:

$$T(r,z,t)\big|_{t=0}=T_0,\quad T(r,z,t)\big|_{r\to\pm\infty}=T_0,\quad \frac{\partial T(r,z,t)}{\partial z}\bigg|_{z\to\infty}=0, \qquad (4.1.2)$$

$$\chi\frac{\partial T(r,z,t)}{\partial z}\bigg|_{z=0}=\eta_h(T(r,z,t)-T_{шар}(r,z,t))\big|_{z=0}.$$

The depth of radiation penetration d_γ into the quartz or mica substrate at the wavelength $\Lambda=10.6$ *mkm* is a magnitude $d_\gamma\le 1$ *mkm*, while the thermal front

extends over the entire depth of the substrate $d \approx 10^3 mkm >> d_\gamma$ and through heat transfer to the amorphous layer. It is shown that the homogeneous distribution of the temperature field along the beam section at the power density of the radiation $P > P_c$

$$P_c = \frac{U\tilde{p}_c}{\eta_h T_a}, \quad \tilde{p}_c = \frac{\Phi_s^2}{\alpha_a} \exp\{\alpha_a / \Phi_s\}, \quad \Phi_s = \frac{T_s}{T_a} \qquad (4.1.3)$$

becomes unstable and a structure with a spatially inhomogeneous temperature field profile is formed. The characteristic spatial scale of heterogeneity L_c and the number of rays m, which is determined by the formed dissipative structure, are equal

$$L_c / r_0 = 2\pi / k_c = 2\pi / \sqrt{\varepsilon / \tilde{k}}, \quad m = (k_c^2 r_0^2 - 1)/4 \ , \qquad (4.1.4)$$

and depend on the radiation power

$$\tilde{p} \ \left(\left(\varepsilon = \left(\tilde{p} - \tilde{p}_c\right)/\tilde{p}_c\right), \tilde{k} = \frac{\chi \cdot d_\gamma}{\eta_h r_0^2}\right). \qquad (4.1.5)$$

Structural changes in the layer that occur during irradiation were recorded due to changes in optical density D in the visible spectral region ($\Lambda = 0.63 \ \ mkm$). For a given radiation power at slight exposures, there is a repetition of the spatial profile of a beam with a continuous increase D in the center. With growth t_p the optical density D begins to decrease, and then grows again, going to saturation (Fig. 4.1.2).

We found that stabilization of thermal instability is realized through self-regulatory mechanisms that lead to saturation of absorption nonlinearity and leveling the rate of growth of the absorbed energy and heat. This bifurcation diagram of temperature dependence of the radiation power of the material explains the non-monotonic behavior optical density D amorphous condensates $Ge-As-Te$

and helps identify the exposure threshold range of laser radiation are considered. For powers $P > P_c = (7.6 \div 8.5) W/cm^2$ (the intensity is $I = 0.3\ W$, the effective radius of the beam is $r_0 = 0.11\ cm$) exposure duration threshold at which the growing instability manner $(0.35 \div 0.4)\ s$ corresponding exposure in the range

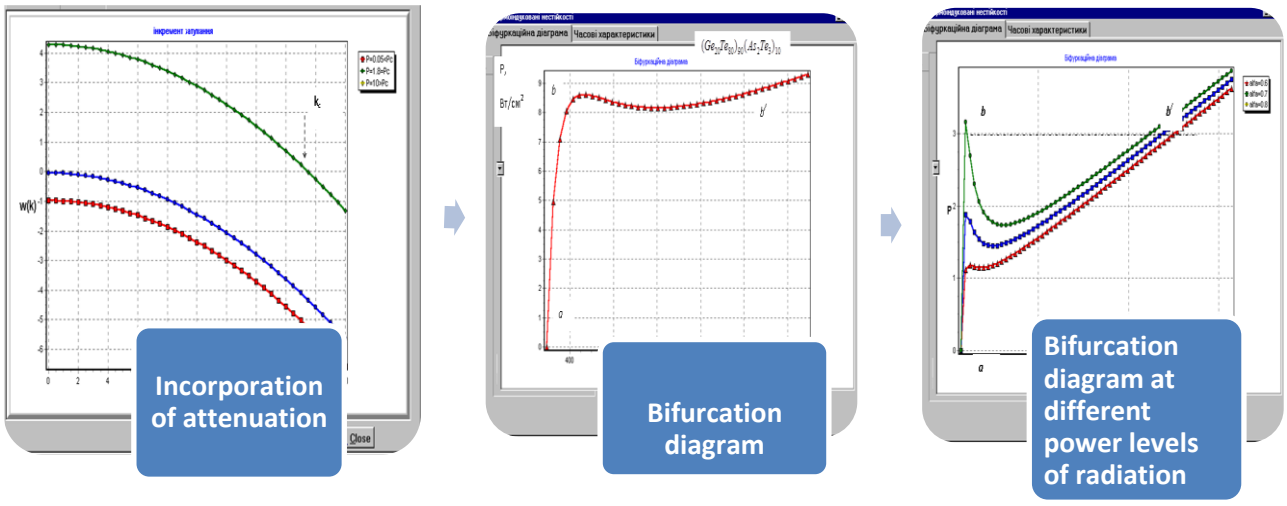


Fig.4.1.2. Thermo-induced transformations in amorphous condensates $Ge-As-Te$ *under the influence of infrared radiation and bifurcation diagram.*

of non-monotonic behavior D. Typical values scale spatial heterogeneity of the temperature profile are $L_c \approx (0.3 \div 0.5) \cdot r_0$, the lifetime of dissipative structures are $\tau_{life} \approx (10^{-1} \div 10^{-6}) s$, consistent with experimental data. It is shown that radial-ring structure with the number of beams $m \geq 3$ formed by irradiation power density $P \geq 18.6\ \ W/cm^2$.

The above principles of the formation of levels and classes of the ordered dissipative structures can perfectly be applied to the development of systems for technical protection of cyber information. The positive aspect of the proposed

approach is, first of all, a mathematical instrument for analyzing the stability of the solutions, their branching, and the ability to control the parameters of the system. In addition to this approach to structuring self-organized systems, we also offer the possibility of adapting algorithms for the formation of radial-ring structures for the development of software encryption-decryption of information, which is extremely important at the present stage of development of information technology (Mar'yan, Seben & Yurkovych, 2018). In particular, the algorithm and software complex for pixel processing and encryption of visual information with the use of raster and fractal graphics for the formation of ordered radial-ring structures have been tested (Yurkovych, Seben & Mar'yan, 2017).

The model of influence of electromagnetic radiation in the visible spectral region ($\Lambda = 0.63\ \ mkm$, laser power density $P \le 1\ \ W/cm^2$) on the formation of dissipative structures in layers of non-crystalline materials of systems $As - S(Se)$

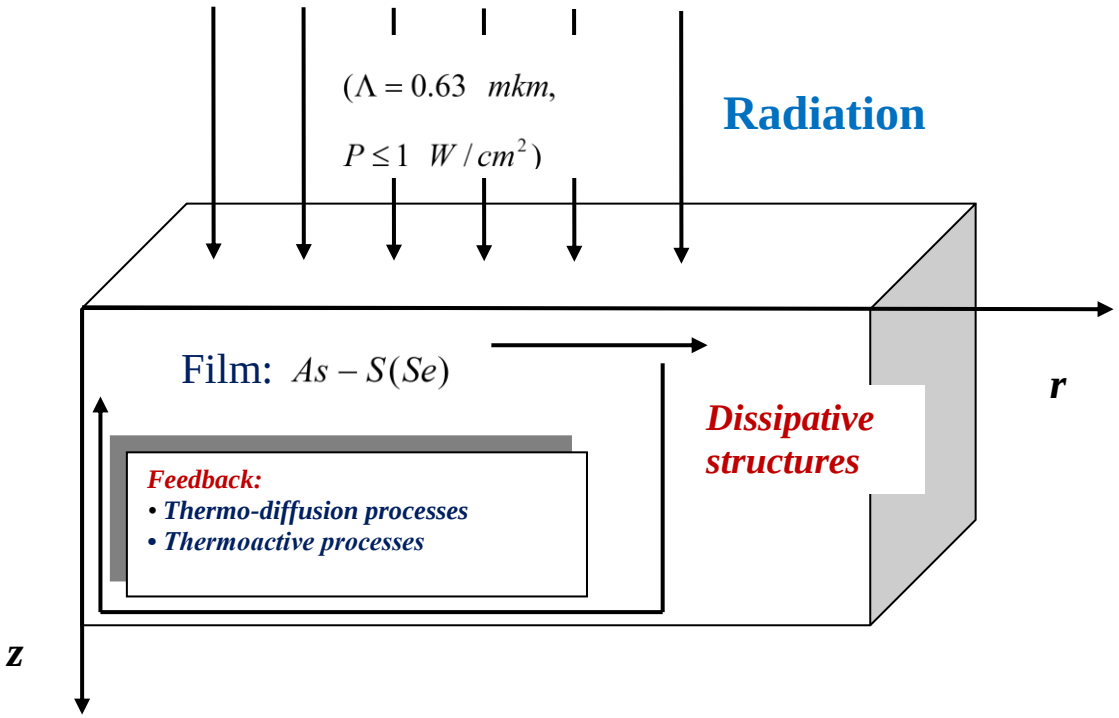


Fig. 4.1.3. Effect of electromagnetic radiation on non-crystalline materials of systems $As - S(Se)$ *in the visible spectral region* $(\Lambda = 0.63\ \ mkm,\ \ P \le 1\ \ W/cm^2)$.

and its analysis on the basis of experimental research is presented (Fig. 4.1.3).

The kinetics of the change in the number of atoms in soft configurations N_2 and temperature T are considered (Mar'yan & Szasz, 2000):

$$\frac{\partial N_2}{\partial t} = G - \frac{N_2 - N_{20}}{\tau_{rel}} + D \cdot \nabla^2 N_{2,} \qquad G = \gamma P \beta V / \hbar\omega, \tag{4.1.6}$$

$$\rho C \frac{\partial T}{\partial t} = div(\chi \cdot grad(T)) + W(T) - Q(T), \qquad W(T) = \gamma \cdot P.$$

Parameters of the dissipative structures (Fig. 4.1.4) are analyzed (Fig. 4.1.5, table 4.1.1):

$$L_c = 2\pi / k_c = \frac{2\pi}{\sqrt{\frac{(G_0 - G_{\min})}{D\tau_{rel} G_{\min}}}}, \qquad G_{\min} = \frac{\gamma_0 \hbar}{\tau_{rel} \beta_{N_2} \left(\frac{\partial \gamma}{\partial \omega}\right)} \left(1 - \frac{\beta_T}{a_T \beta_{N_2}}\right),$$

$$\tau_{life} \approx \left(\frac{(G_0 - G_{\min})}{\tau_{rel} G_{\min}} - D \cdot k_c^2 \right)^{-1}, \qquad m = \frac{k_c^2 r_0^2}{4} - 1 = \frac{G_0 - G_{\min}}{4D\tau_{rel} G_{\min}} \cdot r_0^2 - 1.$$

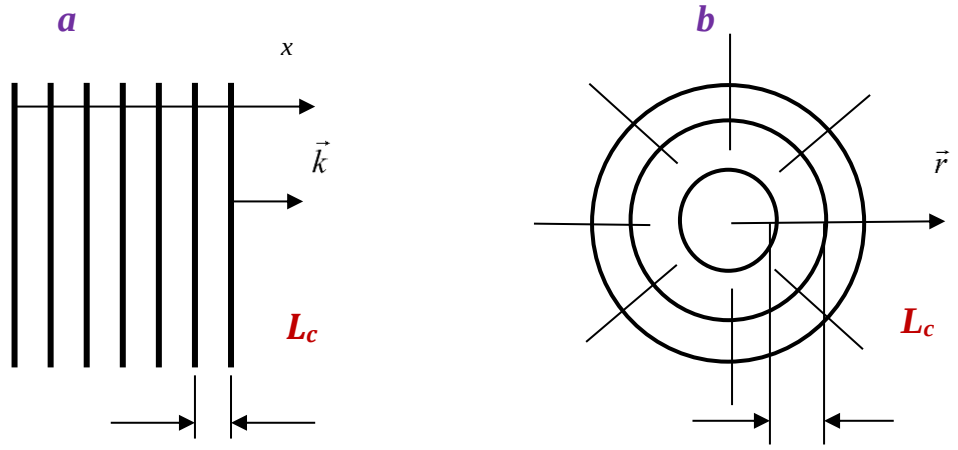


Fig. 4.1. 4. Types of formation of dissipative structures under the influence of electromagnetic radiation: a - linear inhomogeneous structure; b - radial-ring structure.

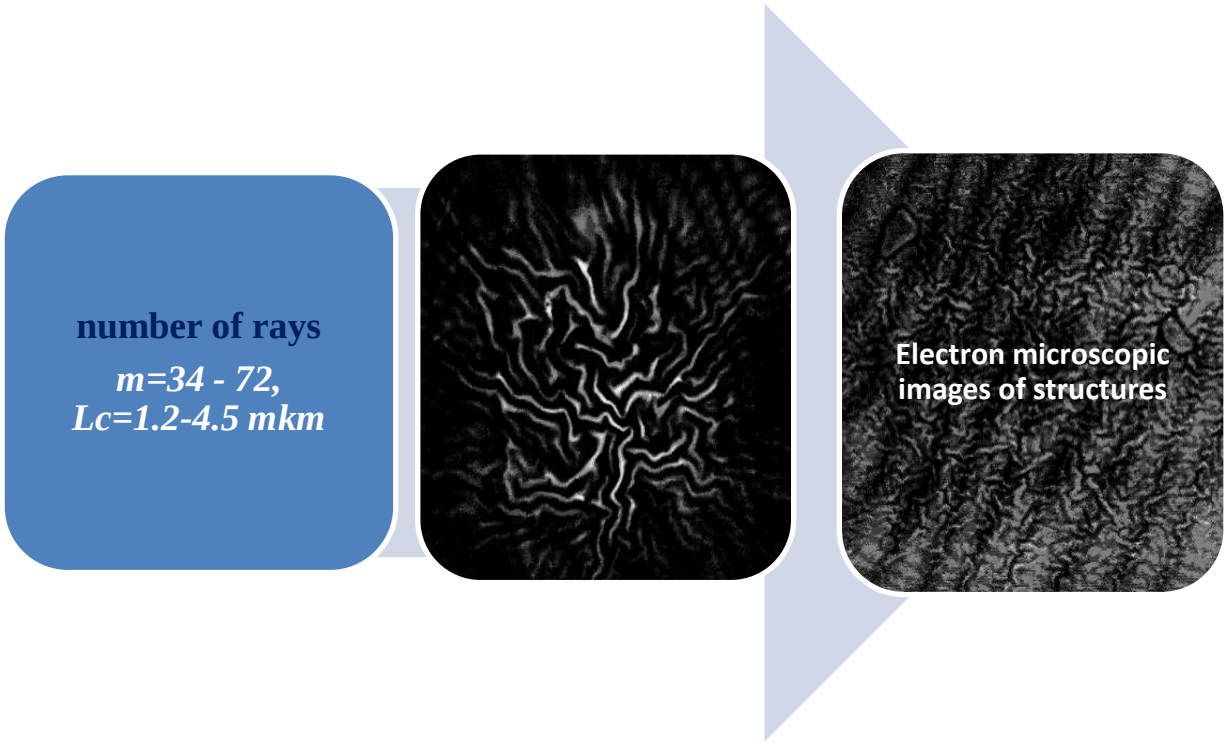


Fig. 4.1.5. Types of dissipative structures under the influence of electromagnetic radiation in the non-crystalline materials As_2Se_3 (Mar'yan, Szasz, Szendro & Kikineshy, 2005).

Table 4.1.1. Parameters of the dissipative structures of systems $As-S(Se)$

Parameters of electromagnetic radiation laser $He-Ne$	$r_0 \approx 0.11 cm,$ $G_{\min} \approx (10^{17} \div 10^{18})\text{quantum}/(cm^2 \cdot s)$
Period of the dissipative structure	$L_c \approx (10^{-2} \div 10) mkm$
The lifetime of a dissipative structure, which is formed on the basis of the distribution of soft atomic configurations	$\tau_{life} \approx (10 \div 10^4) s >> 1$
The lifetime of a dissipative structure based on clusters of soft configurations	$\tau_{life} \approx (10^{-5} \div 10^{-1}) s$

So, the formation of orderly self-organized structures in the non-crystalline materials depending on external factors is considered. The application of these structures in cyber systems is analyzed (Mar'yan, Seben & Yurkovych, 2018).

