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Review

Fundamental Cause of Bio-Chirality: Space-Time Symmetry—Concept Review

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Abstract: The search for fundamental determinants of bio-molecular chirality is a hot topic in biology, clarifying the meaning of evolution and the enigma of life's origin. The question of origin may be resolved assuming that non-biological and biological entities obey nature's universal laws grounded on space-time symmetry (STS) and space-time relativity (SPR). The fabric of STS is our review's primary subject. This symmetry, encompassing the behavior of elementary particles and galaxy structure, imposes its fundamental laws on all hierarchical levels of the biological world. From the perspective of STS, objects across spatial scales may be classified as chiral or achiral concerning a specific space-related symmetry transformation: mirror reflection. The chiral object is not identical (i.e., not superimposable) to its mirror image. In geometry, distinguish two kinds of chiral objects. The first one does not have any reflective symmetry elements (a point or plane of symmetry) but may have rotational symmetry axes (dissymmetry). The second one does not have any symmetry elements (asymmetry). As the form symmetry deficiency, Chirality is the critical structural feature of natural systems, including sub-atomic particles and living matter. According to the Standard Model (SM) theory and String Theory (StrT), elementary particles associated with the four fundamental forces of nature determine the existence of micro- and galaxy scales of nature. Therefore, the inheritance of molecular symmetry from the symmetry of elementary particles indicates a bi-directional (internal [(micro-scale) and external (galaxy sale)] causal pathway of prevalent bio-chirality. We assume that the laws of the physical world impact the biological matter's appearance through both extremities of spatial dimensions. The extended network of multi-disciplinary experimental evidence supports this hypothesis. However, many experimental results are derived and interpreted based on the narrow-view prerogative and highly specific terminology. The current review promotes a holistic approach to experimental results in two fast-developing, seemingly unrelated, divergent branches of STS and biological chirality. The generalized view on the origin of prevalent bio-molecular chirality is necessary for understanding the link between a diverse range of biological events. The chain of chirality transfer links ribosomal protein synthesis, cell morphology, and neuronal signaling with the laterality of cognitive functions.

Keywords: bio-chirality; fundamental forces of nature; space-time relativity; ribosomal protein synthesis; parity violation; elementary particle = fundamental particle = subatomic particle; time-space symmetry

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1. Introduction

Causal claims are an integral part of the natural sciences. Biology arises out of physics [1]. Meaning that the origin, evolution, and maintenance of bio-specific effects, including biochirality, follow nature's fundamental laws [2]. Spatial chirality (handedness) is well-known in atomic and molecular structures. Studies of chirality effects in nuclear and molecular structures reveal that spontaneous reversal of handedness is associated with breaking time-reversal symmetry [3–5]. The interplay (coupling) of space and time symmetries is a convincing illustration of spaice-time chirality.

Non-trivial behavior of chiral molecular compounds, including spontaneous chirality switching [6], transient reversible inversion of chirality [7], light-induced chiral switching [8], and chiral-induced spin selectivity (CISS) effects [9,10] suggest that ribosomal protein synthesis is not the only mechanism involved in the induction and maintenance of prevalent molecular chirality. Progress in this field reignites the search for the fundamental cause of bio-chirality, common for all hierarchical levels of soft-matter organization. As the fundamental determinant of existence, the fabric of space-time symmetry (STS) transformations is our review's immense subject, encompassing subatomic physics, galaxy structure, and the biological world, including the phenomena of intellect. Undoubtedly, non-biological and biological entities obey the fundamental laws of nature [11]. The universe's integrity is a driving force of theoretical and experimental developments in biology. The knowledge of the common principles of existence is needed to solve the mystery of why the origin of life is associated with the prevalent homochirality of biomolecules [12–14].

