On the Concept of “Complexity” in Radiation Physics

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Abstract—The concept of “complexity” is considered in relation to radiation processes in condensed matter. It is shown that a combination of such properties as nanoscale, fractality, low dimension, chirality, and hierarchy in combination with high nonequilibrium create conditions for the manifestation of unusual “emergent” radiation effects (radiation synergetics, great dose reduction of threshold radiation effects, etc.). Examples of radiation effects in living and inanimate systems, interpreted within the framework of the concept of “complexity”, are presented. An overview of both previously obtained and new results is presented.

Keywords: complexity, nano-objects, fractals, low dimensionality, chirality, hierarchical structures, synergetics, radiation processes, emergence, unity of analysis of living and inanimate nature

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INTRODUCTION

In the present state of development of fundamental and applied studies in the area of interaction of charged particles and wave radiation with various materials and radiation processes, the tendencies inherent in modern physics as a whole manifest themselves more and more. In the last third of the twentieth century, in various sciences dealing with the structure of matter, interest arose in objects of a completely new type and in unusual processes occurring in them. This fact was reflected in the appearance of the corresponding key terms: “nanotechnologies”, “fractal”, “low-dimensional systems”, “chiral symmetry”, “hierarchical structure”, and “self-organization”. Around these concepts, vast areas of new effects and phenomena began to form, which were reflected in corresponding areas of materials science. But at the beginning of the 21st century, new tendencies manifested themselves, namely, greater overlap of the areas noted above. For example, the concepts of nanofractals, synergetics, and so on appeared. For all these overlapping areas, the nonlinearity of properties, the openness of systems, and high nonequilibrium became very important.

A characteristic feature of all these areas was the emergence of principally new properties, which were not observed in the patterns. This circumstance is a regular effect, rather than a rare exception, and it is called “emergence”. Objectively, a question arose concerning the need to improve or even create a new paradigm that would be able to become the basis not only of natural sciences (physics, chemistry, and biology), but also the humanities.

In 1972, P. Anderson [1] published an article, in which he put forward the statement that “at each hierarchical level of an object, the sum of the properties is larger than the combination of the components”. He called such systems “complex” and the paradigm yet to emerge “complexity”. It should be noted that the concept of complexity was proposed also before; however, as an indicator of individual sciences, e.g., mathematics [2] (Kolmogorov, Chetin) and chemistry [3] (Bonchev). However, it can be said that this concept appeared relatively long ago: many authors principally consider biology as the science of complex nonequilibrium hierarchical structures, the functioning of which is needed in some specific “biotonic” concepts, which, strictly speaking, precisely led to inevitability of the complex [4]. It is important to note that, in natural philosophy, there are also two principally different methodological approaches: “reductionism”, which has been traditionally developed since ancient times and means the deepening of knowledge as the object is broken down into smaller and smaller parts, and “holism”, which became the basis for complexity [5]. Here, the results by I. Prigogine and his school on
searching for the “A to Z of complexity”, which is characteristic of all sciences of the holistic type [6].

An indicator that the concept of complexity has the right to exist independently is the following: within its framework, a number of fundamental effects were discovered that do not fit into previous methodological approaches, in particular, dynamic chaos and scenarios of its emergence [7], unique sensitivity of the kinetics of processes to the initial conditions [8], and also the self-organizing criticality, which claims to be a universal law of nature [9, 10]. It is quite natural that such a general approach can be very fruitful in such a field of science as radiation physics [11–14], both for living and inanimate objects. Indeed, in the series of works [13, 15–19], concerning a wide variety of objects, regularities, which could be attributed to complexity in radiation physics, appeared. In this context, it is interesting to analyze them simultaneously within the framework of the complexity paradigm. The aim of this work is to demonstrate the above unity.

SYNERGETICS OF RADIATION PROCESSES DURING HIGH-ENERGY ION IRRADIATION

Although fundamental radiation physics [11–14] is a reliable basis of many applied aspects (for example, when solving the problems of the radiation-induced failures of semiconductor apparatus [14]), recently, experimental data have appeared whose interpretation in common schemes is difficult.