4.2. Hypersensitivity of the dissipative structures in cyber systems and self-organizing processes

Under the action of electromagnetic radiation on the layers of non-crystalline materials, during the transition to the non-crystalline state, under the influence of external noise, processes of self-organization and formation of dissipative structures are possible. Dissipative structures have a hypersensitivity that is related to their informational nature and can be applied to the development of sensory devices and diagnostics (Mar'yan, Seben & Yurkovych, 2018).

Stability of solutions by Lyapunov (Mar'yan & Szasz, 2008)

$$Y_j = Y_{js} + \delta Y_j, \qquad \delta Y_j = \left(B_j(t)e^{-\gamma_0 z} + C_j(t)e^{-\delta_j z}\right)\cdot e^{ikx+\int_0^t \lambda dt},$$

λ is increment of development of dissipative structure,

$\left.\frac{d}{dG_0}\lambda(G_0)\right|_{G_0=G_{\min}} = \frac{1}{\tau_{rel}\cdot G_{\min}} \neq 0$ is a condition of transversality. The results of the research of the information component of dissipative structure show that the life time τ_{life} has a fractal structure. This phenomenon defines and forms an extremely unique feature of dissipative structures. This is hypersensitivity. Before considering this phenomenon of synergetics and self-organization, we will turn to this paragraph. The table 4.2.1 shows a time scale hierarchy for a variety of physical processes and processes implemented on the principles of self-organization and integrity.

Table 4.2.1. Hierarchy of time-based.

Time of the experiment $t_{exp} = n_{int} \cdot t_{int}$ **The number of interactions for the measurement** $n_{int} \approx 10^{3} \div 10^{6}$ **Characteristic time of interaction for different effects** t_{int}	
Nuclear magnetic resonance	$t_{int} \approx 10^{-1} \div 10^{-5}\, s$
Paramagnetic electronic resonance, ultrasound absorption	$t_{int} \approx 10^{-4} \div 10^{-8}\, s$
Combination light scattering, infrared spectroscopy	$t_{int} \approx 10^{-10} \div 10^{-11}\, s$
Hyper sensitivity of the dissipative structures in the presence of self-organization processes	
Sensitivity of the self-organized systems to initial conditions	$t_{tr} \approx 10^{-10} \div 10^{27}\, s$
System integrity, non-locality of causes and interconnectedness	$t_{tr} \approx 10^{-10} \div 10^{-27}\, s$
Harmonization of the nature of curves at different time intervals (fractality)	$t_{tr} \approx 10^{10} \div 10^{-27}\, s$

As can be seen, the time scales of structuring self-organization processes not only cover well-known physical systems, but also provide the opportunity to implement radically new areas and directions of structuring. This is achieved through the principles of the functioning of information systems (Fig. 4.2.1, 4.2.2).

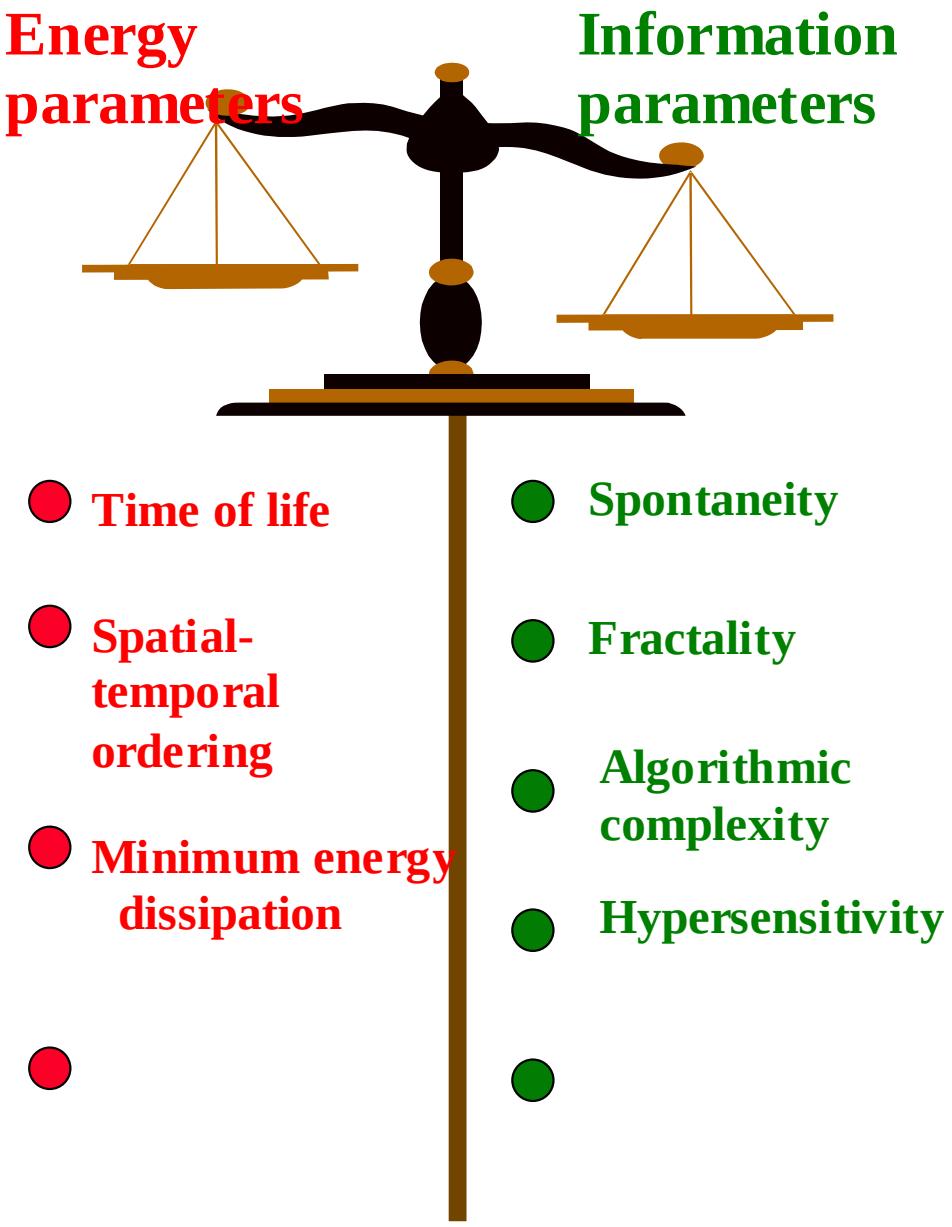


Fig.4.2.1. Synergetic approach to the formation of dissipative structures: hypersensitivity (Mar'yan & Szasz, 2008).

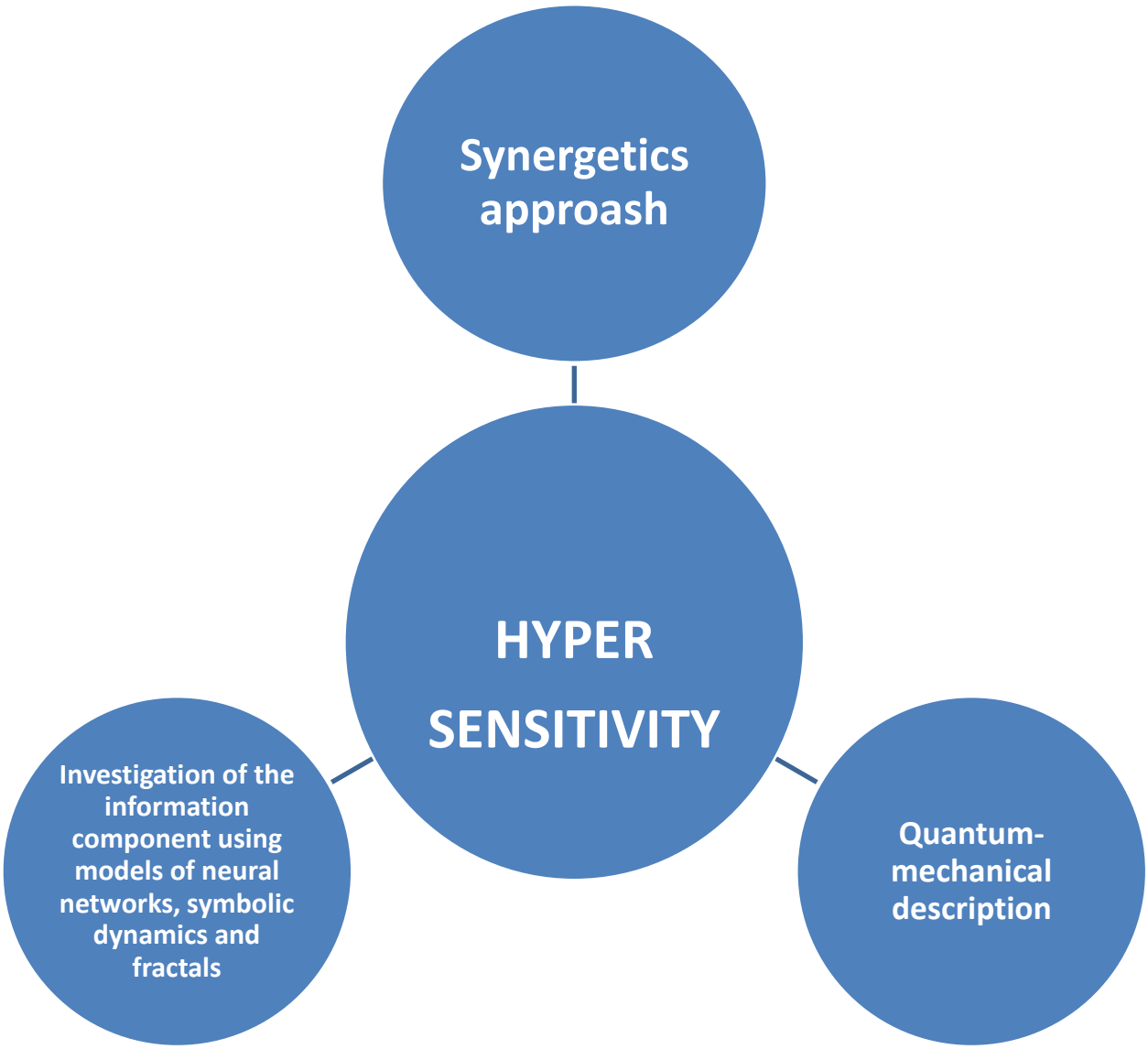


Fig. 4.2.2. Description of hypersensitivity of dissipative structures.

The description of hypersensitivity in the synergistic approach is based on the principles of quantum mechanics and the application of the functioning of information systems, namely, the theory of neural networks, symbolic dynamics and fractals (Fig. 4.2.2). With the term and specificity of hypersensitivity, we encountered in considering the peculiarities of the formation of order in non-

crystalline materials (Section 2), and the innovative development of educational sciences (Section 3). We are now summarizing these approaches and areas of their application. One such further application is the study of algorithmic complexity, which is inherent in both modern information technologies and the development of artificial intelligence (Fig. 4.2.3).

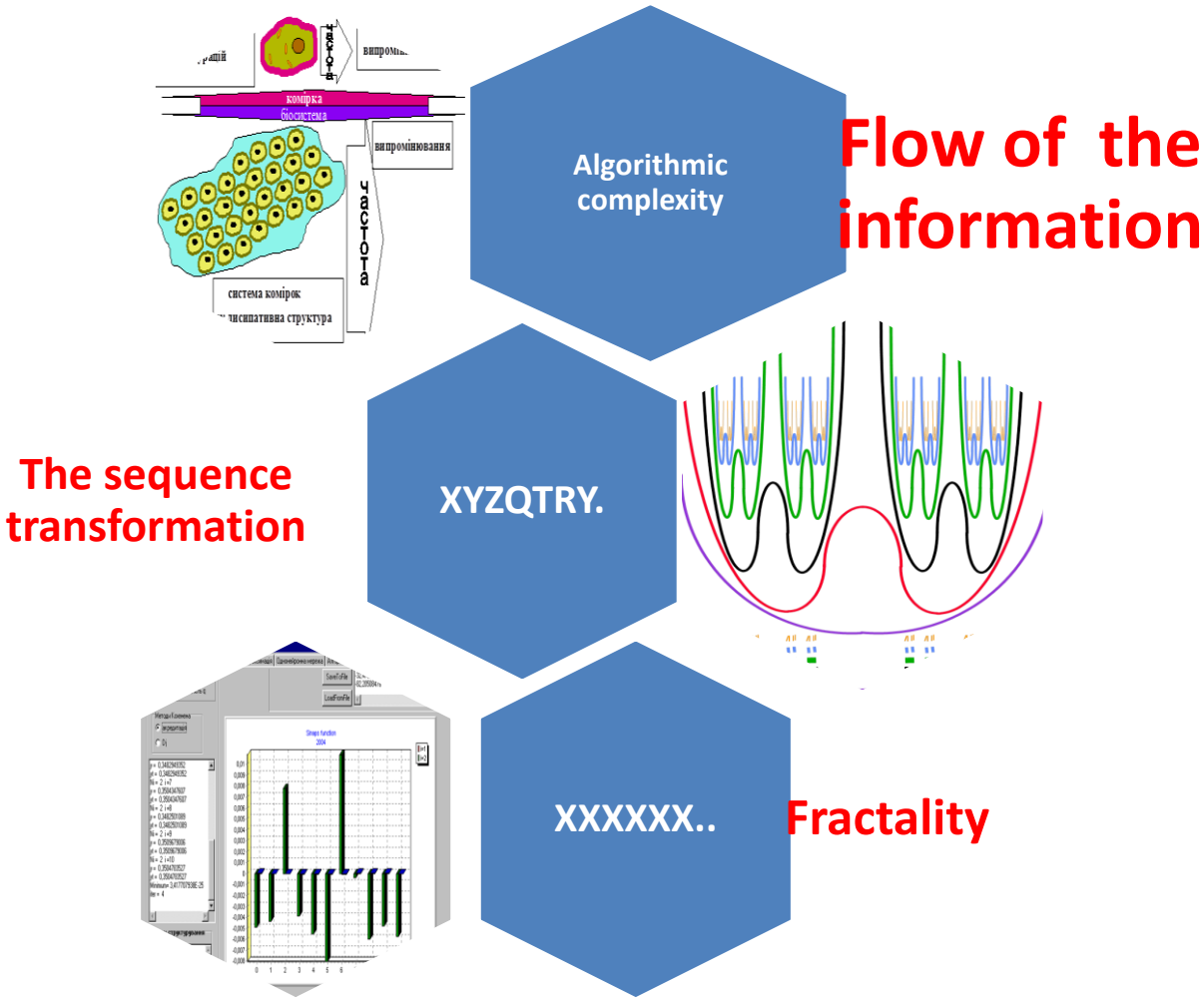


Fig. 4.2.3. Algorithmic complexity of Chapman-Kolmogorov.