Since the time of Greek philosophy, an intuitive perception of the unity of everything sensed has been advanced to speculative and scientific levels. Kant (1724–1804) transformed the unity of the universe hypothesis into an analytical statement that time and space are the most fundamental forms of existence. Long before Noether, Kant pointed out the philosophical significance of chiral objects (which he called incongruent counterparts) to the concepts of space [15,16] and principles of conservation [17]. Newton (1643–1727), Leibniz (1646–1716), Minkowski (1859–1909), Poincare (1854–1912), Einsteain (1879–1955) and Noether (1882–1935) promoted the concept of the STS in the form of mathematical equations [18], bringing an opportunity to analyze space-time-related variables in a more general sense. The relativity of space and time intervals disclosed by Minkowski and accepted by Lorentz become Einstein's main postulates of special relativity theory (SRT) [19–21]. The advances in SRT and the general theory of relativity (GRT), made due to the achievements of the quantum theory of elementary particles (QPT) and the physics of gravity, brought the STS concept to a new level of understanding. However, the multi-dimensional network of links between space-time symmetry and bio-chirality involved in the origin of life is currently not explored systematically. The islands of experimental verifications are dispersed along the net as random spots. This condition is the main obstacle to providing a systematic review with a linear sequence of arguments.

Space-Time Symmetry and Relativity

> "*Geometrical properties of space are not independent, but they are determined by matter. We can draw conclusions about the geometrical structure of the universe only if we base our considerations on the state of the matter*" [22].

So, in our consideration we will propose two essential determinants of state of matter "around" us are elementary particles and galaxy world. Based on Galilean intuition, the concepts of symmetry, reference frames, and the relativity of physical quantities are intimately connected in classical physics. With several mathematical modifications, the same statement remains valid for quantum systems [23]. The equivalence of classical and quantum reference frames assumes the coordinate system invariant under elements of the corresponding symmetry group [24].

After GRT and formulation of Noether's theorem, the studies of inherent/genuine connection between STS and relativity principle become an unavoidable trend in all physical theories including, string theory (StT), Standard Model theories (SMT), and (QPT) [25–28]. The mathematical formalism of contemporary physics become based on the application of two mutually related principles of relativity and symmetry to the space-time domain [29,30]. Depending on the physical conditions, the behavior of these two principles exhibits alterations from similarity to significant differences. Notably, both principles coexist with the observer-independent speed of light, the relativity of photon frequency, and the known effect of symmetry breaking [31] and search for the possibility of breaking relativity [32–34]. We face the situation calling for reexamining existing theories [35,36]. However, the current

level of knowledge is sufficient to examine the fundamental determinants governing the origin and consistency of biological chirality.

2. Standard Model and String Theory

It is beyond this article's scope to elucidate the physical significance of STS in the mathematical language of the Standard Model (SM) and String Theory (StrT) (see, [37–39]), but the logical ground for understanding is provided. The family of SM elementary particles (EPs) (see Figures 1 and 2) adequately describes the physical world at microscopic and cosmological scales [40–43]. However, much more remains to be understood.