In recent times, one such dramatic event was the failure of the “Fobos–Grunt” space probe [20]. Taking into account that the most detailed data on the catastrophic consequences of the radiation-induced effect exist precisely for “Fobos–Grunt”, we present the estimation for this failure. As is known [15], this space probe was placed in an orbit with the mean radius $R =$ 250 km, on November 9, 2011, and, after performing 1.7 revolutions, did not answer any more tele- and radio commands from Earth. A short time later, on January 15, 2012, it left orbit and burnt up in the atmosphere. According to the materials of a commission [20], from two considered versions of failure (the first one is anthropogenic catastrophe; the second one is radiation-induced damage of the WS512K32V20G24M semiconductor microcircuit by heavy charged cosmic particles), the second version was accepted to be more likely. It was analyzed on the basis of existing concepts of radiation physics [11–14], but it was insufficient to understand the event. With a high degree of generality, we can distinguish two features usual for radiation physics that manifested themselves in the accident: the first electronic-equipment failure anomalously fast in time and the intermittent nature of its switching on and off, ending in complete failure. It turned out that, to explain these peculiarities, it is necessary to develop a completely new aspect of the radiation physics of solids, namely, radiation synergetics [15–19].

Structure of Microcircuits and the Character of their Radiation-Induced Modification

Modern microcircuits consist of many elements. In spite of this fact, with a great degree of generality, we can assume that the causes of changes in their main characteristics are changes in the electronic spectrum in the forbidden bands and the energy profile of these band boundaries [14, 21]. In turn, the physical phenomena at the base of similar modification boil down to only three radiation-induced effects: defect formation, radiation-induced diffusion, and quasi-chemical reactions between defects [13]. All these effects can be caused by excitations in the atomic and electron subsystems. Estimations of the efficiency of the basic processes and the concentrations of created electron and atomic excitations on the base of existing concepts of the modern radiation physics of solids [11–14] do not enable one to explain the feature of the accident of the “Fobos–Grunt” space probe [15]. In our opinion, these estimations, in which the parameters of the Earth’s radiation belts [22] are used, do not eliminate the second (radiation) version of the causes of the spacecraft accident [23] with respect to the situation taking place on the spacecraft. All necessary estimations of the space radiation parameters, the type and concentration of defects that appeared under the conditions of the “Fobos–Grunt” spacecraft, and also some other important parameters are given in [16, 19].

Radiation Synergetics

We assume that two conditions combined during the radiation action on microcircuits of the “Fobos-Grunt” spacecraft: high nonequilibrium characteristic of proton irradiation of rather high energies and individual features of the impurity–defect composition, which appeared due to the technology of manufacturing of this microcircuit (for example, the possibility of the realization of so called autocatalytic quasi-chemical reactions between defects). It is a typical synergetic situation, and it was specifically observed in some interactions of radiation with materials [15–19]. Here we are dealing with synergetic systems, in which, first, anomalously large fluctuations, which are not described by the Poisson distribution, appear and, second, the system is critically sensitive to these fluctuations. We consider two possible schemes of realization of this idea in the events with the “Fobos–Grunt” spacecraft.

Fluctuations of the Concentration of an Uncontrolled Impurity and the First Anomalously Fast Failure of the Instrument

In the most general form, the critical behavior of the system is possible as some defect concentration that leads to critical values of the instrument parameters appears in it. Let the system be highly nonequilibrium due to the effect of radiation, and quasi-chemical
reactions between imperfections of $j$ types proceed. If component $Y$ (created by radiation) with a low concentration is added to the system with $X$ components, the whole set of reactions will be different:

$$\begin{align*}
\frac{dX_i}{dt} &= F_i^r + \bar{F}_i(|X_i|, Y, \varepsilon) \\
\frac{dY}{dt} &= \bar{G}_i(|X_i|, Y, \varepsilon).
\end{align*}$$

(1)

(2)

Here, $F_i^r$ describes the radiation-stimulated $i$-components, $\bar{F}_i(|X_i|)$ describes the quasi-chemical reactions in the system, and $\varepsilon$ is a small parameter, such that the system transitions to the before-radiation state at $\varepsilon \to 0$. It turns out [24, 25], if we linearize Eqs. (1) and (2), taking into account the smallness of fluctuations $\delta X_i$ and $\delta Y$ and also that $\varepsilon \ll 1$, the characteristic equation takes the form

$$\varepsilon \omega^{n+1} + a_0(\varepsilon)\omega^n + \cdots + a_1(\varepsilon)\omega + a_0(\varepsilon) = 0.$$  