In the presence of processes of self-organization and synergy, a distinct algorithm ***XYZQTRY…*** for the formation of the system is transformed into a no-dispositive ordering ***XXXXXX…***, one of which variants is a fractal structure. It is

for this type of structuring that the self-sufficiency and self-organization of the system are born due to the integrity algorithm (Mar'yan, Seben & Yurkovych,

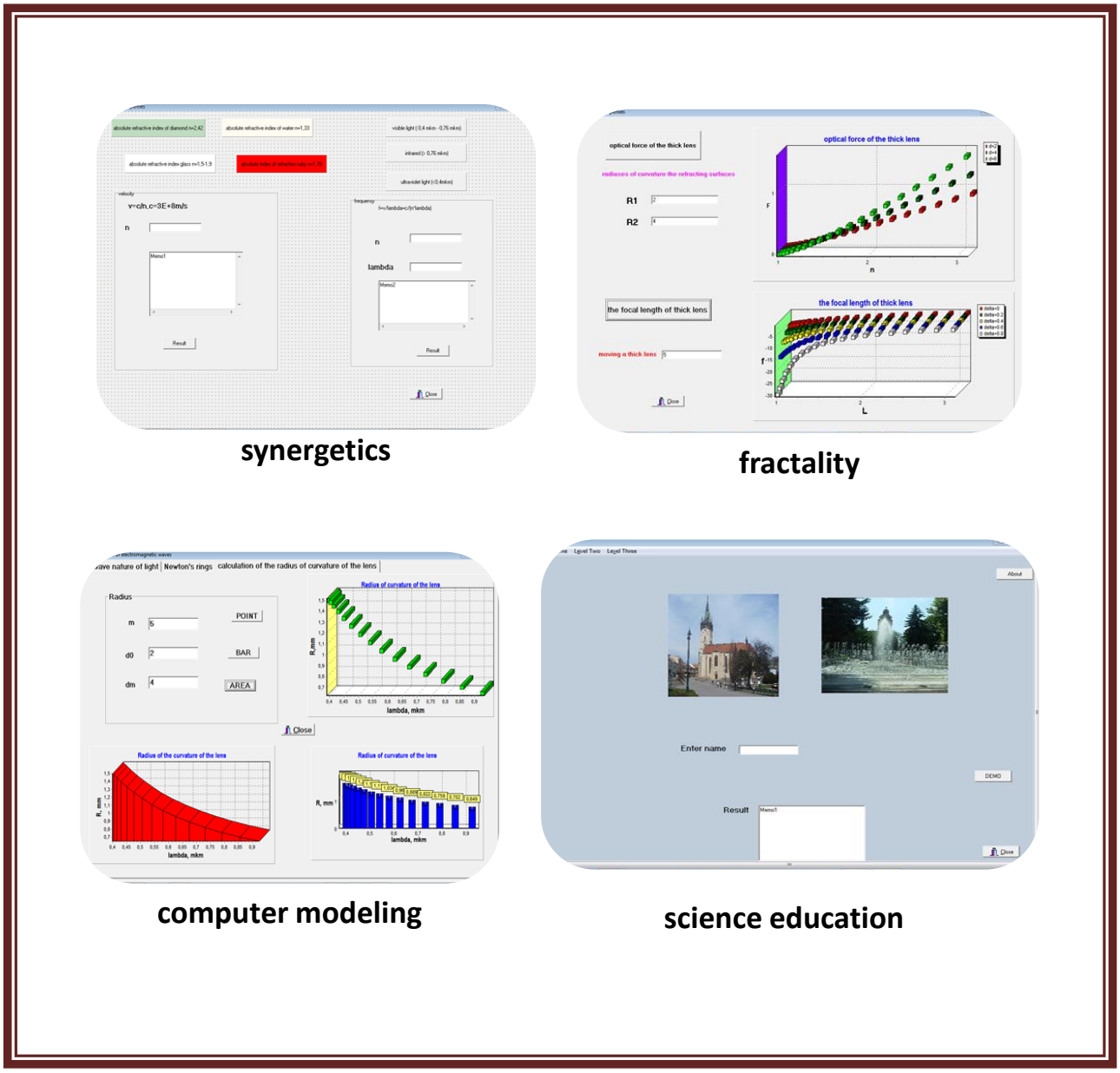


Fig. 4.2.4. Illustration of integration of innovative approaches in the science education.

2018). Such systems and innovative approaches were analyzed in detail in section 3 of this monograph for educational sciences by the example of constructing a fractal structure in the teaching of natural sciences and illustrated in Fig. 4.2.4.

Appendix A. Iteration procedure of the point mapping

We shall apply the iteration procedure of point mapping to the differential equations (2.3.2), (2.3.4) (section II). Consider for simplicity the one-dimensional case. For the initial conditions x_0 we shall draw the phase trajectory, e.g., vertically upward from the point $\{x = x_0, y = 0\}$, until it crosses the curve at the point $\{x_o, y_0(x_o)\}$. Then we draw the horizontal line from the point until it crosses y at the point $\{\varphi(x_o), y_0\}$, i.e. transform the point into the point $x_1 = \varphi(x_0)$. Thus, we obtain a certain set of points which transit sequentially into each other, indicating the occurrence of a certain function , which relates the locations of two sequential points x_n and :

$$x_{n+1} = \varphi(x_n). \qquad \text{(A1.1)}$$

This relation defines the point mapping. The sequential application of the mapping (A1.1) allows one to obtain the infinite sequence of points:

$$x_0, x_1, x_2, x_3, ..., x_n,$$

which is uniquely determined by the coordinate of the initial point x_0. The use of the point mapping instead of differential equations when studying the dynamics of certain systems is of interest both from the standpoint of clarity and in relation with the numerical analysis, since the dimension of the system is reduced by a unit in going to mapping.

A set of $x_1, x_2, x_3, ..., x_n$ iterations is called the orbit or the mapping trajectory. A motionless point x_s is called stable if for sufficiently small values of the external parameter the iterations x_n converge to x_s regardless of the initial value of x_0. A motionless point x_s is called unstable if almost for all x_n the iteration process diverges.

Consider the construction of the bifurcation diagram, i.e. branching of the x_n solutions on the r_m parameter, for the one parameter square Fejchenbaum's mapping:

$$x_{n+1} = r_{m0} x_n (1 - x_n), r_{m0} = 4r_m \quad , \qquad \text{(A1.2)}$$

where r_m, r_{m0} are the parameters of Fejchenbaum's mapping.

The values of parameters, for which the topological (or qualitative) change of movement regimes in the system occurs, are called bifurcation values, and this change is called bifurcation. Let us gradually raise the r_{m0} parameter within the 0 to ∞ range.

- $0 \le r_{m0} \le 1$. In this case the square reflection has only one fix point $x_n = 0$, which is stable.
- $1 < r_{m0} \le 3$. For $r_{m0} > 1$ the fix point $x_n = 0$ loses its stability, because here $d\varphi(x_n)/dx_n > 1$, and one more fix point $x_n = 1 - 1/r_{m0}$ appears in the range [0,3]. The fixe point will be stable, because $d\varphi(x_n)/dx_n = 2 - r_{m0}$ (look Fig. A1.1).
- $3 < r_{m0} \le 1 + \sqrt{6}$. If $r_{m0} > 3$, the mapping again is subjected to a new bifurcation, the fix point $x_n = 1 - 1/r_{m0}$ becomes unstable. A double circle appears, which is created by two fix points

$$x_2^{(1),(2)} = (r_{m0} + 1 \pm (r_{m0}{}^2 - 2r_{m0} - 3)^{1/2})/2r_{m0}. \qquad \text{(A1.3)}$$

- $1+\sqrt{6} < r_{m0} = 3.5699$. When the r_{m0} parameter crosses the value, a new bifurcation takes place: the double circle $\{x_1^{(1)}, x_2^{(2)}\}$ loses its stability, but a new four-fold circle appears. For $r_{m0} \geq 3.54$ this circle becomes unstable and it is replaced by a new stable circle with a period 2, and so on. The successive bifurcations of double periods take place at $r_{m\infty} = 3.5699$.
- For $r_{m\infty} < r_{m0} \leq 4$ the mapping have circles with an arbitrary period, including periodical trajectories. The dynamics of the dissipative structure becomes complicated and versatile, it has an ergodic property and mixing with exponential scattering of close trajectories.

Similarly to Fig. A1.1, the bifurcation pattern will also be observed for an arbitrary point mapping with a single maximum, which is approximated by the square parabola. So, the complicated chaotic evolution regimes are observed for non-linear dynamical systems.

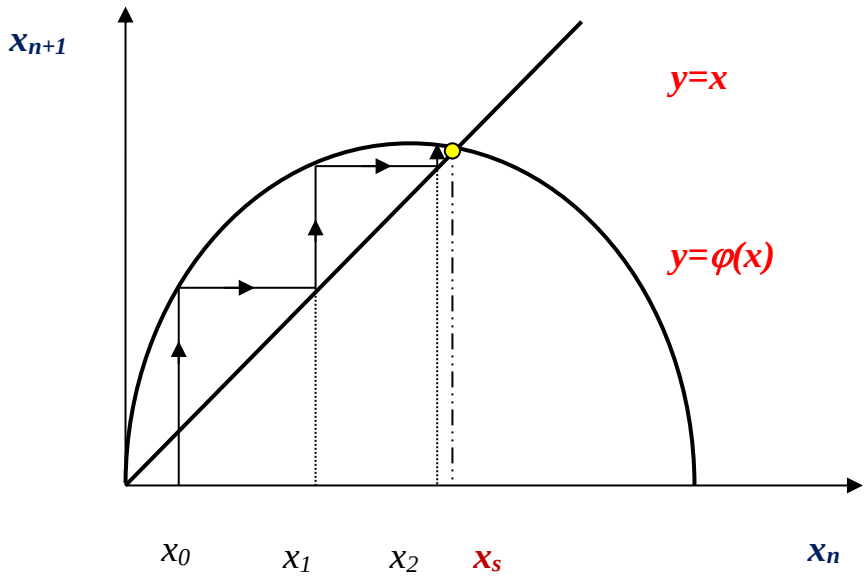


Fig. A1.1. Point mapping of $x_{n+1}=\varphi(x_n)$.

Appendix B. Regular fractals

To clarify the significance of self-similarity considers an example of Koch's regular fractal, i.e. the object which is self-similar at all length scales. Let us introduce the unit length section and partition it into three parts each being 1/3 long. Then remove the central 1/3 long part of the section, thus producing the triangular hump in a curve, whose overall length becomes 4/3. At the next step each 1/3 long segment is partitioned into three parts each being 1/9 long, and this procedure is repeated an infinite number of times producing an infinitely long curve comprising an infinite number of small segments. This curve is called the triangular Koch's curve.

Consider the dimensionality of the regular Koch's fractal. For the unit length section, partitioned into equal parts each of L length. Similarly, for the square lattice we have $N_l = 1/L^2$. Thus, for the d_f-dimensional object, $N_l = 1/L^{d_f}$. Hence, after logarithmic, we obtain:

$$d_f = \log(N_l)/\log(1/L), \qquad \text{(B2.1)}$$

For the Koch's curve, at each reduction of the length L by factor 3, the number of segments increases four times. Therefore, for the Koch's curve, $N_l = 4, L = 1/3$ and $d_f = \log(4)/\log(3) = 1.262$. Thus, the Koch's curve is not just an one-dimensional object, but a two-dimensional one.

Similarly, the regular fractals of the square Koch's curve, is built.

Thus, the sequential stages for the Serpinsky's spacer are as follows (Fig. B2.1). The unit triangles are partitioned into nine equal parts and the central triangle is removed. The same procedure is repeated for each of the rest parts, and the shaded regions are removed.

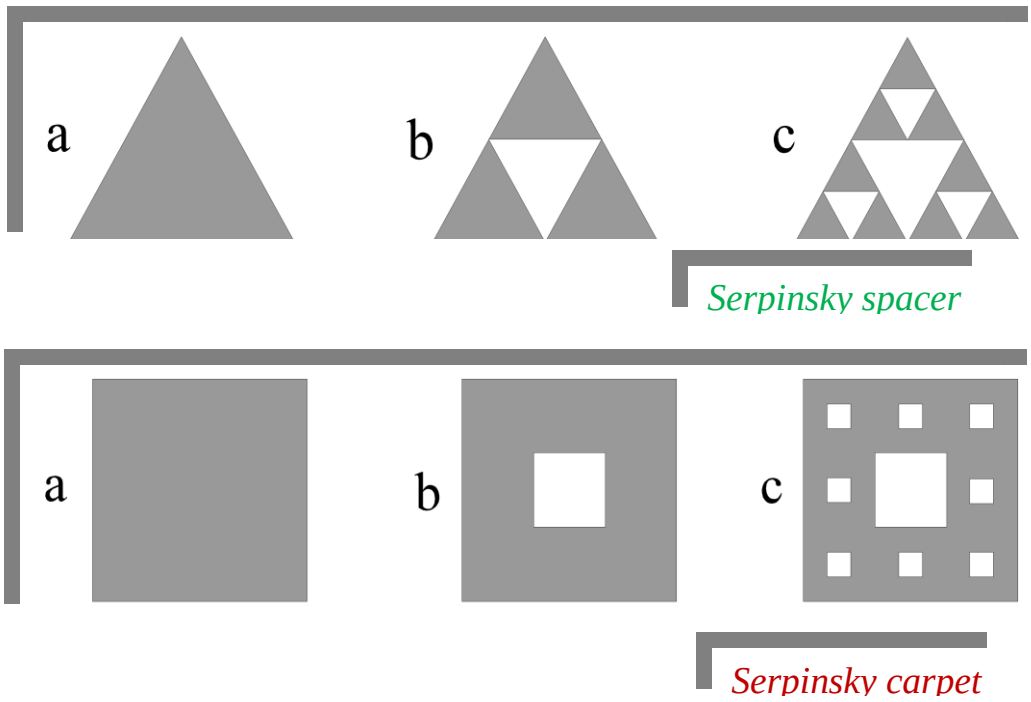
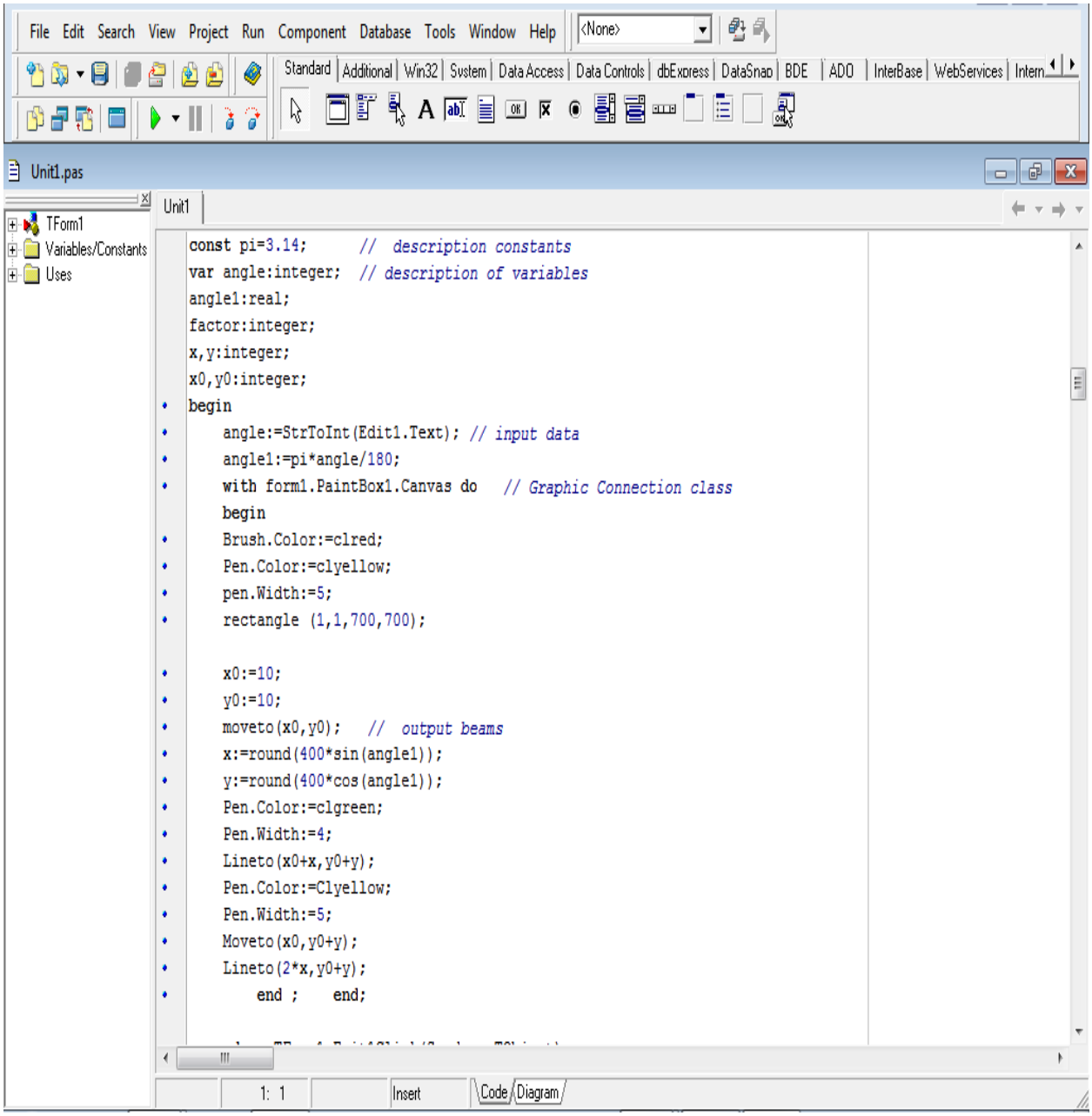
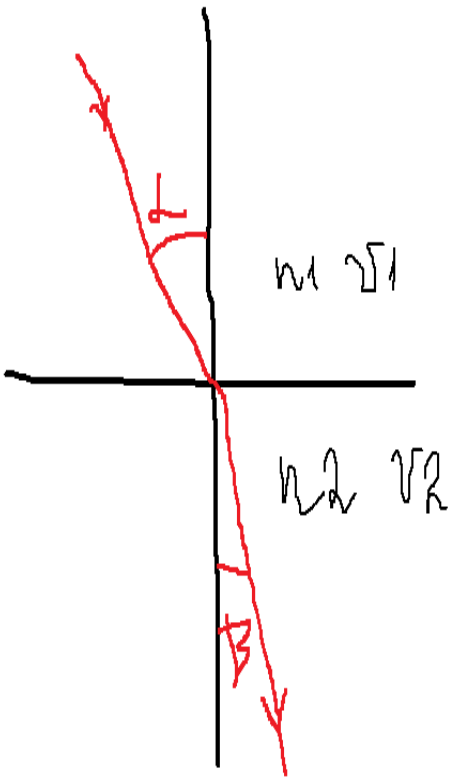


Fig. B2.1. Geometrical fractals of the Serpinsky's spacer and Serpinsky's carpet.