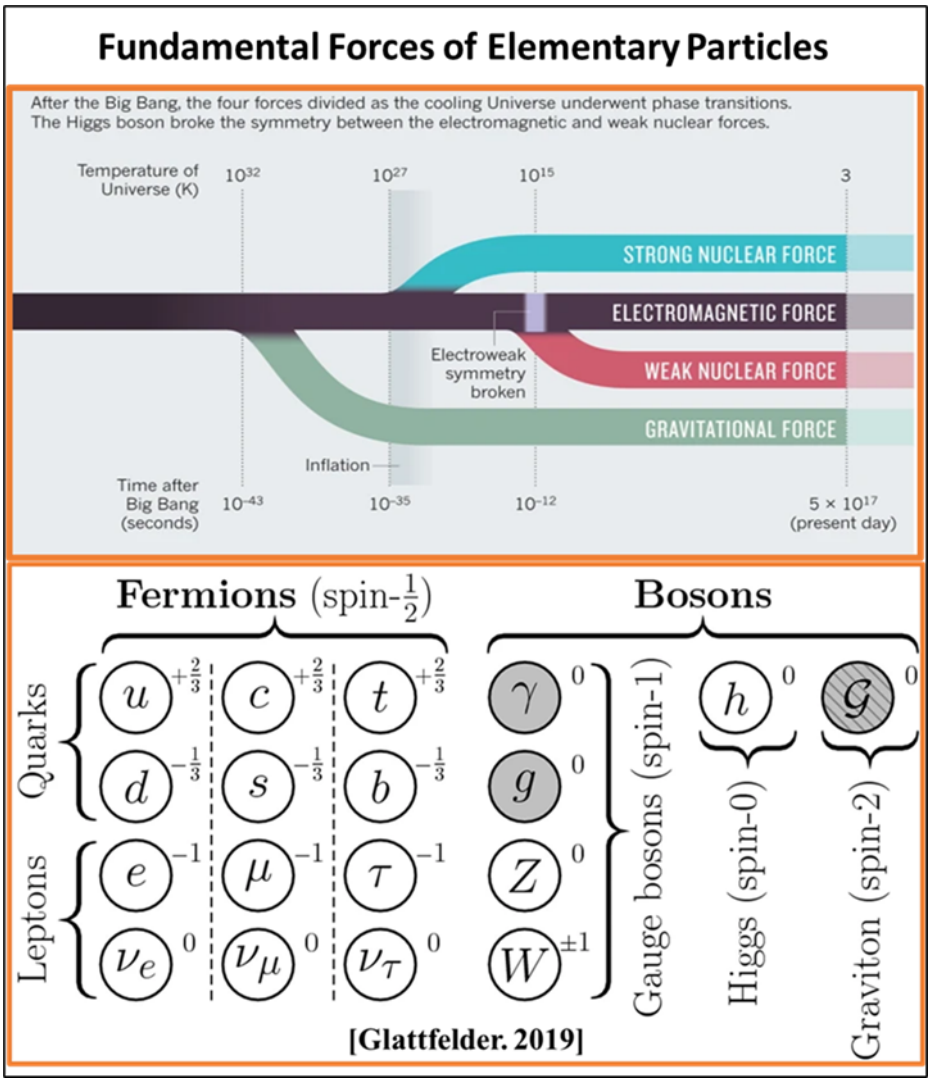

Figure 1. The fundamental forces of elementary particles (electromagnetism, gravitation, strong interaction, and weak interactions). The matter particles (fermions, half-integer spin), are classified either as quarks or leptons and come in three generations. The six types of quarks are labeled according to their flavor, up (u), down (d), charm (c), strange (s), top (t), and bottom (b) and are the constituents of composite particles (such as protons and neutrons). The muon (μ) and tau (τ) can be understood as heavier versions of the electron (e), each coming with an associated neutrino (ν). The three non-gravitational forces are associated with spin-1 gauge bosons, where the photon (γ) mediates the electromagnetic force, gluons (g) the strong nuclear force, and the Z and W ± bosons the weak force. The graviton (G) is the hypothetical quantum particle associated with gravity. The elementary particles represented by gray circles are massless, and each particle comes with an electric charge, given by the number associated with it on the upper right side. Adopted from [40] with alterations.