(3)

At low $\varepsilon$, we obtain from Eq. (3) the additional solution:

$$\omega_{n+1} = -a_n(\varepsilon)/\varepsilon.$$  

(4)

It is important that, at $a_n(\varepsilon) < 0$ and $\varepsilon \to 0$, this root is large and positive, which means structural instability of the system (1) and (2) and demonstrates a very fast increase in time of the concentration of some components, i.e., defects. This takes place as new component $Y$ takes part in system (1) and (2) only via autocatalytic reactions: so some function with specific properties $\bar{G}_i$ is arranged [24]. This is the reason of the first feature of the dynamics of the accident with the “Fobos–Grunt” spacecraft.

We note that autocatalytic reactions are nowhere near always realized. For example, such a variant is always realized. For example, such a variant is possible: an impurity with the properties of strong electron–phonon interaction of the type of the Yahn–Teller effect that is introduced by radiation-induced electron excitations can enter near a Frenkel pair generated by radiation. Then, according to the “weak point” concept [13], the autocatalytic reaction of the nucleation of vacancies (interstitial sites) is realized, namely: lattice $+ V_0 + \Pi_p \rightarrow$ lattice $+ 2V + \Pi_p$, interstitial atom (vacancy).
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three interstitial atoms in the region of localization of
three generation defects (if they are vacancies).

Then, Eq. (8), after its reduction to the dimensionless
form, can be written as

\[ X_{n+1} = \xi + X_n^2 + uX_n^3 - \xi X_{n-1}^3. \]  

(9)

Here, \( \xi \) is proportional to \( I \), \( u \) is proportional to \( N_n \), \( X_n \) is the dimensionless concentration of “representative”
defects in the \( n \)-generation, and \( g \) is a positive param-
eter [27].

Computer analysis of Eq. (9) [27] shows that the
evolution of \( \{X_n\} \) is dependent on quantities \( \xi, u, \) and \( g \). In the problem under consideration, all these param-
ters are positive, and, under these conditions, the
characteristic Lamerey diagram has the form shown in
Fig. 2. From Fig. 2, it is seen that, in the \( 0 < X_n < X_{\text{max}} \)
region, defects are steadily accumulated, while, in the \( X_n \approx X_{\text{max}} \) region, there are several sharp jumps in the concentration \( X_n \). This result
implies that dynamic chaos appears in the defect system
(in the intermittance mode of the I type); in this chaos,
the laminar phase (monotonic part) and the turbulent
phase (the region of jumps) coexist (Fig. 3).

Turning to the continual description [25–28], we obtain from Eq. (9):

\[ dX/d\tau = \xi + uX^2 - gX^3, \]  

(10)

which is possible in the case of the condition
\( (X_{n+1} - X_n)/X_n \ll 1 \), and \( \tau \) is dimensionless time. At
small \( X \), we can neglect term \( gX^3 \), and the integration of
Eq. (10) gives the expression for the laminar portion:

\[ \tau(X_{\text{out}}, X_{\text{in}}) = 1/\sqrt{\xi u} \left[ \arctan(X_{\text{out}} / \sqrt{\xi u}) - \arctan(X_{\text{in}} / \sqrt{\xi u}) \right]. \]  

(11)

For the mean duration of the laminar portion, we
have from Eq. (11) (according to the formalism of the
dynamic chaos [26, 27]):

\[ \langle \tau \rangle = 1/\sqrt{\xi u} \arctan(C / \sqrt{\xi u}). \]  

(12)

Here, \( C \) is close to \( X_{\text{max}} \) (Fig. 2). At \( C / \sqrt{\xi u} \gg 1 \) we obtain
\( \langle \tau \rangle = \pi/2\xi u \).

