https://doi.org/10.46813/2025-157-139

SPONTANEOUS CHIRALITY OF THE ORGANIC ENVIRONMENT AS A SIGN OF EXTERNAL RADIATION EXPOSURE

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This study investigates the phenomenon of spontaneous mirror symmetry breaking as a fundamental mechanism underlying the emergence of chiral purity in biological systems. It examines the transition from a racemic state, characteristic of inanimate matter, to the exclusive homochirality observed in living organisms, wherein amino acids exhibit left-handed (L) configurations and sugars adopt right-handed (D) forms. Employing phase transition theory and mathematical modeling, the research elucidates the conditions under which symmetry breaking occurs through cooperative interactions and fluctuations in prebiotic environments. The study underscores the relevance of phase transitions in chemical evolution and highlights the necessity for experimental investigations into systems exhibiting autocatalytic amplification of chiral asymmetry.

PACS: 87.15.B-, 87.15.Zg, 11.30.Qc, 61.80.-x

INTRODUCTION

Monitoring the value of the external radiation background is an indispensable component of the implementation of nuclear and radiation technologies. At the same time, in order to understand the processes that occur in organic, including living biological environments under the influence of ionizing radiation, it seems necessary to clarify the boundary between harmful, acceptable (neutral) and destructive effects of the latter. After all, there are a number of undeniable examples of the fact that under the influence of radiation, processes in biological systems are activated [1]. In [2], an assumption is made about the important role of ionizing radiation in the evolution of organic systems, which is realized due to the ability of DNA molecules excited by radiation to re-radiate coherent quanta, which in turn activate vital processes in cells. As for the destructive effects of radiation that arise as a result of emergency situations, various radioprotectors are used to prevent it, the development of which requires, among other things, fundamental ideas about the interaction of radiation with matter. Given that any system under irradiation is open, its state is expedient to describe from the standpoint of a thermodynamic approach. Signs that radiation-stimulated transformations are occurring in the system are changed physical, chemical and biological parameters. Since in the dosimetry of living systems one of the key indicators is the coefficient of relative biological efficiency, which characterizes the ability of a portion of radiation energy to cause biological changes, it seems interesting to us to turn to the phenomenon of optical isomerism.

In 1848, Louis Pasteur's discovery of optical isomerism in chemicals transcended his groundbreaking work in microbiology. Molecules containing an asymmetric carbon atom, bonded to four distinct atoms or groups, exhibit a unique property: they exist as two mirror-image forms, analogous to left and right hands. These mirror images, termed left-handed (L) and right-handed (D) enantiomers, possess distinct optical activity, rotating the plane of polarized light in opposite directions. This phenomenon, known as chirality.

Biochemically significant compounds, like amino acids and sugars, exhibit mirror isomerism. Laboratory synthesis typically yields racemic mixtures, containing equal amounts of both enantiomers, resulting in no overall optical activity. Racemization, the process of forming a racemic mixture, is thermodynamically favored due to the increased entropy of the system. Consequently, racemization is a spontaneous occurrence indicative of non-living nature. Conversely, in living organisms, there exists absolute chiral purity: all natural amino acids are left-handed, and all natural sugars are right-handed. This stark contrast between the racemic state of inanimate matter and the chiral purity of the biosphere constitutes a fundamental distinction between the living and non-living.

PROBLEM SETTING

A thorough physical and mathematical analysis indicates that under actual conditions, wherein fluctuations, racemization, and preferences interact, certain classes of interconversion involving mirror isomers and optically inactive substrates can, under critical conditions, lead to a sudden qualitative shift in the entire racemic system toward a state that breaks mirror symmetry and achieves chiral purity.

The emergence of chiral purity within organic matter is associated with spontaneous breaking of mirror symmetry during the chemical evolution stage. The transition to chiral purity from an initially racemic environment can be regarded as a “phase transition”. This theoretical scenario builds upon not only process kinetics within chiral systems but also the cooperative behavior of even low-viscosity solutions of mirror isomers.