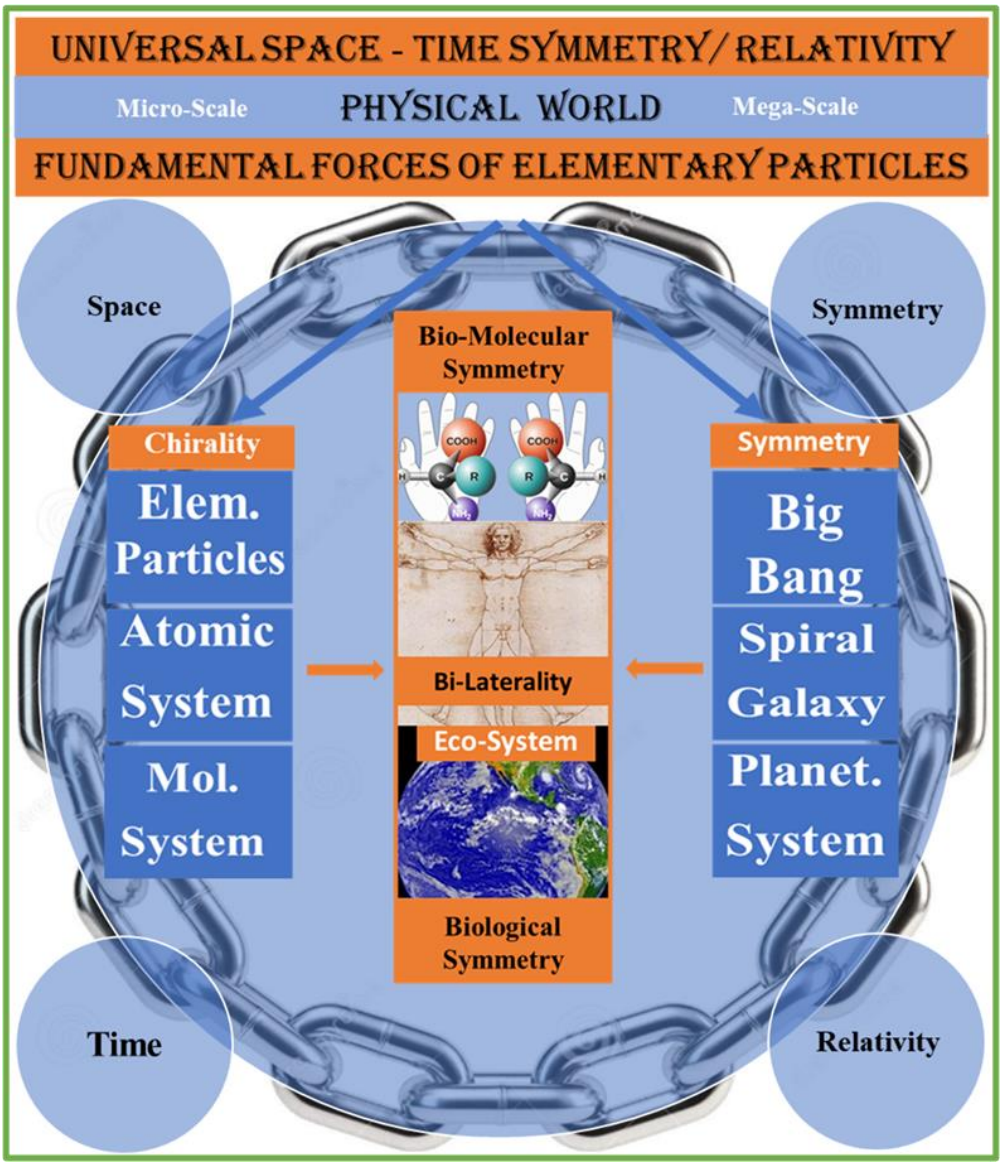

Figure 2. Bidirectional chain of chirality transfer. Internal and external determinants of Bio-Chirality. B. After the Big Bang, the four forces divided as the cooling Universe underwent sequential phase transitions. Adopted from [44,45] with alterations.

The Higgs particle (h), a scalar spin-0 boson, is associated with the phenomena of mass. The graviton (G) is the hypothetical quantum particle associated with gravity (up-to-date, has not been detected). The elementary particles represented by gray circles are massless, and each particle comes with an electric charge, given by the number associated with it on the upper right side. Adopted from [40] with alterations.

The continuous development of SM is an attempt to explain how the internal properties of EPs are related to four known fundamental forces (electromagnetic, weak, strong, and gravity interactions) [46,47] within the concept of STS [48].

2.1. Fundamental Forces of Nature

According to the SM, the symmetry parameters of EP associated with nature's fundamental forces (see Figures 1 and 2) play a causal role in all observed events in the universe at broad spatial scales from the subatomic (10^{-16} m) to the cosmological (10^{20} m) levels. Biological matter, represented by amino acids, macromolecules, cells, organs, and organisms correspond to the narrow intermediate scale interval (1.0–10^{10} nm). The assumption that