In our problem, we relate \( \langle \tau \rangle \) to the time of the laminar
accumulation of defects and, correspondingly, steady degradation of the properties of the instrument
material. Upon completion of \( \langle \tau \rangle \), there are jumps in the
concentration \( X \), such that the instrument becomes inoperative. Since dose accumulation
leads to “drawing in” of the impurity catalyst \( N_n, u \) increases
and \( \langle \tau \rangle \) decreases. This fact leads to acceleration of the
beginning of the turbulent phase in the defect system, and,
as a result, the instrument fails completely \( \langle \tau \rangle \to 0 \). We note that the most incomprehensible moment,
namely, the temporary return to the operating state

\begin{figure}
\centering
\includegraphics[width=0.8\textwidth]{Fig_2.png}
\caption{Lamerey diagram (9) that demonstrates the sequential combination of two phases of laminar (from \( \alpha x_0 \) to the region of the maximum of the reverse parabola) and turbulent (the region of intersecting the reverse parabola and the straight line going through the origin of coordinates) [16, 17].}
\end{figure}
(i.e., to low $X_n$), occurs, specifically, as a result of the turbulent phase ($X_n \rightarrow X_{in}$) (Fig. 2). It should be noted that, since $X_{in}$ is a random value, we can introduce the probability density $P(\tau)$ of realizing the laminar period with the duration $\tau$ [27, 28]. Then, the probability of normal service of the instrument for the time $\tau_0$ and more, will be determined as

$$\Omega(\tau_0) = \int_{0}^{\infty} P(\tau)d\tau. \quad (13)$$

Here, the boundary value $\tau_0$ is determined from condition $\tau_0 = \tau(X_{out}, X_{in})$ (11), where $X_{out}^0$ is the limiting concentration of defects, at which the instrument can still operate. Thus, the quantity

$$W(\tau_0) = 1 - \Omega(\tau_0) \quad (14)$$

is the probability of instrument failure in the concept of synergetic radiation processes developed in this work, which radically differs from widely accepted concepts [29].

Summing up this Section, we can state that, the modes of synergetic anomalously large fluctuations in the parameters of objects, which can lead to catastrophically fast and abrupt failures inexplicable in terms of “the mean”, can occur if autocatalytic reactions between excitations in the atomic and electron subsystems occur in a semiconductor system–instrument subjected to strong irradiation. In some cases, the failures have the character of synergetic intermittence, which is characteristic of the turbulent mode. All of these together could be observed in the “Fobos–Grunt” spacecraft [15, 16].

Recently the possibility of radiation-stimulated segregation realized according to the intermittence scenario was predicted in a mixed organic–inorganic perovskite (iodine/bromine) [30]. A short time later, a new effect of radiation synergetics related to that which occurred in the above microcircuit during the accident of the “Fobos–Grunt” spacecraft was observed experimentally during detailed study of the degradation of solar cells based on this material [31].

In principle, now, we can judge more or less reliably the chaos mode in the form of intermittence in any given system by the manifestation of some qualitative properties and the type of the dependence of some quantities on a parameter. In the case under consideration, they are the mean time $\tau$ and the exponent in the last term in variable $X$ (Eq. (9)). The radiation intensity also can be such a parameter. In the case of the “Fobos–Grunt” spacecraft, it naturally requires experiment repeatability, which can sometimes be done better or worse [28]. However, it is in the case of a spacecraft, that there is an additional possibility: the overall time of absolute failure of the instrument must be larger or equal to the time of entering (“sucking” by radiation) the catalyst, which stops autocatalytic reactions between defects described by Eq. (5). It seems likely that this time can be controlled in natural experiments. At this stage, it makes sense to judge the intermittence mode in the case of the “Fobos–Grunt” spacecraft in terms of qualitative characteristics, which appear paradoxical in the framework of existing concepts [14].

**SELECTIVE RADIATION EFFECT ON POLYMERS AND ITS INVOLVEMENT IN THE DEGRADATION OF REAL VIRUSES**

In the radiation physics of condensed matter, it is stated that the basic mechanism of the radiation-induced destruction of objects, such as molecular chains, is the Auger ionization mechanism, the essence of which is described as the sequence of the following processes: ionization of the deep shell of a multielectron atom of the chain (particularly, K shell) → Auger cascade with the involvement of valence electrons → the formation of a group of multiply charged positive ions → the decay of this unstable group (“Coulomb explosion”) occurring in competition with electron neutralization (filling with neighboring electrons) → stabilization of the defect structure (destruction) [13]. The cross section of such (subthreshold) destruction is determined by the equation [32]:

![Fig. 3. Kinetics of defect accumulation in the intermittence mode that shows the coexistence of laminar (smooth) and chaotic (jagged) phases [16].](image-url)
The problems of the deformation of polymers were considered in [33, 34], where the role of $\sigma$ and $\pi$ electrons (for the $\tau_\alpha$ problem) was specified. However, it is in the case of biopolymers that new aspects form: for these objects in specific conditions (in cells and in cell organelles), it is necessary to take into account the deformed conformations and the heteroatomicity of biopolymer monomers [35, 36]. We discuss these aspects in the framework of the theory of the radiation physics of condensed matter (i.e., changes in $\sigma$), thus complementing the standard phenomenology of radiobiology (“the hit and target principle” by Kräutcr and Timofeev–Resovskii et al. [37]).