Appendix C. Program code in Object Pascal language in Delphi environment



Appendix D. Example of the Snell's law record for students



$$\frac{\sin\alpha}{\sin\beta} = n_{21}$$

$$n_{21} = \frac{v_2}{v_1} = \frac{n_2}{n_1}$$

Appendix E. Two-parametric approximation

The two-parametric dependence has been considered

$$y = g \cdot e^{m \cdot z} \ , \qquad \text{(E5.1)}$$

where m, g - vibrational parameters which are determined in the process of computer modeling.

Having taken the logarithm, we receive:

$$\ln(y) = \ln(g) + m \cdot z \ . \qquad \text{(E5.2)}$$

Here from:

$$\ln(y) - \ln(g) - m \cdot z = 0 . \qquad \text{(E5.3)}$$

Summing the squared values in (E5.3), we obtain the mean square deviation

$$\delta_n^2 = \sum_{i=1}^{n} (\ln(y_i) - \ln(g) - m \cdot z_i)^2 \ , \qquad \text{(E5.4)}$$

where n is the number of experimental values. Taking derivatives of the vibrational parameters m, g :

$$\begin{aligned} \frac{\partial \delta_n^2}{\partial m} &= 2 \cdot \sum_{i=1}^{n} (\ln(y_i) - \ln(g) - m z_i) \cdot (-z_i). \\ \frac{\partial \delta_n^2}{\partial g} &= 2 \cdot \sum_{i=1}^{n} (\ln(y_i) - \ln(g) - m z_i) \cdot \frac{1}{g}. \end{aligned} \qquad \text{(E5.5)}$$

A necessary condition for the minimum value $\delta_n^2(m, g)$ till m, g is the equality of the partial derivatives to zero (E5.3). Therefore,

$$\begin{aligned} \ln(g)\cdot\sum_{i=1}^{n} z_i + m\cdot\sum_{i=1}^{n}(z_i)^2 &= \sum_{i=1}^{n} z_i\cdot\ln(y_i). \\ n\cdot\ln(g) + m\cdot\sum_{i=1}^{n} z_i &= \sum_{i=1}^{n}\ln(y_i). \end{aligned} \qquad \text{(E5.6)}$$

From (E5.6) we obtain:

$$\begin{aligned} m &= n\cdot\frac{\sum_{i=1}^{n} z_i\cdot\ln(y_i) - \sum_{i=1}^{n}\ln(y_i)\cdot\sum_{i=1}^{n} z_i}{n\sum_{i=1}^{n} z_i^2 - \sum_{i=1}^{n} z_i\cdot\sum_{i=1}^{n} z_i}, \\ \ln(g) &= \frac{\sum_{i=1}^{n} z_i\cdot\ln(y_i) - m\cdot\sum_{i-1}^{n}(z_i)^2}{\sum_{i=1}^{n} z_i}. \end{aligned} \qquad \text{(E5.7)}$$

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Notation

$A(t)$, $B(t)$ - Arbitrary operators

$A(x)$ - Spatial region of soft structural states

a, b - Potential constants

a - Average interatomic distance

a_r - Relaxation process constant

a_{ij} - Matrix elements

C_P - Heat capacity

C_i - Reagent concentration

$C(t)$ - Product concentration

CN - Co-ordination number

$c(\tau)$ - Correlation function

c_0 - Correlation function constant

D - Diffusion coefficient

$D_0(x)$ - Soft domain of the diffusion constant

$\widetilde{D}_{ll'}^{\alpha\beta}$ - Self-consistent mean-square of atomic displacements

d - space dimensionality

d_f - Fractal dimensionality

d_l - Layer thickness

dE - Energy increase

dN_k - Particle number of the k-th component increase

dS - Entropy increase

dV - Volume increase

$(dS)_i$ - Entropy production inside the system

$(dS)_e$ - Entropy flux due to the matter and

E - Energy of state

$\widetilde{E}$ - Self-consistent energy of system

$\vec{E}$ - Electrostatic field vector

$E(t)$ - Emission initiation of laser

E_g - Energy gap

$E(\vec{r},t)$ - Electromagnetic wave

F - Free energy functional; force

F_0 - Free energy functional for equilibrium state

$\mathtt{F}$ - External force

$\mathtt{F}_0$ - Amplitude of the external force

$\mathtt{F}_c$ - Critical value of amplitude external force

$\mathtt{F}\{x(t)\}$ - Fourier-transformation of the function

$\Im$ - Transformation function

$F(t)$ - Correlation function

$F(X,\lambda)$ - Non-central function of reagent concentration in the Belousov-Zhabotinsky reaction

$F_1(\sigma), F_2(y_l), F_3(y_t)$ - Non-linear functions σ, y_l, y_t

$\widetilde{F}_1'(\sigma)$ - The first derivative $\widetilde{F}_1(\sigma)$ with respect to σ

f - Elastic constant

$\widetilde{f}$ - Effective force constant

energy exchange with the environment

f_N - Force which results in the production of the diffuse fluxes

$f_\lambda(X(r,t))$ - Non-linear functional dependence

$G(ll',t)$ - Green's function

$G(k,\omega)$ - Green's function in k-representation

$G(\delta)$ - Non-central potential

$\widetilde{G}(\delta)$ - Self-consistent interaction non-central potential

G_0 - Non-central potential parameter

g - Force constant

$\widetilde{g}$ - Effective force constant

g - Gravitational acceleration

g_f - Statistical weight

$g(x,r,t)$ - Distribution function

H - Hamiltonian

$\widetilde{H}$ - Effective Hamiltonian

H_f - Hamiltonian of subsystem f

$H(\{\chi\})$ - Configuration Hamiltonian

$\hbar$ - Plank's constant

I - Intensity density of the incident wave

$I(x)$ - Intensity distribution across laser beam cross-section

$I(x,t)$ - Flux of the particles

I_0 - Constant of laser beam

$\widetilde{I}_\alpha(l,l')$ - Self-consistent interaction potential

J_e - Current density

$J(\eta,t)$ - Probability flux

f_T - Force which results in the production of the thermal fluxes

k_c - Critical wave-vector

k_B - Boltzmann constant

k_F - Fermi wave-vector

$k^+(x), k^-(x)$ - Velocity grows and decreases

L - Length

L_S - Short-range order distance

L_M - Mezo-scoping media-range order distance

L_c - Dissipative structure period

L_a - Transition energy difference

$L_{bistable}$ - Domains for bi-stable-element dimension

L_{multi} - Domains for multi-vibrating-element dimension

L_{auto} - Domains for auto oscillating-element dimension

M - Mass

N - Number of atoms

N_o - Defect states density

N_e - Number of equal parts

N_{grain} - Number of grains

N_1 - number of atoms in the solid-like state

N_2 - Number of atoms in the soft-like state

N_f - Number of atoms in the f state

N_{norm} - Normalization factor

$\aleph(\vec{r})$ - Local physical quantities

P - Pressure

k - Wave- vector

P_c - Critical value of power

$\widetilde{P}$ - Reduced laser radiation power

$\vec{P}$ - Electric polarization vector

p - Parameter of relaxation process

p_S, q_S - Schlafly's symbols

$p(l)$ - Atom momentum

$p([\delta s])$ - Generalized entropy

$\vec{Q}$ - Reciprocal lattice vector

Q_i - Distribution parameter which characterizes the disordering in the system

$Q(T)$ - Heat exchange with the environment

q - Cooling rate

q_c - Critical cooling rate

$\widetilde{q}$ - Reduced cooling rate

$\widetilde{q}_c$ - Reduced critical cooling rate

q_1, q_2 - Bifurcation values of the cooling rate

q - Heat flux

R - Radius

R - Constant molecular gas

$\vec{R}_l$ - Average equilibrium position of the l -th atom

r - Interatomic distance

$\vec{r}_l$ - Radius-vector of the l -th atom

$r_m, r_{m0}, r_{m\infty}$ - Parameters of Fejchenbaum's mapping

$r_0(\eta), r_1(\eta)$ - Transformation function

S - Entropy

$S(f)$ - Spectral density function power

P^* - Reduced pressure

$\Re$ - Probability density

P - Laser radiation power

s_F - Forster's constant

s_0 - Beam cross section

T - Temperature

T_1, T_2 - Temperature of liquid layer lying between two parallel planes

T_m - Melting temperature

$T_f(l)$ - Kinetic energy of the l -th atom

$\widetilde{T}_f$ - Self-consistent kinetic energy of the f -th subsystem

t - Time

t_η, t_κ - Reduced time

U - Optical transmission

$U_f(\vec{r}_l)$ - One-particle potential

$U(\vec{r}_1, \vec{r}_2, ..., \vec{r}_N)$ - Potential energy of system

$u(l)$ - Dynamic displacement of atom

$u_{\alpha\beta}(l, l')$ - Relative displacement

V - Volume

$\widetilde{V}$ - Reduced volume

V_0 - Parameter of potential

V_{grains} - Volume of grains

V_{total} - Total volume

$V_{product}$ - Product volume

$V_{extended}$ - Extended volume

$V(x)$ - Rate of the change in the soft domain dimensions

$W(R_i)$ - Relaxation rate

s - Short-range order parameter

$X_s(\vec{r},t)$ - State system stationary parameter

$\dot{x}$ - Velocity

$\overline{x}$ - Average size of the sort configuration domain

x_o, y_o - Initial condition of the phase trajectory

Y_i - General intensities belonging to the i-th interaction

$y_{\alpha\beta}(l,l')$ - The mean-square relative displacement of the l,l/ atoms

y_l - Reduced mean-square displacement of atom along the bond

y_t - Reduced mean-square displacement of atom normally to the bond

$Y(\vec{r},t)$ - State system parameter

z - Number of closest neighbors

Z - Average coordination number

α - Optical absorption coefficient

α_T - Linear expansion coefficient

α_{ij} - Matrix quasi-stationary solutions elements

$\widetilde{\alpha}_i$ - reduced matrix elements

α_a - Non-linearity parameter

α_{norm} - Normalization parameter

β - Parameter of relaxation process

β - Quantum yield

β_T, β_N - Distribution constants

β_0 - Diffusion soft domains constant

X_i - General extensive belonging to the i-th interaction

$X(\vec{r},t)$ - State system parameter

γ - Damping constant

γ_i - Parameter of Landau-Khalatnikov regression equation

γ_o - Absorption coefficient prior to lighting

$\gamma(\omega)$ - Absorption coefficient

Δ - Laplacian

ΔT - Temperature gradient

ΔT_c - Critical value of temperature gradient

$\Delta\omega_2$ - Short-range disordering destroying

$\Delta y_l(\widetilde{q})$ - Reduced thermal displacements of particles in the equilibrium state along the bondings

δ - Deflection of the atom in the plane normal to the direction of the bond

δ_i - Mean-square displacement

$\delta(t)$ - Kronecker's symbol

$\delta(x)$ - Dirac function

δF - Free energy functional variation

$\delta\widetilde{\phi}_f^{\alpha\beta}$ - Force constant variation

$\delta\sigma$ - Fraction of atoms in the liqiud-like states variation

$\delta y_{\alpha\beta}$ - Mean-square relative displacements of atoms variation

δT - Temperature field variation

δg - Distribution function variation

∂_y , ∂_{yy} - First and second derivative

$\delta y_{\alpha\beta}$ - Mean-square relative displacements of atoms variation

δT - Temperature field variation

δg - Distribution function variation

δN_2 - Number atoms in soft configuration variation

$\delta\eta(r,t)$ - Order parameter variation

∂_y , ∂_{yy} - First and second derivative with respect to y

ε - Dielectric susceptibility

ε - Bethe's parameter

ε_m - Measure of the removal from the white noise approximation

π - 3.14

$\theta(t-t')$ - Heaviside's function

θ - Angle deviation

θ - Temperature expressed in Boltzmann constants

ϑ_E - Energy band deformation potential

η - Order parameter

$\vec{\eta}$ - Vector n-dimensional with the components $\eta_1,\eta_2,\ldots,\eta_n$

η_s - Stationary solutions of the order parameter

$\vec{\eta}_s$ - Vector n-dimensional with the components $\eta_1,\eta_2,\ldots,\eta_n$ in the

η_h - Heat exchange constant

$\sigma_f(l)$ - Configurationally function of two

δN_2 - Number atoms in soft configuration variation

$\delta\eta(r,t)$ - Order parameter variation

λ - External control parameter

λ_i - Eigenvalues

λ_t - External parameter for a system with white noise

$\lambda(k)$ - Damping decrement

$\lambda_{\max}$ - Maximum value of the function $\lambda(k)$

μ - Chemical potential

μ_k - Chemical potential of the k-th component

ν - Frequency

$\vec{\nu}(l)$ - Vector static displacement of the l-th atom

$\nu_\alpha(l/m)$ - Static displacements of the l-th atom when the atom m is in the liquid-like state

ν_{0f} - Geometrical-structure factor

ξ - Fluctuation around the average value

ξ_P - Anisotropy for different potentials parameter

ξ_d - Activation energy diffusion

$\vec{\xi}(t)$ - Negligibly small vector

ρ - Material density

κ - Compression modulus

κ_o - Heat conduction coefficient

$\tilde{\kappa}$ - Reduced heat conduction coefficient

ρ_e - Electric charge density

σ - Long-range order parameter

microscopic states

σ_2 - Fraction of atoms in the liquid-like states

$\sigma[\delta s]$ - Generalized entropy production

τ - Reduced temperature

τ_m - Reduced melting temperature

τ_c - Reduced critical temperature

τ_0 - Reduced synthesis temperature

τ_g - Reduced softening temperature

τ_p - Exposure time

τ_i - Relaxation time

τ_t - Reduced time

τ_{cor} - Correlation time

τ_{life} - Life-time

$\Phi(r,t)$ - Reduced temperature field

Φ_s - stationary temperature field

$\Phi(r)$ - Pair potential

$\Phi_1(r)$ - Long-range component of the pair potential

$\Phi_2(r)$ - Short-range component of the pair potential

$\widetilde{\Phi}_f$ - Self-consistent potential energy of the f -th subsystem

$\phi(\eta,q)$ - Non-linear function in equation bifurcation diagram

$\bar{\phi}(\eta,q)$ - Non-linear function in a stable stationary state

$\phi_{ff'}(\vec{r}_{ll'})$ - Interatomic interaction potential

$\widetilde{\phi}_f^{\alpha\beta}(l,l')$ - Force constant

φ - Soft states potential

$\varphi(x_n)$ - Point mapping function

χ_o - Effective beam radius

χ_l^f - Local characteristic function

$\widetilde{\Psi}(r)$ - Self-consistent central interaction potential

$\psi(r)$ - Central Morse-like potential

$\omega(\vec{k})$ - Frequency vibration of atoms

ω_0 - External force frequency

ω_{0k} - Resonant frequency

ω_L - maximum vibrational frequency

ω_f - Fraction of atoms in the f - th state

ω_2^e - Fraction of atoms in the equilibrium disordered state

Subject index

S

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W

Michajlo Marian, Vladimír Šebeň, Natalia Jurkovič. Synergetika a fraktality vo vede a vzdelávaní. – Prešov: Prešovska univerzita v Prešove, 2018. - 168 s.