The works of L.L. Morozov and V.I. Goldansky [3, 4] were instrumental in formulating the problem of the causes and mechanisms of chiral purity in the biosphere. They proposed applying phase transition theory to spontaneous chiral symmetry breaking. This theory requires higher derivatives of order parameter

fields (OPF), essential for representing spatially modulated OPF structures as free energy extremes.

Lagrangians are integral to phase transformation theories and to instances of spontaneous violation of combined parity (CP) (for instance, of the type $\varphi(\pm x) = \pm\varphi(x)$, where $\varphi(x)$ is the OPF), along with effects generated by vacuum polarization in gravitational fields and string theory. Vector (tensor) OPF in such systems often degenerate into scalar ones, simplifying the solution of the variational problem defined by higher-order differential equations.

A new analytical approach developed in a model generalizing Landau's phase transition theory [5–11] allows deriving a new approximate solution for the spatial distribution of a one-component order parameter in systems with competing interactions. This approach provides an algorithm for constructing successive nonlinear approximations to the exact solution of the variational equation. In the simplest case, these solutions can be expressed through elliptic Jacobi functions, which are more convenient for analysis than Fourier series and provide more information about the properties of incommensurate order parameter distributions.

This work focuses on the time evolution of inanimate nature into animate nature using phase transition theory.

DISCUSSION AND FINDINGS

Let's focus on the theory of a scalar stationary real field $\varphi(x)$ characterized by one-dimensional gradients. Describing spontaneous symmetry breaking (SSB) for consolidated pairing necessitates $(\varphi(\pm x) = \pm\varphi(x))$ formulating the Lagrangian for the field $\varphi(x)$, where the value at any spatial point x represents the generalized coordinates of the system, which possesses infinite degrees of freedom. The principle of proximity, typical in field theories, corresponds to interactions among neighboring degrees of freedom in space described by OPF gradients. To depict SSB in the field system, transformation is required from a symmetric phase $\varphi(x) \equiv 0$ to a modulated phase $\varphi(x)$ with infinitesimal amplitude and infinitely large periods through a second-order phase transformation (PT). These phases and their transformations can apply across various physical field systems.

The dynamics of chiral systems are studied in terms of "chiral polarization" variables [11]:

$$\varphi = \frac{x_L - x_D}{x_L + x_D}, \tag{1}$$

where x_L and x_D are the concentrations of chiral left-handed and right-handed molecules, respectively. The chiral polarization φ plays the role of an order parameter for chiral systems: the fully ordered – chirally pure – state corresponds to $|\varphi| = 1$, and the racemic state corresponds to $\varphi = 0$.

The concept of parametric evolution will draw on phase transition theory involving a single-component order parameter [5]. The thermodynamic potential is expressed as follows:

$$F = F_0 + \int dx \left[\frac{1}{2}(\varphi'')^2 - \frac{g}{2}(\varphi\varphi')^2 - \frac{\gamma}{2}(\varphi')^2 + \frac{q}{2}\varphi^2 + \frac{p}{4}\varphi^4 + \frac{h}{6}\varphi^6\right]. \tag{2}$$

Here g, γ, p, h encompasses the material parameters. This expression can be seen as an initial step in expanding the functional in series regarding small values of the order parameter and its derivative.

The variational equation (2) for this functional is a fourth-order nonlinear differential equation:

$$\varphi^{(IV)} + g\left[\varphi^2\varphi'' + \varphi\varphi'^2\right] + \gamma\varphi'' + q\varphi + p\varphi^3 + h\varphi^5 = 0. \tag{3}$$

The variational equation arising from this functional is a fourth-order nonlinear differential equation, guiding the evolution of the system. The basic tenets of thermodynamics regarding nonequilibrium processes indicate the rate of change φ is proportional to the coupled thermodynamic force when slightly deviating from equilibrium:

$$\dot{\varphi} = -\Gamma\frac{\delta F}{\delta\varphi}. \tag{4}$$

Substituting the variational equation (3) into this expression (4) yields a linearized form near equilibrium φ_0:

$$\frac{1}{\Gamma}\delta\dot{\varphi} + (q + 3p{\varphi_0}^2 + 5h{\varphi_0}^4)\delta\varphi + (\gamma + g{\varphi_0}^2)\delta\varphi'' + \delta\varphi'''' = 0. \tag{5}$$