the ST evolution is the primary source of these phenomena in mega- and micro-worlds [49] immediately points to two complementary fundamental causes of biological chirality. In other words, the inheritance of molecular symmetry from the symmetry of EPs implies the existence of bi-directional pathways leading to the origin of prevalent bio-chirality, one thought an impact of the symmetry of atomic orbital on molecular chirality (Figure 2) and others through an organism's environmental and ecological domains, which means that both extremities of spatial dimension naturally shape all transitional states' appearance. The unification of the four fundamental forces of nature in StrT allows presupposing natural link between the micro-, meso-, macro-, and mega- worlds [50,51]. It is not accidental that the central to StrT is the assumption of a symmetry between fermions and bosons, which can be tested experimentally [18]. Recognizing STS' significance in particle physics promotes the idea that parity violation (PV) on the micro-scale may contribute to the molecular level of biochirality. Indeed, one of four interacting forces (weak nuclear force) demonstrates parity violation's, specific effect which is supposed to interfere with sub-atomic particles'geometry and, consequently, bio-molecular compounds' homochirality. The experimentally observed PV for the weak nuclear force may presumably generate the energy difference between biomolecules' ground and excited states. Theory predicted fact [52–55]. However, experimental confirmation remains challenging. Despite their different appearances, all four fundamental forces of nature, and corresponding scalar, vector, and spinor fields, exhibit differential inherent relations to the various forms of the STS [56,57]. It is reasonable to expect that factors contributing to biochirality are probably not restricted to the impact of the weak nuclear interaction. For example, the possibility of PV in gravity is widely discussed [58,59]. Ironically, the force most familiar to human experience, gravity, remains the biggest obstacle to a unifying view of nature. SM is a symmetry-based theory covering chiral, fractal, and topological branches. SM is frequently referred to as a chiral theory because the left-handed and right-handed partners are transformed differently under the symmetry group transformations [60–62]. Chiral features of SM and StT [37], evident in the physics of particles, condensed matter, and cosmology, suggest the prominent role of fermion-bosons symmetry in biological chirality origin [63–66]. The question on the table is how physical chirality relates to biological chirality. An apparent sharp difference between the living and non-living worlds requires close attention to the diverse network of links and associations of STS with the notions of entropy, statistics, phase- transitions, thermodynamics, and homochirality of protein synthesis and physiology of biological information processing.

2.2. Symmetry and Relativity

The relativity of physical symmetry has many faces (see Appendix A). Not trivial relations between fundamental concepts of modern physics such as symmetry, equivalence, invariance, and relativity have a tale from the time of Copernic and Galileo to the present [40,67]. In classical physics, symmetry, reference frames, and the relativity of frame-dependent quantities are intimately connected [23]. All variants of the relativity concept distinguish between the frame-dependent and frame-independent quantities of physical objects.

In group theory, the symmetry group of a geometric object is the group of all transformations under which the object is invariant. The relativity of space-time invariants is encoded under the action of corresponding symmetry group transformations. Einstein considered additional variables—the space and time intervals. Galilean, Lorentz/Poincare, and gouge symmetry group transformations reflect the fundamental symmetry of space and time. STS is critical to many physical laws, equations, and theories. Among them are Maxwell's equation for electromagnetism, the kinetic law of SRT, the Dirac electron equation, and the standard model (SM) of elementary particles (EPs) [46,68–70]. Gauge symmetry group transformations (relevant for all four fundamental quantum fields) involve spatial and temporal variables [71] as the objects of relativity principle. The synthesis of symmetry and relativity concepts in the series of theoretical approaches {including string

theory (StrT), the grand unified theory (GUT), and super unified theory (SUT)} gradually shaped the scientific conception of the physical and biological worlds [72–74].

Symmetry arguments have critical importance in two opposing spatial domains physics represented by the behavior of EPs [2,75] and the universe's structure [49,76,77]. While the contribution of EPs' spatial symmetry to biological chirality is under theoretical development and experimental verification, the impacts of the mega-world and its mirror partner are in theoretical modeling. Hence, the chain of related questions remains open. The history of science illustrates (represents) the chain of theories of natural events, including classical mechanics, electromagnetism, SRT, GRT, SM, and StrT. Notably, this chain represents the gradual evolution of the relativity concept in the direction of overlapping with the concept of symmetry. The spontaneous emerging and breaking of symmetry in space-time events are complementary processes underlying the mechanisms of many physical phenomena in two opposing spatial domains of physics represented by the Higgs mechanism of EPs [2,3] and the universe's structure [49,76–78] complemented by effects in condensed matterphysics and biological objects [79,80]. Beginning with Galilei, a many great names have contributed to a proper understanding of the inherent link between the principle of relativity and the concept of symmetry. The most prominent are Newton, Lorentz, Minkowski, Poincare, Einstein, and Noether. Non-trivial relations between the notion of STS and relativity principles are a continuous area of development and discussion in theoretical physics [28,81,82].