Vytvorenie a zachovanie funkčnej organizácie, jej vývoj a realizácia je cieľom výskumu a jeho prvej etapy. Týka sa to problémov spojených s vývojom materiálov so štruktúrne citlivými vlastnosťami a rôznymi stupňami objednávania (vo väčšine prípadov tam je najdôležitejšie vytvorenie potrebného priestorového alebo priestorovo-časového usporiadania). Otázka optimálne štruktúrovanie a organizácie takisto relevantné pri štúdiu globálnych otázkach, vrátane energetiky, životného prostredia, vzdelávacie a iné, ktoré vyžadujú obrovské prostriedky. V tomto prípade je ťažké preceňovať dôležitosť samoorganizovanie a organizácie zákonov vo fyzických, technických a informačných systémoch.

Táto práca je venovaná tvorbe usporiadaných štruktúr a precitlivenosti systémov rôzneho charakteru (non-kryštalických pevných látok, materiály umelej inteligencie, informačných a komunikačných systémov, vzdelávania) prostredníctvom synergie myšlienok a počítačového modelovania. Naproti tomu niekoľko známych kníh o problém štruktúry, táto kniha poskytuje matematický základ a počet teoretických skutočností týkajúcich sa informačných technológií, prírodných vied. Dôležitý problém vplyvu rôznych oblastí na metastabilné systémy je v mnohých ohľadoch dôsledne analyzovaný a vedie k pochopeniu základného významu výskumu v tomto smere. Z tohto hľadiska vzdelanie je vnímané ako živý organizmus, v ktorých môžete dosiahnuť minimálnu úroveň disipatívnymi procesy a komplexné informačné vnímanie. Z úseku do sekcie sú uvažované úlohy čoraz jasnejšie a zodpovedajúce matematické modely samoorganizovaných procesov sú viditeľné. Takže táto kniha môže byť zaujímavá pre odborníkov pracujúcich v tejto oblasti vedy a pre tých čitateľov, ktorí sa len snažia porozumieť hlbokým vzťahom vo vedeckých materiáloch a informačných objektoch.

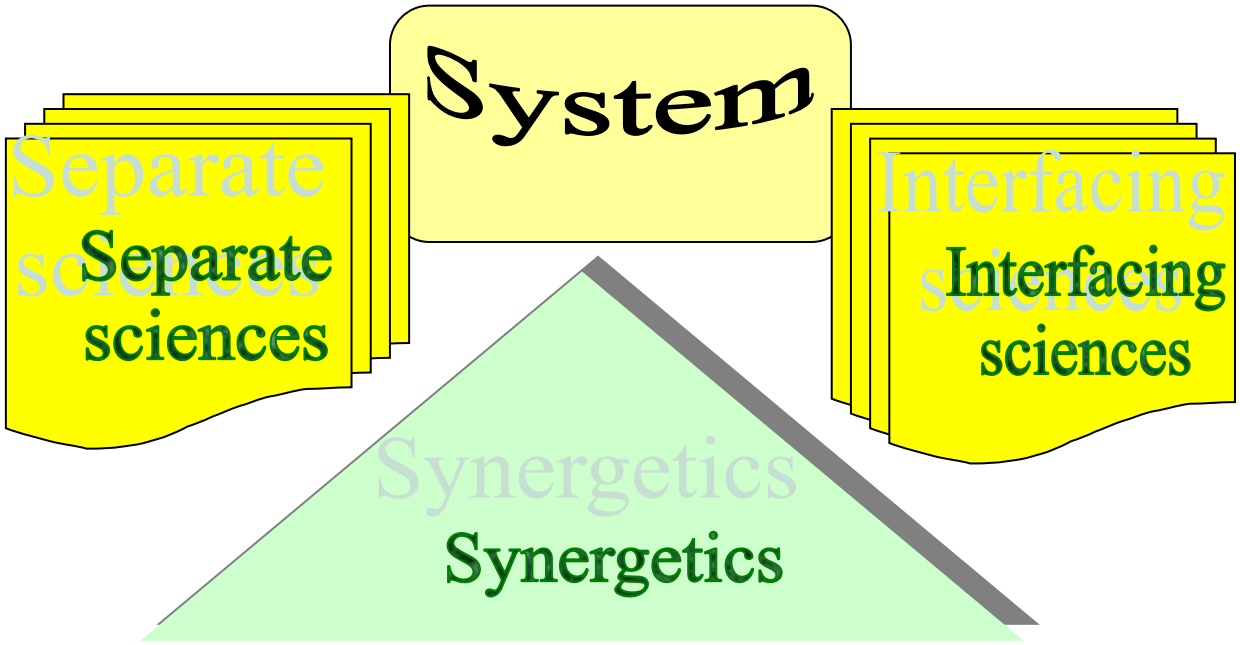
Михайло Мар’ян, Владімір Шебень, Наталія Юркович. Синергетика та фрактальність в науці та освіті. – Прешов: Прешовський Університет, 2018. - 168 с.

Формування і збереження функціональної організації, його розвитку та імплементації - це і мета дослідження, і її першочерговий етап. Це стосується насамперед проблем, пов'язаних із розробкою матеріалів зі структурно-чутливими властивостями та різним ступенем упорядкування (у більшості випадків тут найбільш важливим є створення необхідного просторового або просторово-часового упорядкування). Питання про оптимальне структурування та організацію також актуальне при вивченні глобальних проблем, зокрема енергетичних, екологічних, освітніх та інших, які потребують величезних ресурсів. У цьому випадку важко переоцінити важливість самоорганізації та законів упорядкування в фізичних, технічних, інформаційних системах.

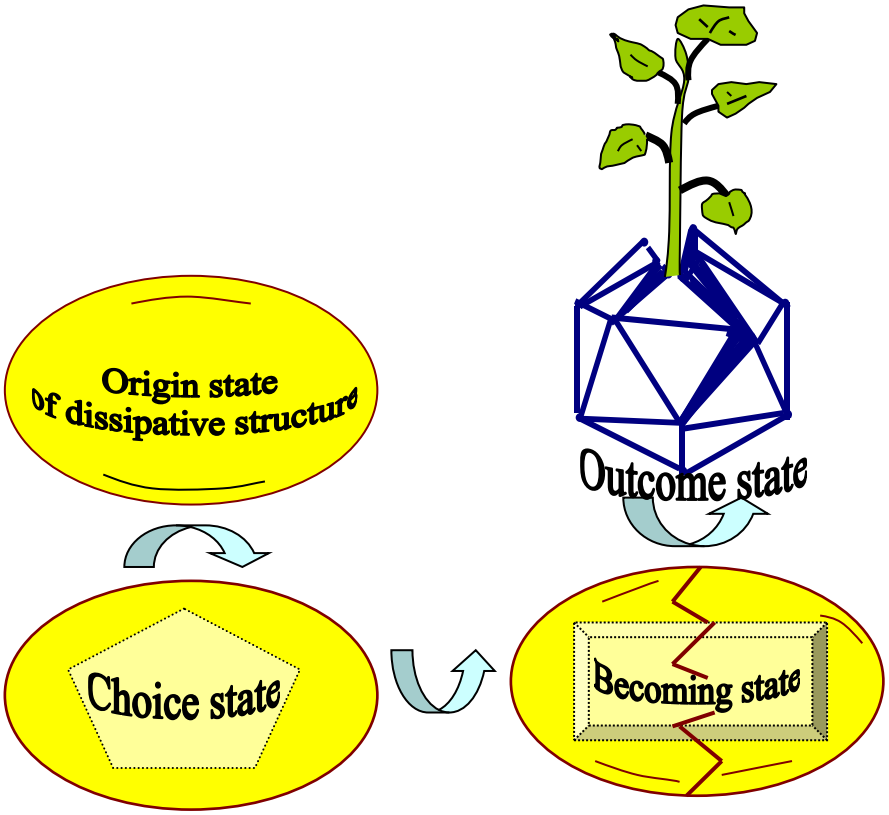
Дана книга присвячена дослідженню формування упорядкованих структур та гіперчутливості в системах різної природи (некристалічні тверді тіла, інтелектуальні матеріали штучного інтелекту, інформаційно-комунікаційні системи, освіта) за допомогою ідей синергетики та комп'ютерного моделювання. На противагу ряду відомих книг про проблему структурування, ця книга містить як математичний базис, так і ряд теоретичних фактів, що стосуються інформаційних технологій, природничих наук. Важлива проблема впливу різних областей на метастабільні системи послідовно аналізується у багатьох аспектах і призводить до розуміння суттєвої важливості досліджень у цьому напрямку. З цієї точки зору освіта розглядається як живий організм, для якого можна досягти мінімального рівня дисипативних процесів та всебічного інформаційного сприйняття. З розділу до розділу розглянуті завдання стають все більш ясними, а відповідні математичні моделі самоорганізованих процесів - більш наочні. Тож дана книга може бути цікавою для професіоналів, які працюють у цій галузі науки, так і для тих читачів, які просто намагаються зрозуміти глибинні взаємозв'язки в матеріалознавстві та інформаційних об'єктах.

FOR NOTES AND REVIEWS

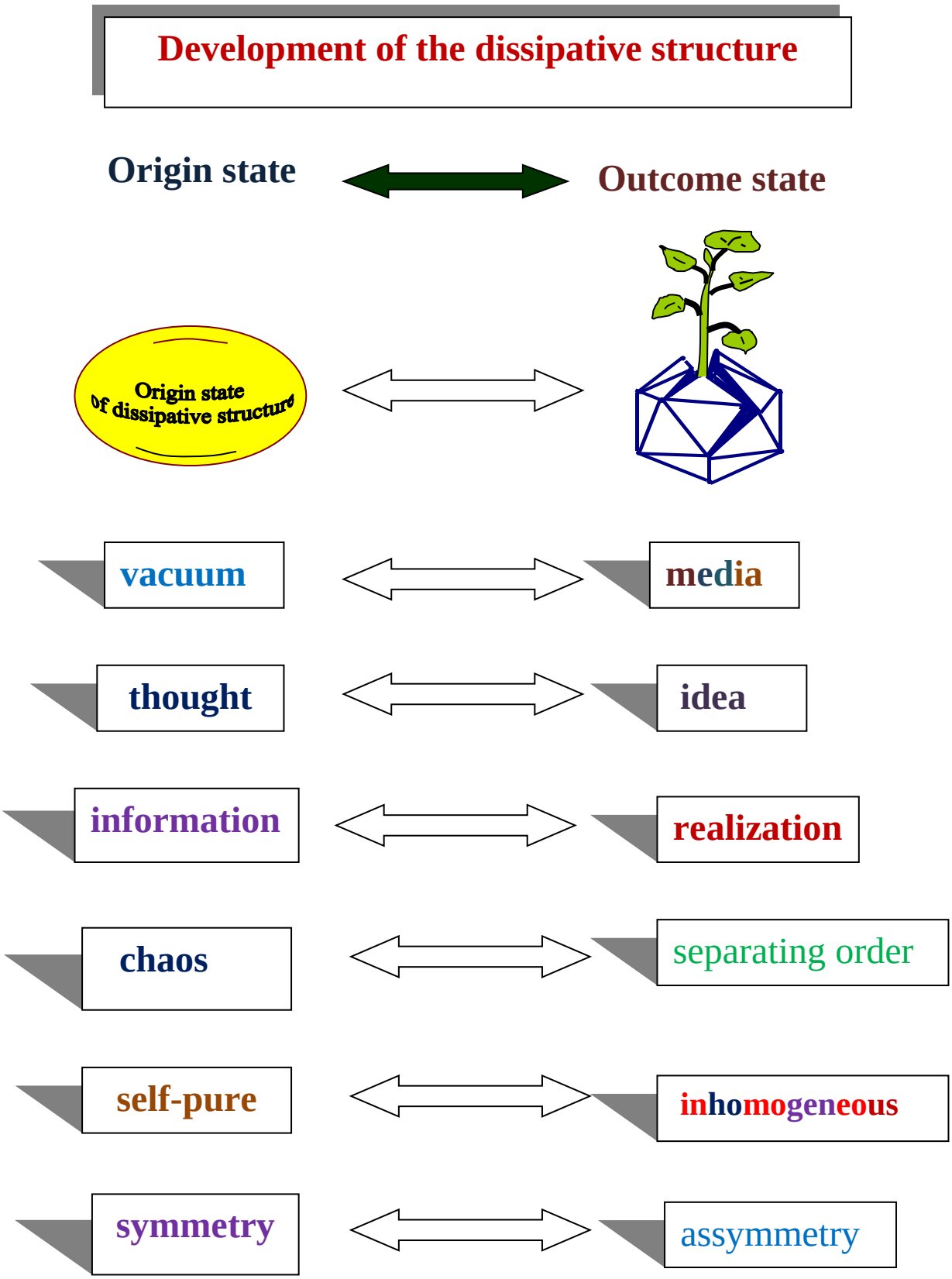
COLOR ILLUSTRASIONS



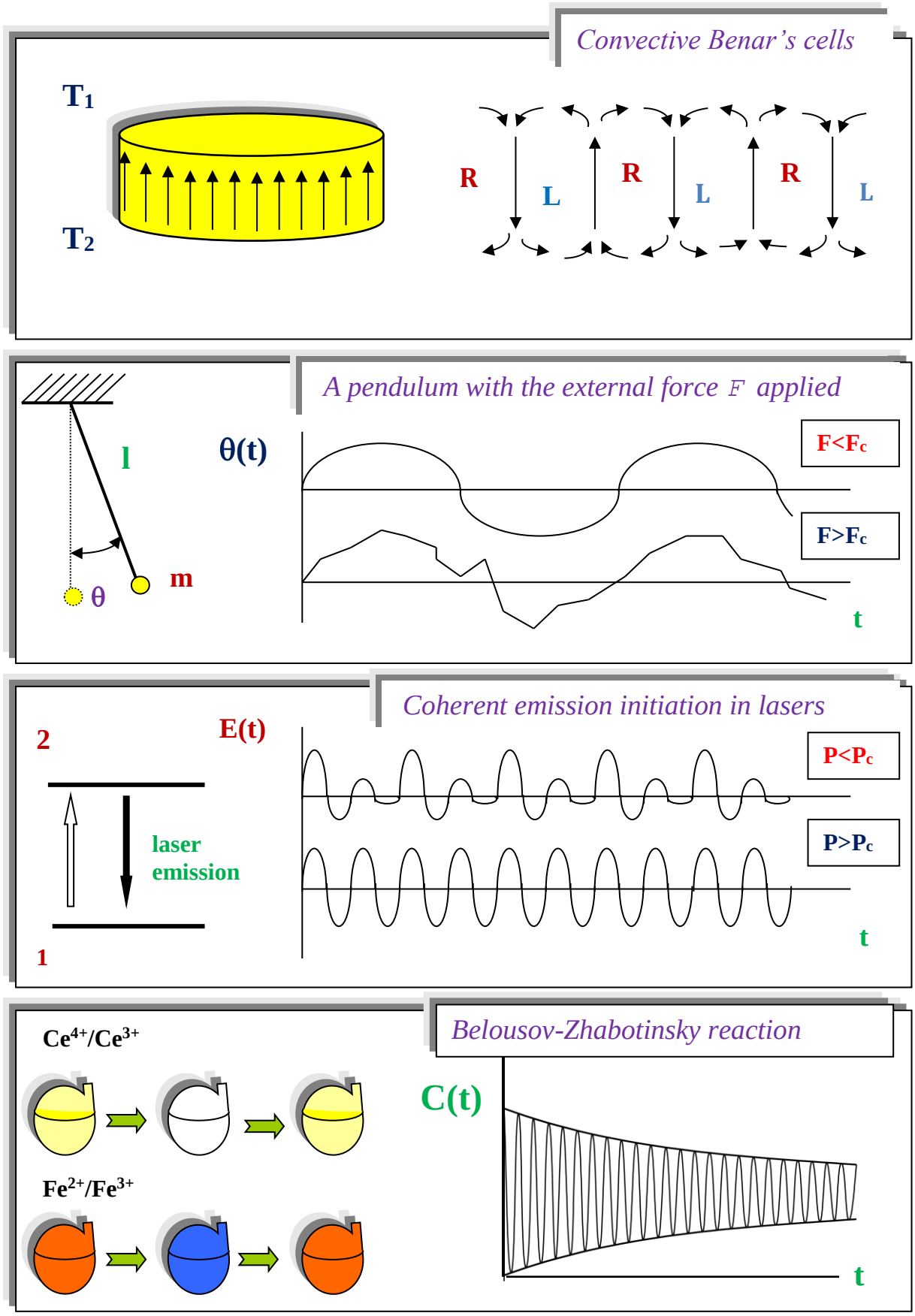
Synergetics as interdisciplinary field of science