If $\delta\varphi(t, x)$ is decomposed into Fourier components, we obtain:

$$\frac{d\,\delta\varphi_k}{dt} = -\frac{\delta\varphi_k}{\tau_k}, \tag{6}$$

where

$$\frac{1}{\tau_k} = \Gamma(q + 3p{\varphi_0}^2 + 5h{\varphi_0}^4) + \Gamma\{k^4 - (\gamma + g{\varphi_0}^2)k^2\}. \tag{7}$$

The hypothesis of spontaneous mirror symmetry breaking suggests that under certain conditions, the mirror-symmetric state loses stability, leading to a jump transition to a chiral-ordered state based on cooperative interactions of fluctuations in the antipodal composition of the medium during physical and chemical transformations forming the first living systems. This problem aligns with the broader issue of spontaneous symmetry breaking widely discussed in modern natural science.

The deracemization of the organic primordial is not due to inherent differences in the evolution dynamics of left- and right-handed mirror-isomeric molecules. Instead, symmetry breaking results from the instability of the racemic state, where small fluctuations in the isomer concentration ratio, autocatalytically intensifying, can lead to near-complete predominance of one isomeric form before biological evolution.

Recent discussions have revolved around whether PT induced by weak neutral currents could determine the chiral purity's "sign" in the biosphere. Systems capable of spontaneous deracemization may "amplify" weak PT, even with fluctuations determining the final state.

However, research [12] shows that PT caused by weak neutral currents cannot resist diffusion and determine the chirality of the entire prebiosphere. The use of L-amino acids and D-sugars in Earth's biosphere, released by weak neutral currents' PT, is likely coincidental. The Earth's chemical evolution could have equally favored a biosphere based on D-amino acids and L-sugars.

CONCLUSIONS

A duality emerges between two molecular realms: a symmetric, racemic world linked to inanimate nature, and a wholly asymmetric, "chirally pure" world representative of living systems. The most viable explanation for achieving chiral purity within the pre-biosphere involves spontaneous mirror symmetry breaking – intertwining the emergence of this vital property of life with the self-organization of chirality in the "primordial soup". Nonetheless, it's crucial to note that the connection between critical phenomena in simple chemical systems and the evolutionary dynamics of the pre-biological era remain tenuous.

It is noteworthy that experiments aimed at modeling asymmetry (symmetry breaking) within chiral systems have mostly concentrated on various phase transitions, exploring destructive processes or catalytic synthesis. Future experimental efforts should aim at systems where the chains of physical and chemical transformations generate positive feedbacks on the chiral polarization of products – systems characterized by spontaneous mirror symmetry breaking.

The above processes can be most subtly initiated in closed systems by the flow of ionizing radiation.

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Article received 14.04.2025

СПОНТАННА КІРАЛЬНІСТЬ ОРГАНІЧНОГО СЕРЕДОВИЩА ЯК ОЗНАКА ЗОВНІШНЬОГО РАДІАЦІЙНОГО ВПЛИВУ

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Ця робота присвячена дослідженню явища спонтанного порушення дзеркальної симетрії як фундаментального механізму, що лежить в основі виникнення кіральної чистоти в біологічних системах, та з'ясуванню можливості його використання як ознаки радіаційно-біологічного ефекту. Досліджено перехід від рацемічного стану, характерного для неживої матерії, до виняткової гомокіральності, що спостерігається у живих організмах, де амінокислоти демонструють ліві (L) конфігурації, а цукри приймають праві (D) форми. Використовуючи теорію фазових переходів та математичне моделювання, дослідження з'ясовує умови, за яких відбувається порушення симетрії через кооперативні взаємодії та флуктуації в пребіотичних середовищах. Дослідження підкреслює важливість фазових переходів у хімічній еволюції і вказує на необхідність експериментальних досліджень систем, що демонструють автокаталітичне посилення кіральної асиметрії.