In the most general form, the local deformation (bending and twisting) described by the $\delta$ and $\theta$ angles, respectively (Fig. 4), leads to changed overlap integrals $S'$:

$$S' = S_{\sigma-\sigma} (\cos \delta)^2 + S_{\pi-\pi} (\sin \delta)^2 \cos \theta. \quad (16)$$

A changed value of $S'$ leads to a change in the transfer integrals ($\beta'$):$$\beta'/\beta = [S'/\sqrt{1+S'}]/[S/\sqrt{1+S}] = S'/S. \quad (17)$$

Correspondingly, after the introduction of multiple positive charges in the valence band, its time of “settled life” $\tau'_e$ is changed too:

$$\tau'_e/\tau_e = (\hbar/\Delta E_e)/((\hbar/\Delta E_e) = S'/S. \quad (18)$$

Taking into account Eqs. (15) and (17), we obtain the ratio of the destruction sections for the deformed and nondeformed versions:

$$\gamma(\delta, \theta) = \frac{\sigma_d}{\sigma_d} = \frac{\exp [-\tau_e/\tau_e]}{S'/S}. \quad (19)$$

Equation (19) has very important particular cases: $\delta = 0; \theta \neq 0$, which gives $d\sigma_d/d\theta > 0$ (chiral conformation), $\delta \neq 0; \theta = 0$, which gives $d\sigma_d/d\theta \leq 0$ (binding conformation; the sign of this quantity is dependent on the initial type of coupling: $\sigma - \sigma$ or $\pi - \pi$).

Role of Heterogeneous Monomers

The studies of P. Anderson [35, 36] showed that the existence of monomers of various types in a polymer leads to the partial (or complete) localization of electrons during their motion along the chain, which can be simulated by a set of “electron lakes” (or “ellipsoidal droplets”) along the chain, and also change the spectrum of electronic states, combining the band states with their deep tails in the electron gaps. This fact leads to three consequences: the energy position of the highest occupied and anti-binding molecular orbitals is changed, the probability of Auger transitions $\alpha_\gamma$ which is different for the band and localized states is changed, and the time of the “settled” life of holes $\tau_e$ sensitive to their degree of localization is sharply changed.

Here, the most general results should be considered. The lower the highest occupied molecular orbital, the higher the probability of Auger transitions ($\alpha_\gamma$ increases). Simulating the localized states by an electron droplet (for example, using Mie theory [38]), we can estimate $\tau_e$ as $1/\omega_{pl}$, where $\omega_{pl}$ stands for plasmon, and it is close to the case of metals. Thus, these regions have a higher radiation resistance. We should bear in mind that the loci of DNA and RNA molecules carry a large amount of information correspond to localized states. The last two results enable us to refine the object of ionization attack (the higher the level of information of a locus, the larger $\tau_e$ and the higher the efficiency of its destruction).

Problems of the Selective Destruction of DNA and RNA Loci

In the radiation genetic engineering and also microbiology, it is desirable to implement the directed local destruction of the loci of inheritance molecules by the Auger-destruction method. We consider this...
problem using the fight against the SARS-CoV-2 virus (Fig. 5) as an example.

The application of this method to any objects, first and foremost, is related to the necessity to select a weak but main link of interaction of a virus with a healthy cell (just as the key-lock mechanism acts on AIDS) and to determine the locus of the inheritance molecule of the virus, which is responsible for the above interaction function (like cnv for AIDS). There is already certain information even for COVID-19 [39–41]: from all 30 000 nucleotide bases which code 10 albumens of SARS viruses, it is of great importance to know the locus coding the SP albumen which interacts with CD 147 albumen filtering the penetration into a human cell. Knowing the size of the required RNA locus (target), the effect–dose dependence can be completely described based on the radiological hit and target approach by R. A. Krauter, K. G. Tsimmer, and N. W. Timofeev–Resovskii [37]).