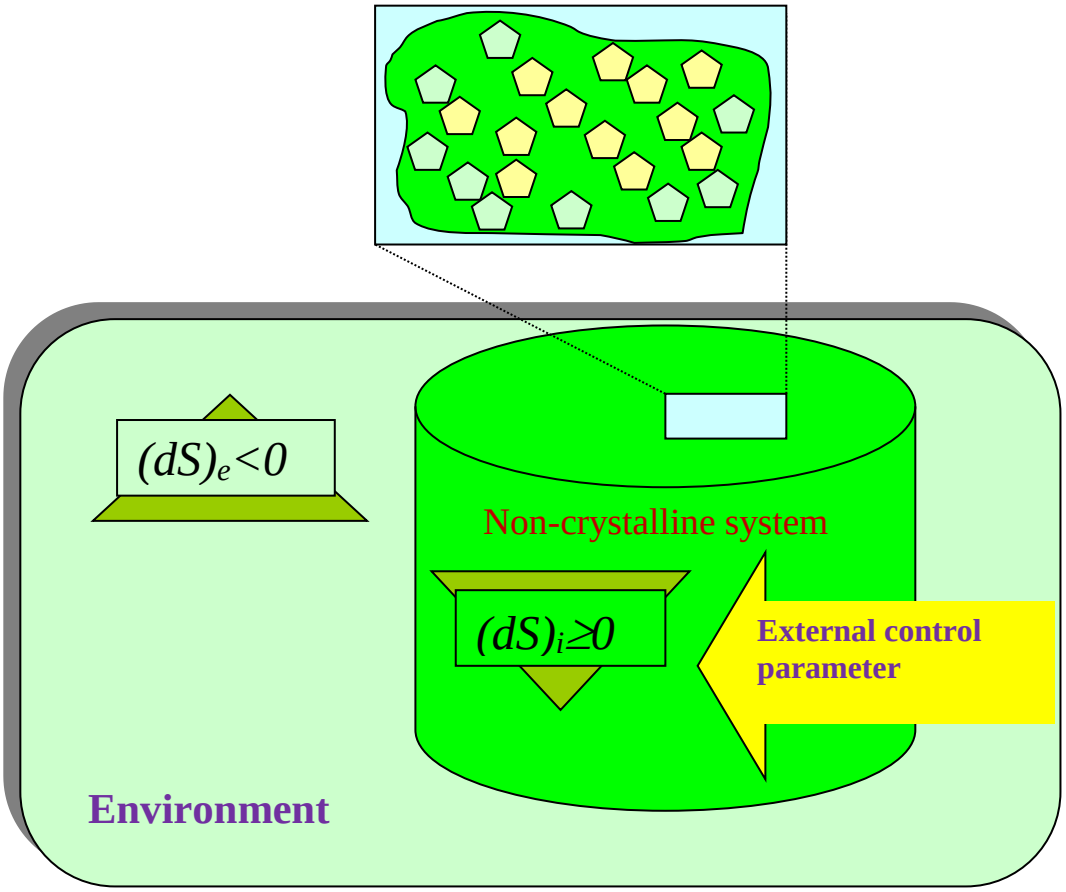
Development of the dissipative structure in science education



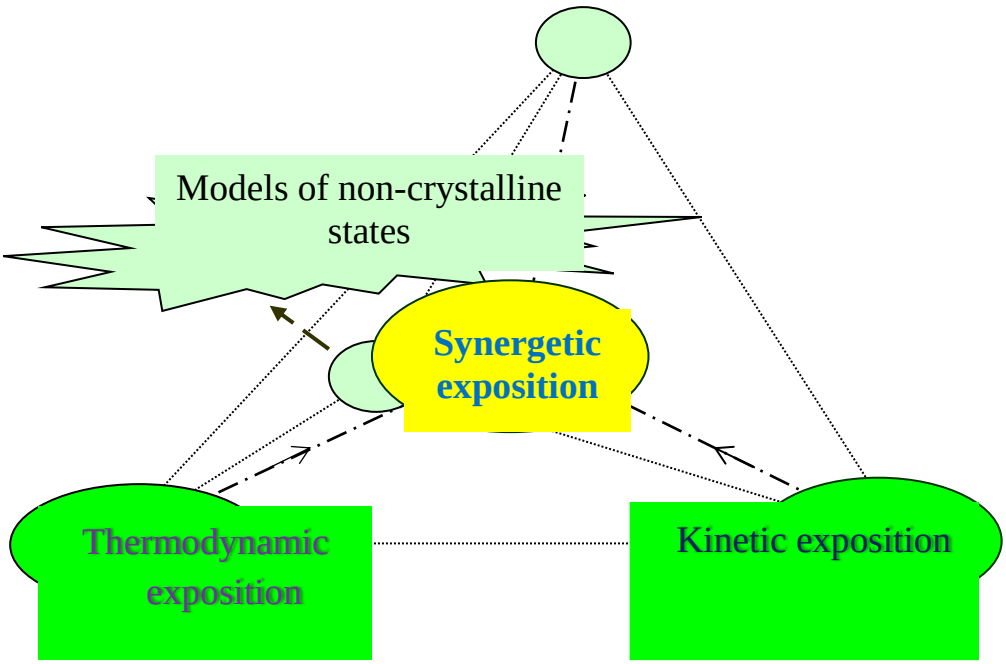
Examples of the dissipative structure in science education



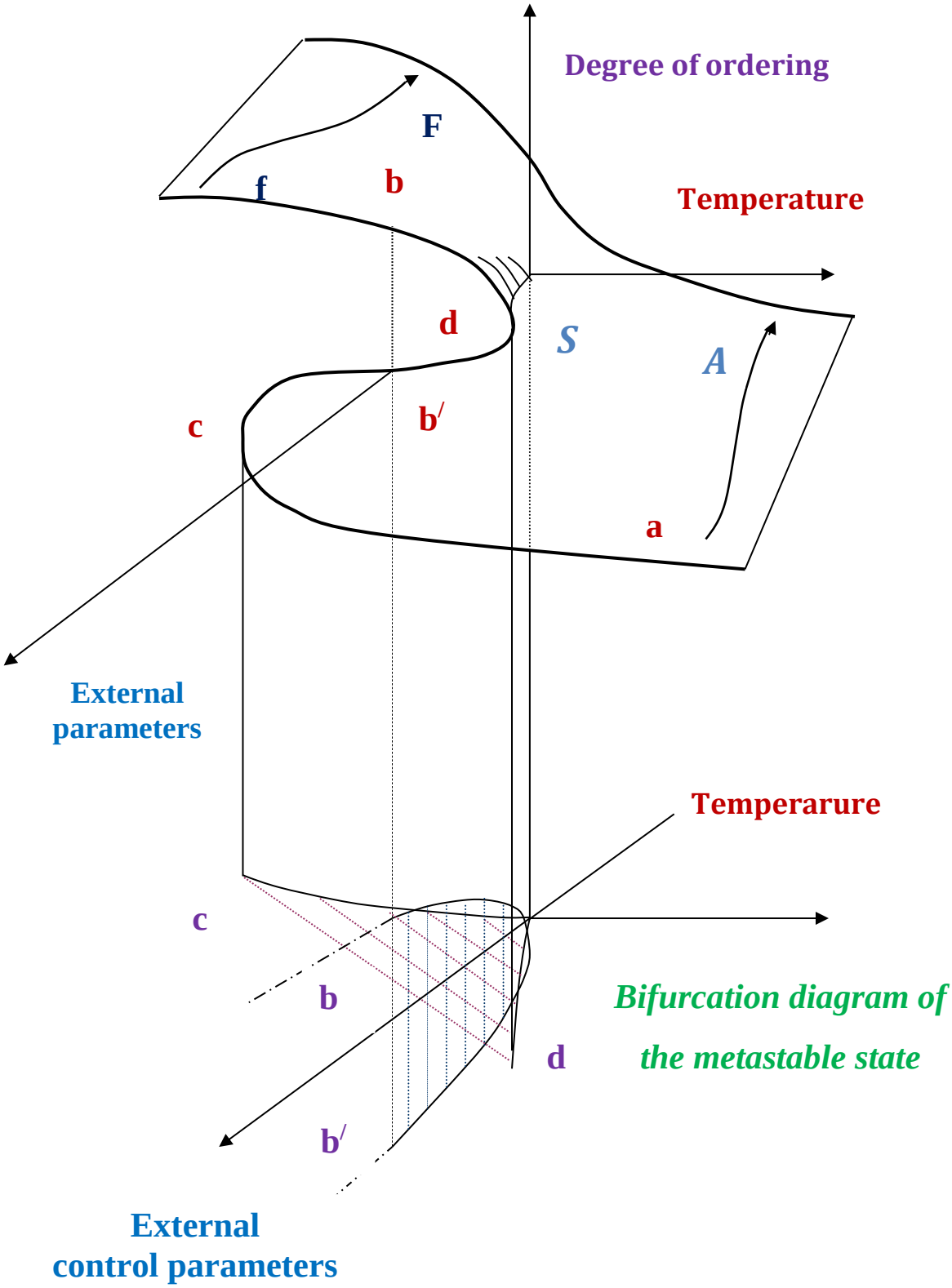
Self-organizing processes in the natural systems



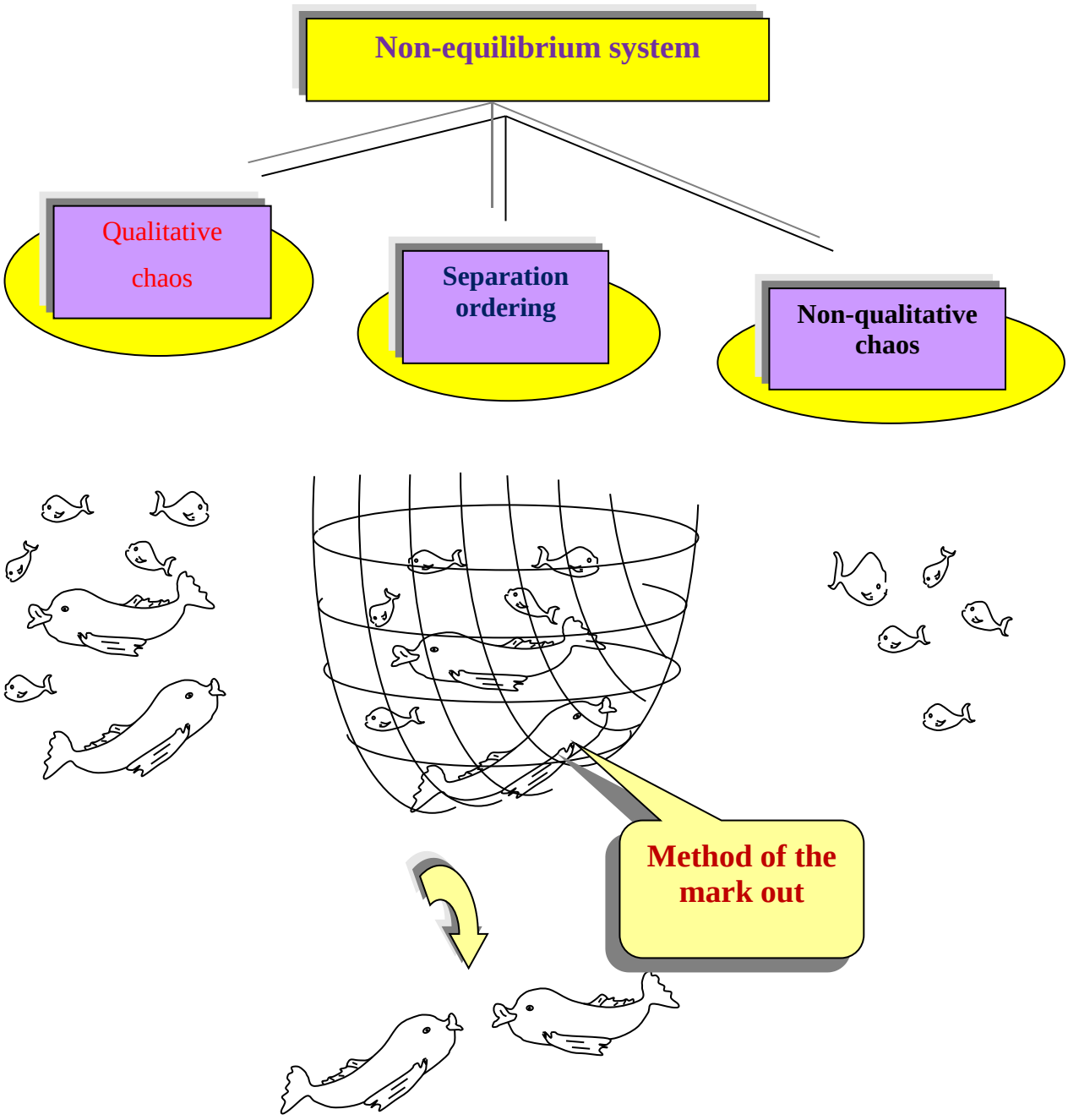
Formation of the non-crystalline state



Expositions of the non-crystalline states



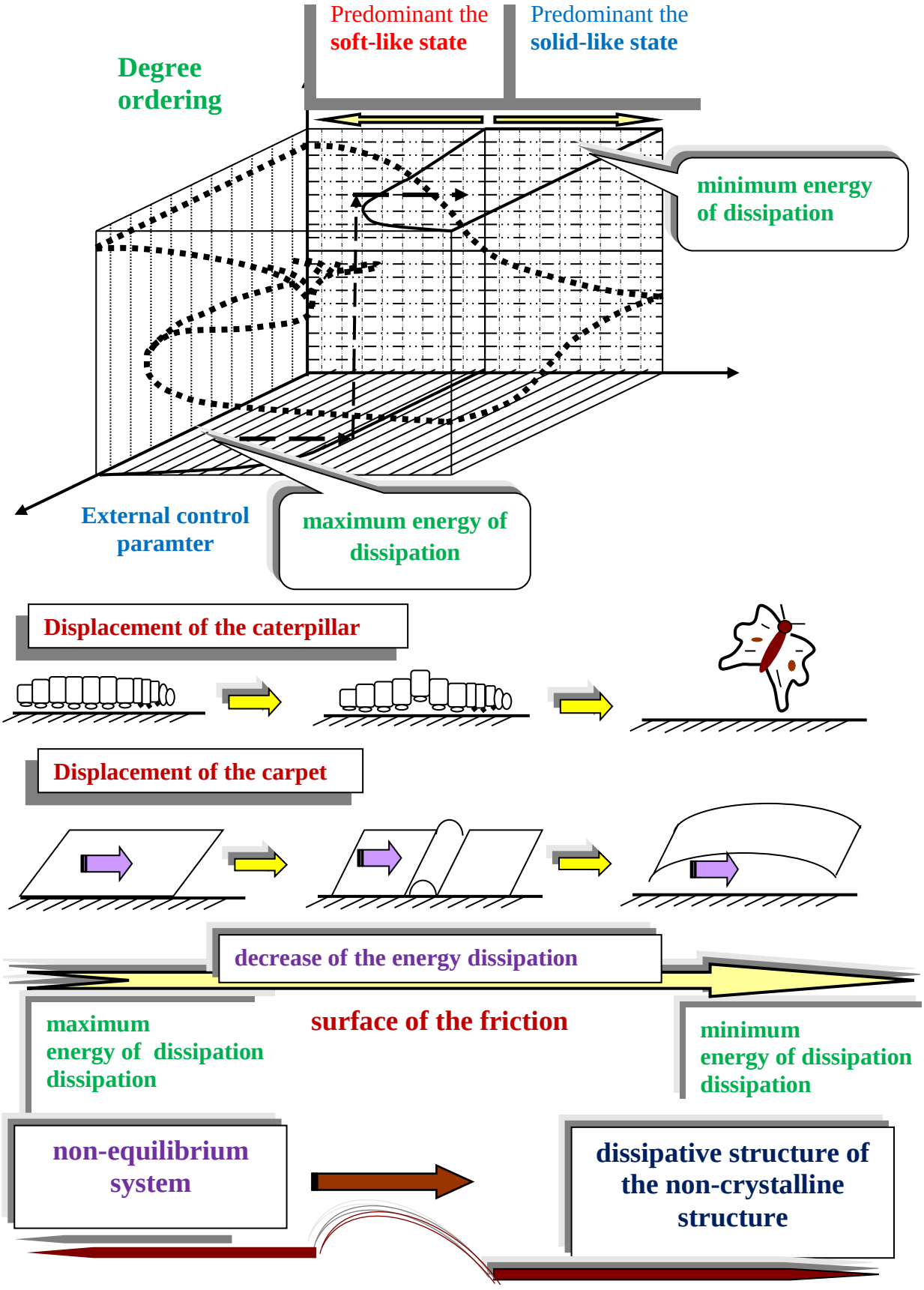
Branching of the solutions of the characteristic equation at different of the external control parameters



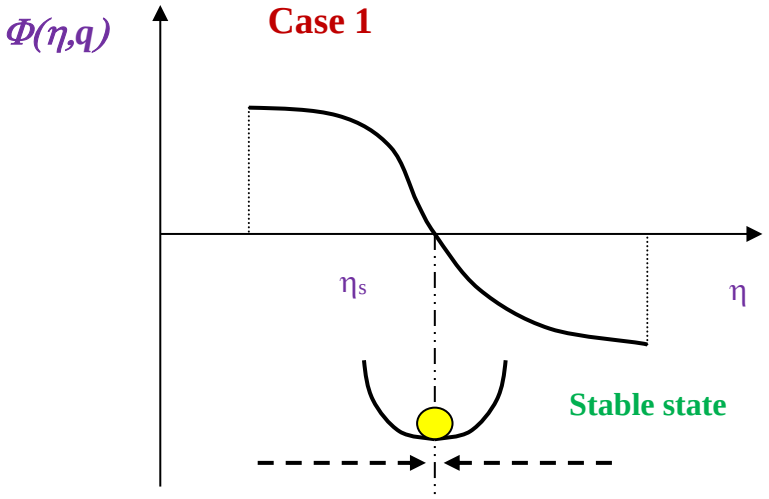
• vacancy, dislocation, soft-like state, solid-like state

• macroscopic domain, dissipative structure

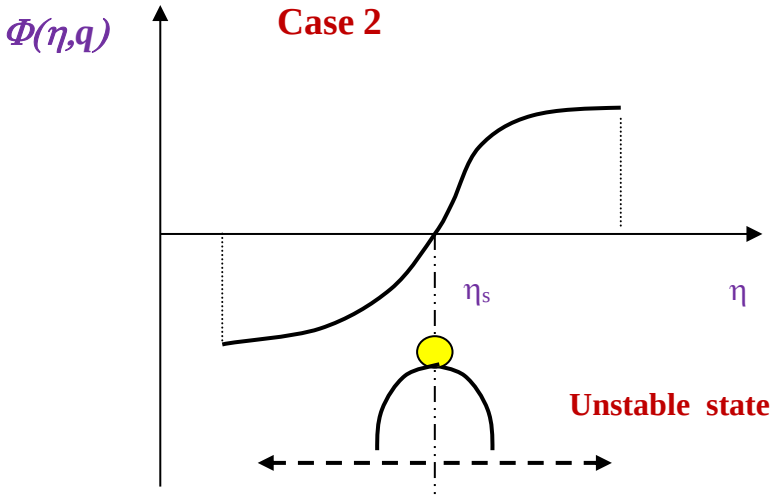
Illustration of the separation and transformation of the ordering at action of the external control parameters



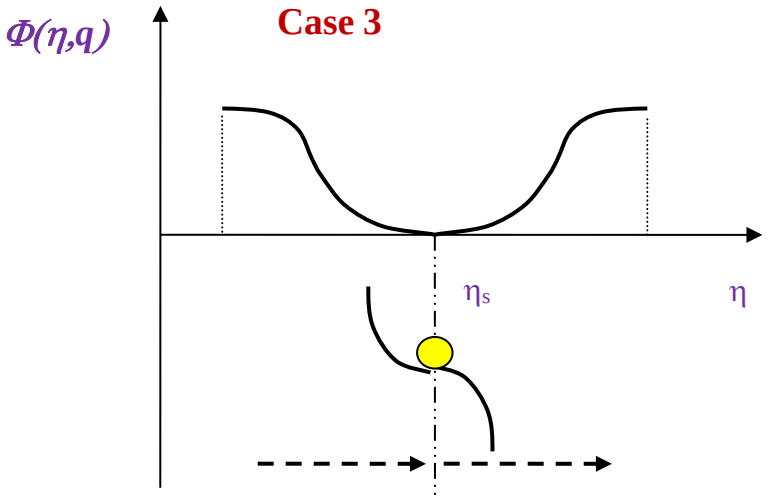
Formation of the dissipative structure of the non-crystalline state



Function Φ(η,q) changes its sign close to η_s (from "+" to "–"). Here $\Phi'_\eta(\eta,q)<0$, i.e. the function decreases with η.

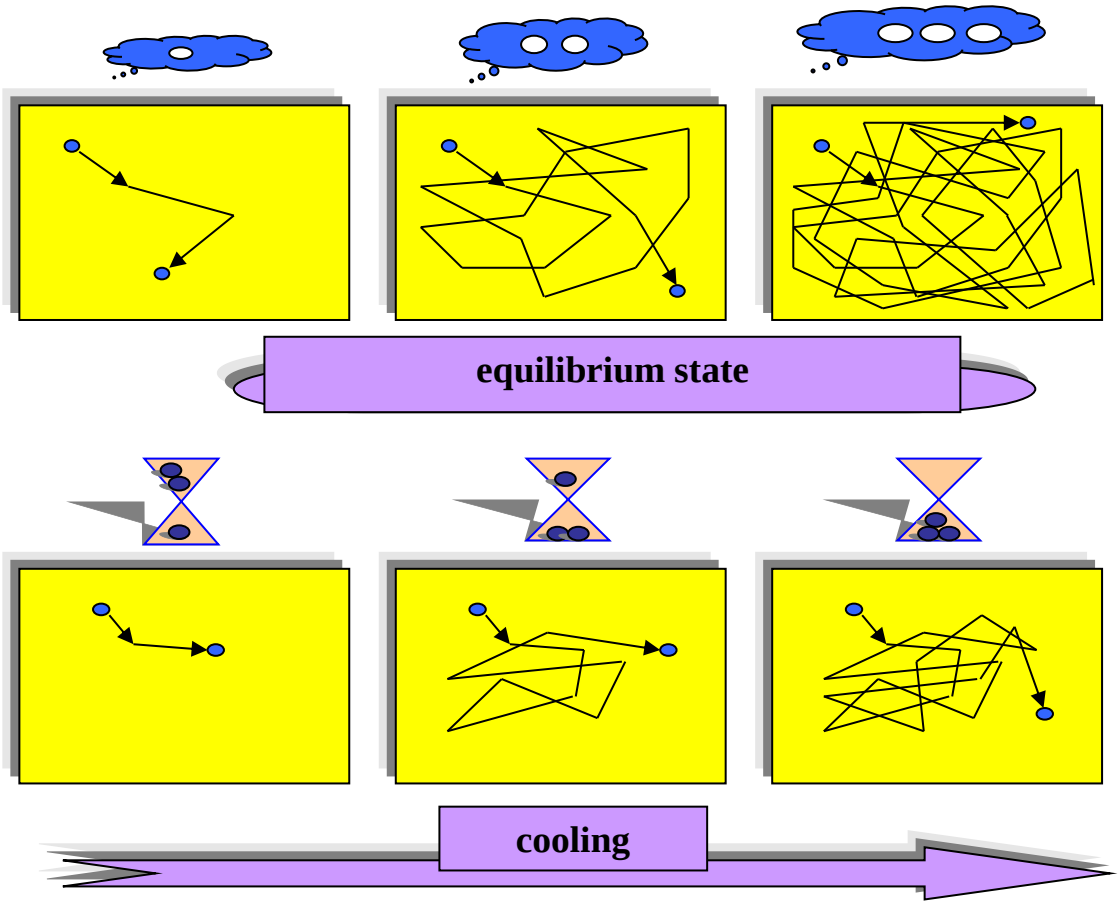


Function Φ(η,q) changes its sign close to η_s (from "–" to "+"). Here $\Phi'_\eta(\eta,q)>0$, i.e. the function increases with η.

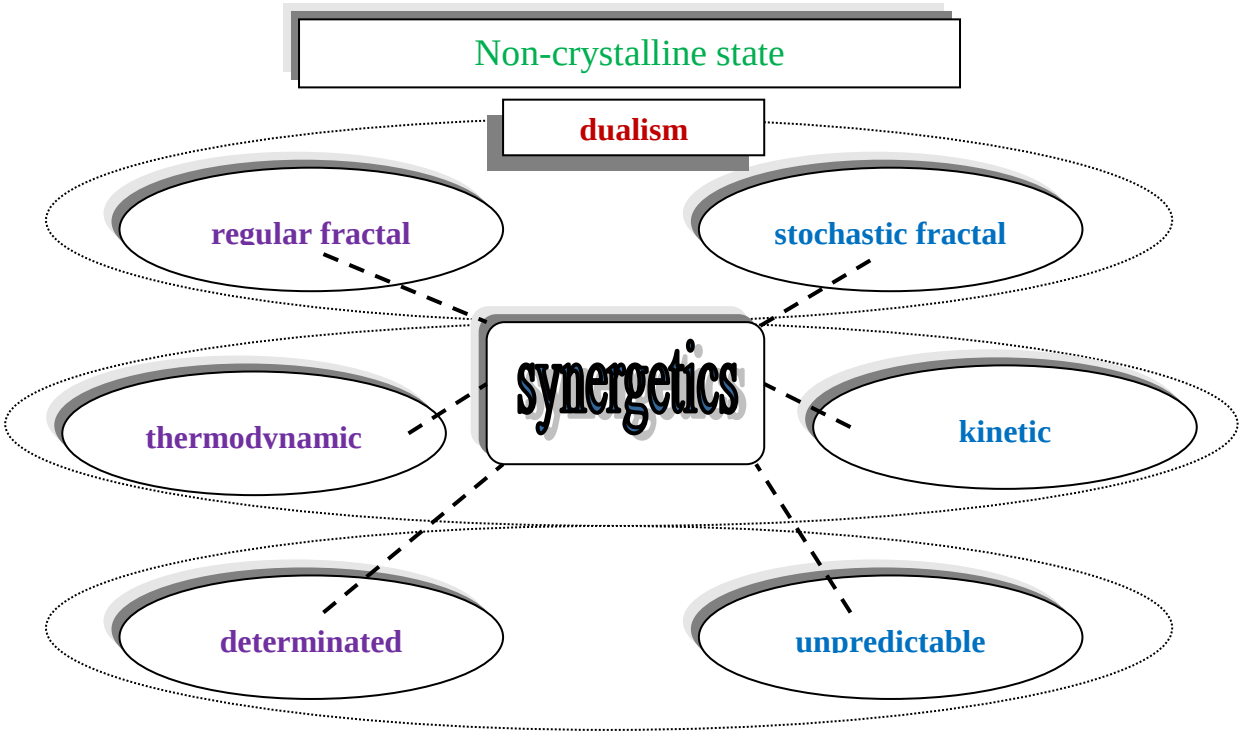


Function Φ(η,q) does not change its sign close to η_s with increasing η. Here $\Phi'_\eta(\eta,q)=0$. This means that the illustrative point located rather close to η_s on one side will approach it, while this point being located on the other side will move away.

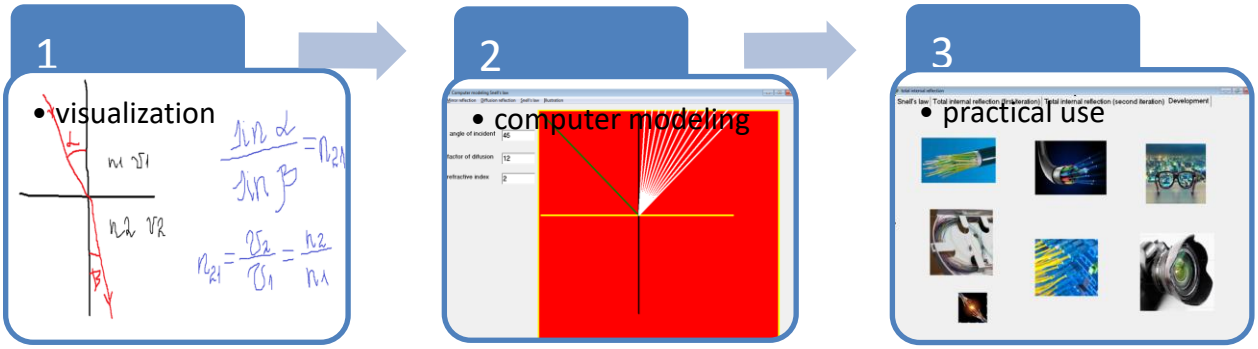
Possible cases of the behavior of the function state



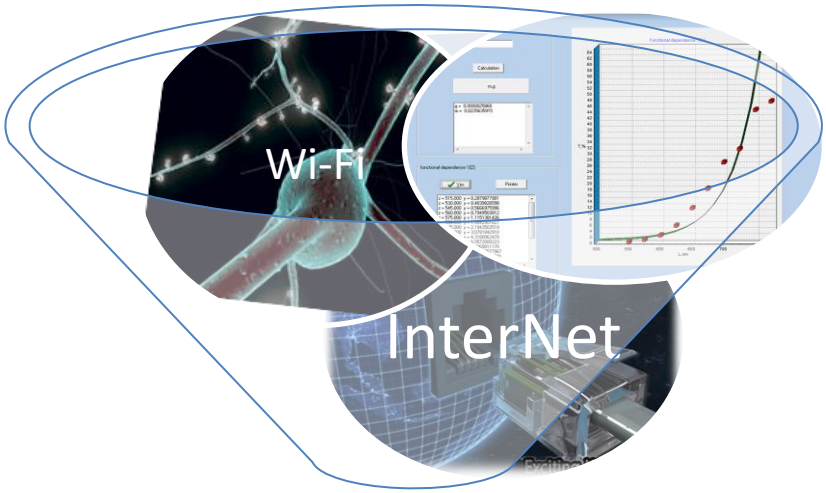
Trajectory of Brownian particle and stochastic fractals