Radiation-Biology Analysis of Virus Degradation

The quantity $\sigma_d$ obtained using the microscopic approach allows one to transfer the classical approach, i.e., “the hit and target” method [37] to a completely new level. We discuss this algorithm as applied to a model virus. Being interested in the damage (due to ionization of the $K$ shell of P) of only an individual locus responsible, for example, for the key–lock mechanism, we assume that it is sufficient to ionize the number $\tilde{n}_p = n_p^0 L$ of $P^-$ ions in this locus (here, $n_p^0$ is the linear density of phosphorus along RNA (DNA), $L$ is the RNA (DNA) length in the locus).

Then, as a result of mixing initial viruses with the number $N_0$, the fraction (theoretical) of inactivated viruses (i.e., with a damaged locus) will be

$$\gamma_f = 1 - N/N_0 = 1 - \exp(-\sigma_d D) \sum_{k=0}^{\tilde{n}_p} \frac{1}{K!}(\sigma_d D)^k. \quad (20)$$

Here, $N$ is the number of undamaged viruses, and $D$ is the radiation dose. Figure 6 shows the dose dependence of retained undamaged viruses. Comparing the $1 - \gamma_f(D)$ dependence with the experiment, it is easy to find the minimum number of ionization acts of the $K$ shell damaging the required locus. We note that, without preliminary knowledge of $\sigma_d$, the comparison of $\gamma_f$ with $\gamma_{exp}$ gives an ambiguous two-parameter problem of finding $\sigma_d$ and $\tilde{n}_p$.

Now we discuss the case of SARS-CoV-2 coronavirus. At the present time, its genome is known in

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**Fig. 4.** Scheme of monomers: (a) undeformed conformation, (b) binding deformation, (c) chiral deformation, (d) schematic deformation of the allowed band ($E_c$ is the conduction-band bottom, $E_v$ is the valence-band top). The $\pi-\pi$ bonds are denoted. The neighboring monomer atoms are in planes 1 and 2; $\delta_1$ and $\delta_2$ are the slopes of the axes of neighboring orbitals (1 and 2) to the axis of the local portion of the chain; $\theta$ is the angle of chiral twisting (spirality).
As shown above, significant deformations (bending and torsion) sharply increase the positions along the nucleic acid a “hot point”, which are particularly subject to Auger destruction compared to the “mean value”, i.e., \( \sigma_d \). Moving along RNA, we can perform the mapping of all “hot points” and determine, through them, all groups of \( P^- \) ions, which act most efficiently as a result of ionization of the \( K \) shell, disrupting the properties of coronavirus. If we are interested in the radiation-induced switching off of the entire set of malicious actions of coronavirus, then (taking into account the hierarchical structure of the virus) the dose dependence of the fraction of damage of all \( m \) targets will have the form \[ N^+ / N_0 = \prod_{i=1}^{m} (1 - B_i), \] \[ B_i = \exp \left( -\sigma_d D \right) \sum_{k=0}^{n_i-1} \frac{1}{K^k} \left( \sigma_d D \right)^k. \] In this case, each target is its own locus; each locus has \( n_i \) of active \( P^- \) ions (as a result of ionization of the \( K \) shell). From Eq. (21), it is seen how complicated the expression for the total dose of damage of the whole RNA will be and how important it is to know the preliminary theoretical estimation of all \( \{ \sigma_d \} \).

Now we note that it is the radiation method of the degradation of viruses (in particular, COVID-19) that occupies its own unimplementable niche in modern medicine. As it is known, the additional infection of cancer patients with COVID-19 sharply impairs their state and hampers their treatment. At the same time, in principle, such an approach is possible: if the radiation parameters required by the regulation of acting on metastases agree with the parameters of the radiation degradation of COVID-19 virus using X-ray radiation, it is quite possible to count on the benefit of the parallel action of radiation on such cancer patients due to the simultaneous death of both metastases and viruses.

Summing the results, we note the following most important points. The combination of local deformation of the biopolymer (Fig. 7) with the peculiarities of its elemental composition significantly increases its Auger destruction, increasing its probability by 1000 times [42, 43]. It is the polymer heterostructure that enables one to perform the selective choice of the location of local Auger destruction [44]. Mapping of the sequence of deformed portions of an RNA virus can be performed. In combination with the abovementioned, the methods of medical nanotechnology [45] enable one to decrease the general radiation stress on “the healthy surrounding of the human body” (in particular, by decreasing the X-ray radiation dose for the
inactivation of SARS virus by a factor of 1000 [42]). The mechanism of the great decrease in the dose (to fractions of a Gray) predicted for the action of X rays [42–44] is likely to be based on various stages of the suppression of the covid–pneumonia by X-ray beams, which was experimentally observed in many countries of the West [46]. It is the direct inactivation of the virus that is likely to add channels of combating pneumonia, proposed even before the Covid pandemic [47].

CONCLUSIONS

The main propositions of the concept of complexity described above and the presented examples (as many others) enable us to outline the main conditions of the implementation of this paradigm: fractal order, hierarchy of the system, specific role of decreased sizes and dimensionalities, and chiral properties, and all these characteristics under conditions of strong non-equilibrium increase the nonlinear effects of self-organizing systems. Such unification of the causes of many effects will enable one to separate the groups of these effects into new subareas of the science of matter: radiation physics, chemistry and biology, in particular, radiation synergetics, nanophysics, fractal physics, and other sciences. However, we should note the specific novelty of such a separation: the radiation effects in living and inanimate systems naturally fall into one class. This fact gives new hopes that it is complexity that is a possible way towards second grand unification of the laws of living and inanimate systems, including radiations of various types, which has always been allocated a specific role.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. P. W. Anderson, Science 177, 393 (1977).
2. A. N. Kolmogorov, Probl. Inf. Transm. 1, 1 (1965).
3. D. Bonchev, Theochemistry 185, 155 (1989).
4. M. V. Vol’kenshtein, Molecular Biophysics (Nauka, Moscow, 1975) [in Russian].
5. D. Bonchev and W. A. Seitz, in Concepts in Chemistry: Contemporary Challenge, Ed. by D. H. Rouvray (Res. Studies, Taunton, 1996), p. 353.
6. G. Nikolis and I. Prigozhin, Cognition of the Complex (URSS, Moscow, 2008) [in Russian].
7. H. G. Schuster, Deterministic Chaos (Physik, Weinheim, 1984; Mir, Moscow, 1988).
8. D. S. Chernavskii, Synergetics and Information (URSS, Moscow, 2017) [in Russian].
9. P. Bak, How Nature Works: The Science of Self-Organized Criticality (Springer, New York, 1999; URSS, Moscow, 2013).
10. G. G. Malinetskii, in How Nature Works: The Science of Self–Organized Criticality (Springer, New York, 1999; URSS, Moscow, 2013), Russian edition, p. 15.
11. N. Itoh and A. M. Stoneham, Materials Modification by Electronic Excitation (Univ. Pres, Cambridge, 2001).
12. E. Parilis, L. Kishinevskiy, and N. Turaev, *Atomic Collisions on Solid Surfaces* (Elsevier, Amsterdam, 1993).
13. B. L. Oksengendler and N. N. Turaeva, *Radiation Condensed Matter Physics*, Vol. 1: Concepts (Fan, Tashkent, 2006).