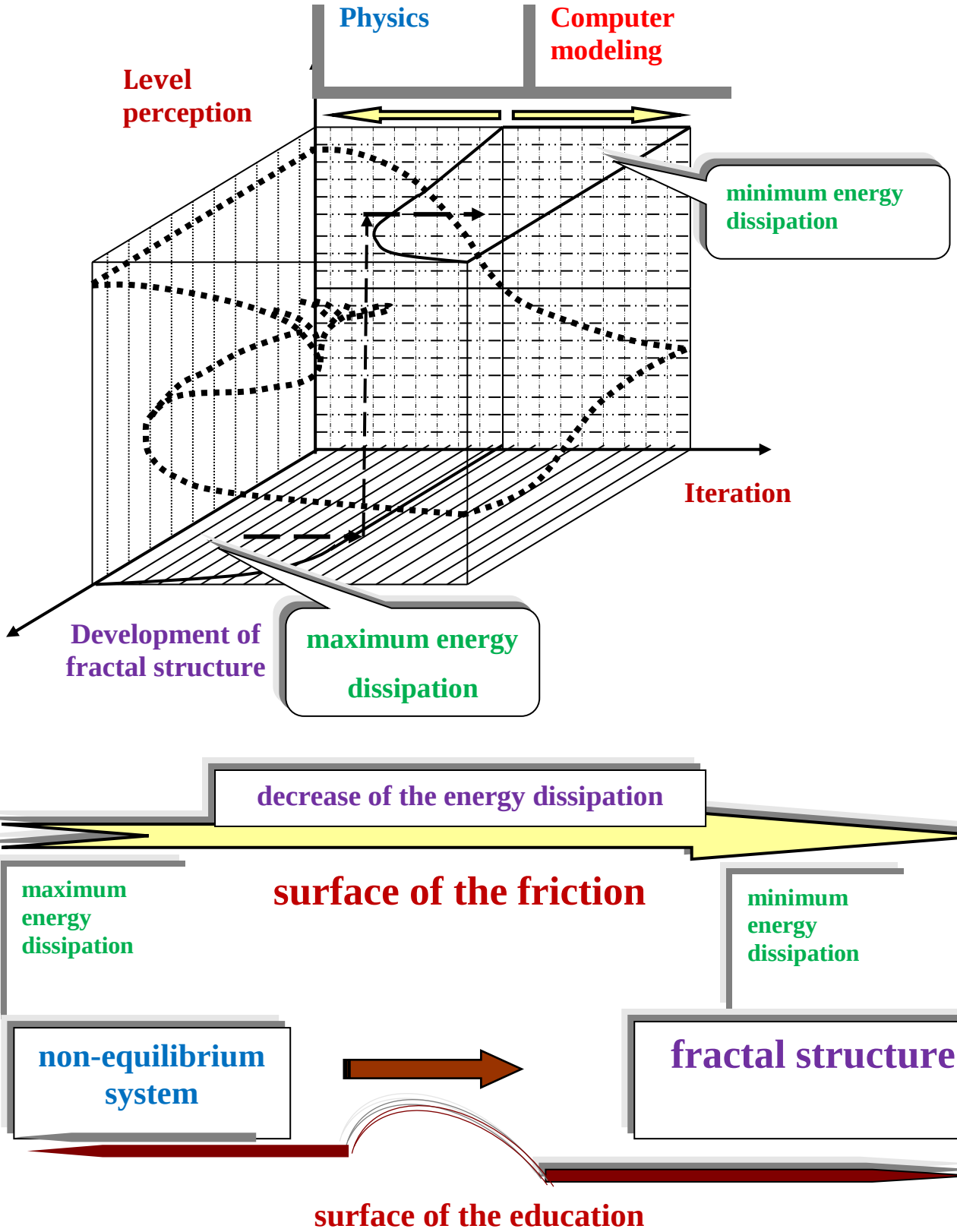
Demonstration of the synergetics in the non-crystalline state



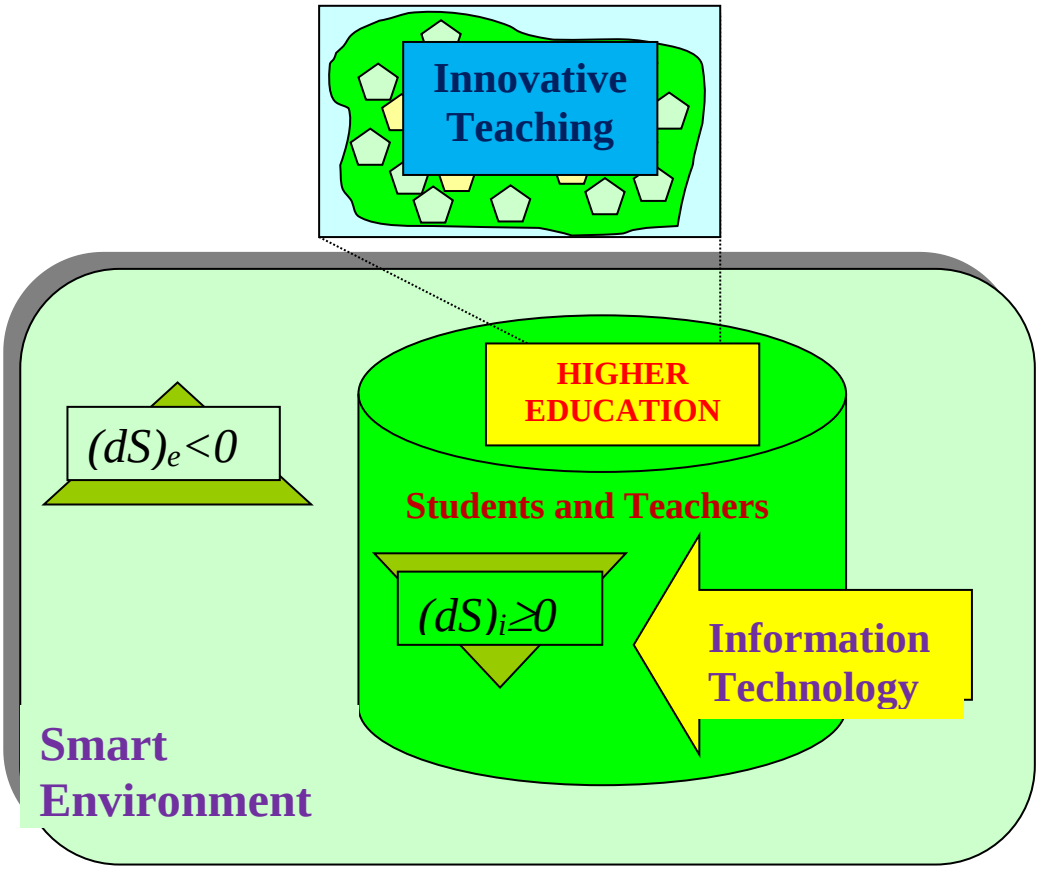
An example of one of the branches for the fractal structure



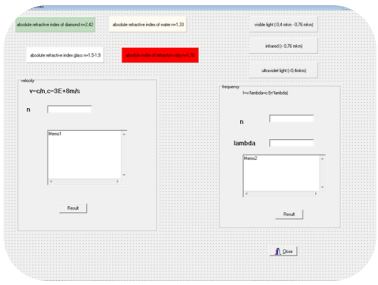
the branches of the fractal structure



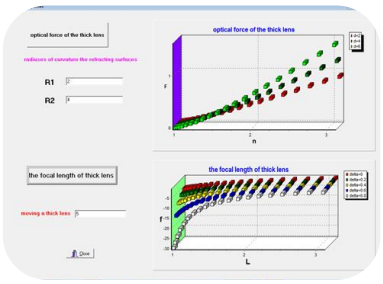
Formation of the fractal structure for the science education



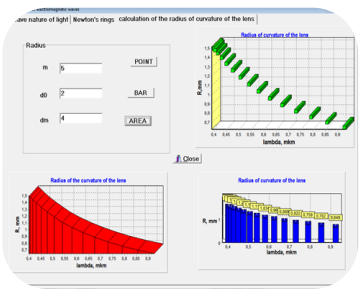
Synergetic of the fractal structure in science education



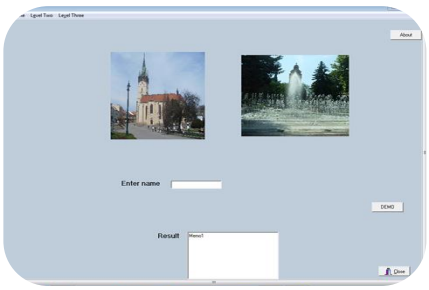
synergetics



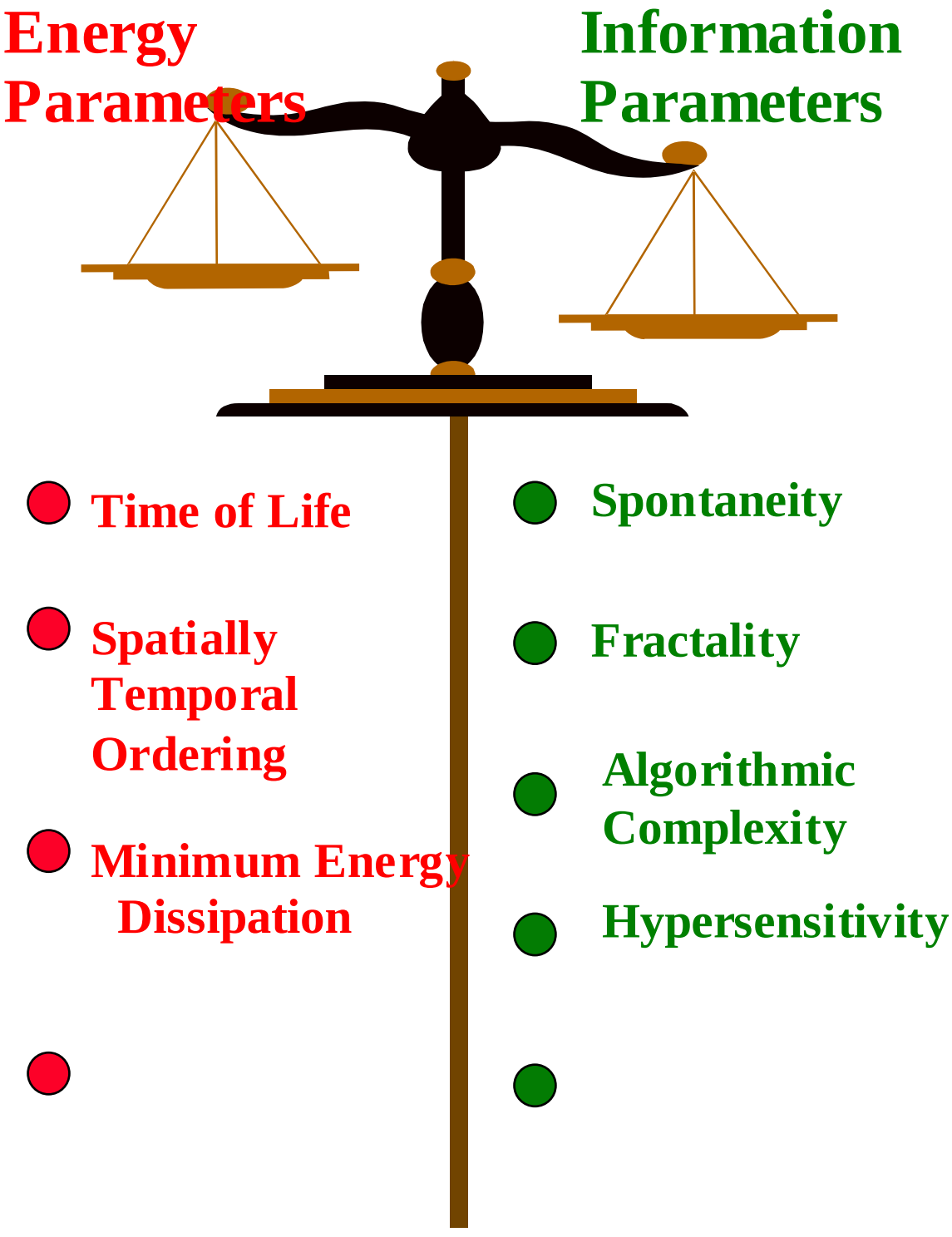
fractality



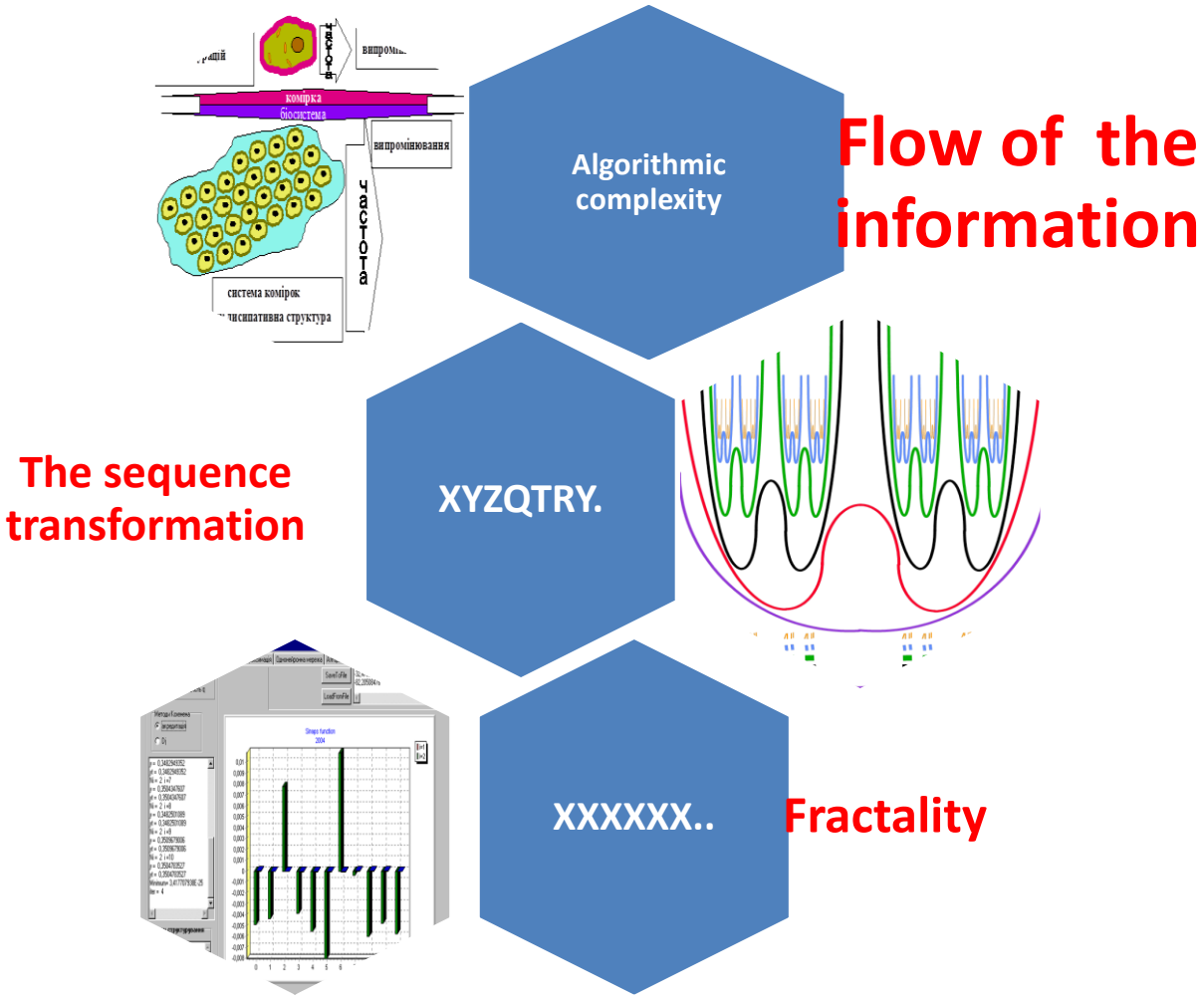
computer modeling



science education



Synergetic approach to the formation of dissipative structures: hypersensitivity



Algorithmic complexity of Chapman-Kolmogorov for information systems

Mykhaylo Mar'yan, Doctor of Sciences (Physics & Mathematics)
Department of solid-state electronics & information security Faculty of Physics
Uzhgorod National University
Uzhgorod, Ukraine
E-mail: mykhaylo.maryan@uzhnu.edu.ua
Web site: http://www.uzhnu.edu.ua

Vladimir Seben, PhD
Department of physics, mathematics & technics
Faculty of Humanities and Natural Science
University of Presov
Presov, Slovak republic
E-mail: vladimir.seben@unipo.sk
Web site: http://unipo.sk

Nataliya Yurkovych, PhD
Department of solid-state electronics & information security Faculty of Physics
Uzhgorod National University
Uzhgorod, Ukraine
E-mail: nataliya.yurkovych@uzhnu.edu.ua
Web site: http://www.uzhnu.edu.ua

Mykhaylo Mar'yan. ***The scientific interests are associated with studies and implementation of the self-organization processes in the synergetics systems of diverse nature (non-crystalline materials, fractal structures, information and cybernetic systems).***

Vladimir Seben. ***A sphere of the scientific interests is associated with study of didactics and to the development of innovative information products of teaching physics.***

Nataliya Yurkovych. ***Scientific focus on the researches of innovative information technologies for addressing educational, environmental problems, and the fractal teaching of the natural sciences is placed.***