14. F. P. Korshunov, G. V. Gatal’skii, and G. M. Ivanov, *Radiation Effects in Semiconductor Devices* (Nauka Tekh., Minsk, 1978).
15. B. L. Oksengendler, S. E. Maksimov, N. N. Turaeva, and F. G. Djurabekova, Nucl. Instrum. Methods Phys. Res., Sect. B 326, 45 (2014).
16. S. E. Maksimov, B. L. Oksengendler, and N. Yu. Turaeva, Dokl. Akad. Nauk Resp. Uzb., No. 6, 24 (2011).
17. S. E. Maksimov, B. L. Oksengendler, and N. Yu. Turaeva, J. Surf. Invest.: X-ray, Synchrotron Neutron Tech. 7, 333 (2013).
18. B. L. Oksengendler, S. E. Maksimov, N. N. Turaeva, and N. Yu. Turaeva, J. Surf. Invest.: X-ray, Synchrotron Neutron Tech. 9, 305 (2015).
19. B. L. Oksengendler, S. E. Maksimov, and N. Yu. Turaeva, J. Surf. Invest.: X-ray, Synchrotron Neutron Tech. 10, 1492 (1958).
20. http://ru.wikipedia.org/
21. R. S. Muller and T. I. Kamins, *Device Electronics for Integrated Circuits* (Wiley, New York, 1986; Mir, Moscow, 1989).
22. *Physical Encyclopedic Dictionary* (Sov. Entsiklopediya, Moscow, 1984), p. 944.
23. V. L. Vinetskii and G. A. Kholodar’, *Radiation Physics of Semiconductors* (Naukova Dumka, Kiev, 1979) [in Russian].
24. I. Prigogine, C. Nicolis, and A. Babloyantz, Phys. Today 25 (12), 38 (1972).
25. H. Haken, *Advanced Synergetics* (Springer, Heidelberg, 1983).
26. I. Matheson, D. Walles, and C. Gardine, J. Stat. Phys. 12, 21 (1975).
27. H. G. Schuster, *Deterministic Chaos* (Physik, Weinheim, 1984; Mir, Moscow, 1988).
28. P. Berge, Y. Pomeau, and Ch. Vidal, *Order within Chaos* (Wiley, New York, 1987; Mir, Moscow, 1991).
29. V. S. Vavilov, B. M. Gorin, and B. M. Danilin, *Radiatsionnye metody v tverdotele'noi elektronike* (Radio Svyaz’, Moscow, 1990) [in Russian].
30. B. L. Oksengendler and N. N. Turaeva, Appl. Sol. Energy 5, 318 (2018). https://doi.org/10.3103/S0003701X1805019
31. C. G. Bischak and A. B. Wong, J. Phys. Chem. Lett. 9, 3998 (2018).
32. M. S. Yunusov, S. N. Abdurakhmanova, B. L. Oksengendler, et al., *Physical Properties of Irradiated Silicon* (Fan, Tashkent, 1987) [in Russian].
33. M. S. Yunusov, M. A. Zaikovskaya, and B. L. Oksengendler, Phys. Status Solidi A 35, 145 (1976).
34. N. N. Turaeva, B. L. Oksengendler, and I. N. Ruban, Dokl. Chem. 387, 302 (2002).
35. Ph. Anderson, Phys. Rev. 109, 1492 (1958).
36. J. M. Ziman, *Models of Disorder: The Theoretical Physics of Homogeneously Disordered Systems* (London, 1979; Mir, Moscow, 1982).
37. Yu.B. Kudryashov, in *Radiation Biophysics (Ionizing Radiation)*, Ed. by V. K. Mazurik and M. F. Lomanov (Fizmatlit, Moscow, 2004) [in Russian].
38. G. Mie, Ann. Phys. 25, 377 (1908).
39. S. Paul, Virolology 537, 198 (2019). https://doi.org/10.1016/j.virol.2019.08.031
40. T. Zhang, Q. Zhang, J.-H. Tian, and J.-F. Xing, MRS Commun. 8, 303 (2020). https://doi.org/10.1557/mrc.2018.49
41. J. Lan, J. Ge, J. Yu, et al., Nature 581, 215 (2020). https://doi.org/10.1038/s41586-020-2180-5
42. B. L. Oksengendler, N. Yu. Turaeva, N. N. Turaeva, S. Kh. Suleimanov, A. Kh. Ashirmetov, and F. Iskandarova, Dokl. Akad. Nauk Resp. Uzb., No. 3, 43 (2020).
43. B. L. Oksengendler, S. Kh. Suleimanov, A. Kh. Ashirmetov, N. N. Turaeva, and A. F. Zatsepin, in *Proc. XXX Int. Conf. “Radiation Solid State Physics,”* Sevastopol, 2020, p. 457.
44. B. L. Oksengendler, N. N. Turaeva, N. N. Nikiforova, and F. Iskandarova, Aktual. Vopr. Biol. Fiz. Khim. 5, 571 (2020).
45. R. R. Letfullin and T. F. George, *Computational Nanomedicine and Nanotechnology: Lectures with Computer Practicum* (Springer, New York, 2016).
46. P. E. Metcalfe, Phys. Eng. Sci. Med. 43, 761 (2020). https://doi.org/10.1007/s13246-020-00915-x
47. E. J. Calabrese and G. Dhawan, Yale J. Biol. Med. 86, 555 (2013).

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