Generalized relativity principles say that all physics laws should be mediated concerning STS [2]. Quantum mechanics, developing the mathematical language for relational formalism, bring more fundamental meaning to these affinities [83,84]. Therefore, the identity of the reference frames should be considered a form of symmetry. In their original forms, the quantum field theory (QFT) and GRT unsuccessfully describe the complete ensemble of the fundamental forces of nature. Moving forward, all modern attempts to develop the quantum theory of gravity, including string theory, are based on considering the STS [85,86]. In fundamental physics, relativity is recognized as "a first place where the idea of symmetry begins to be felt" [87]. The photon's physical properties are the most convincing illustration of the natural link between the relativity principle and STS [88,89]. The history of science is the search for the mathematical expression of intuitive concepts of space, time, inertial motion, the principle of relativity, entropy, and symmetry. The idea of meaningful relevance between the relativity principle and the notion of symmetry has a long-term incubation period. It is a categorical imperative that the laws of nature must be the same for all observers. In the language of physics and mathematics, such conditioned invariability and uniformity (or conservation) is called symmetry. According to Newton (1642–1724), inertial motion's relativity can be comprehended under a proper interpretation of STS [90]. In agreement with this intuitive statement, it was shown that both the Galilean (1564–1642) and Lorentz (1853–1928) transformations might be derived from the relativity principle based on certain elementary assumptions regarding space and time [91]. In classical physics, the equality of physical laws is provided by Galilean transformations (G) and corresponding relativity principles {see Equations (1) and (2)}. In this scientific period, attention to the speed of light and equality of physical laws was associated with the concept of relativity but not the STS. Experiments by Michelson and others (in the 1880s), that demonstrated the independence of the photon's speed from the relative velocity of its source and observer, inspired a new generation of scientists to find agreement between classical and quantum mechanics. Conceptual changes to the universe's postulated ontology from three-dimensional absolute space to the four-dimensional space-time of relativistic physics open the hidden link between space-time symmetry and the relativity principle [35,92,93]. Explicit understanding of the significance of the closely related concepts of relativity and STS in physics requires a considerable mathematical background. This condition is an objective obstacle to sharing the achievements of modern physics with the field of bio-chirality.

Einstein's statement (1878–1955) that "inertia resists acceleration relative to space" point attention to the inherent link between concepts of space, time, inertial motion, gravitation, and the principle of relativity [21,91–95]. The STS transformation, relating a physical object's speed to the speed of light, which allows the laws of physics to be the same for all observers is known as a Lorentz symmetry transformation (L) (see Equations (1) and (2)).

Equations (1) and (2).

$$vx' = x - vt;\ y' = v;\ z' = z;\ t' = t \tag{1}$$

$$x' = \frac{x - vy}{\sqrt{1 - \frac{v^2}{c^2}}};\ y' = y;\ z' = z;\ t' = \frac{1 - \frac{vx}{c^2}}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{2}$$

Galilean (a) and Lorentz (b) transformation (G and L): coordinates (t′, x′, y′, z′) of an event in K′ system correspond to the event's coordinates (t, x, y, z) in K system. The validity of Lorentz transformation suggests that the constant c (the speed of light in vacuum) is a universal speed limit [96].

The inclusion of gravity force and accelerating frame of reference undertaken by Einstein to move from SRT to GRT initiates essential new insight into the relativity principle, bringing explicit recognition that the relativity principle is s symmetry-associated principle [93]. Hilbert and Klein's mathematical analysis of GRT field equations reveals the remaining inconsistency. Resolving the problem, Noether comes to far-reaching conclusions (Noether's theorems). She showed that GRT could adequately describe natural events only under the assumption of an intrinsic link between concepts of symmetries, relativity, and gravity-induced curvature of space-time [97]. These theorems perfectly agree with the role of four fundamental forces of nature in the macro- and mesoscale of physical events. Notable that an exploration of the symmetry role in SRT shows that L transformation requires the speed of light invariance [28,83,98]—a conclusion consistent with the spirit of Noether's theorem. Relativity, space-time domain, and STS have become significant focuses of interest in physics, mathematics, and philosophers of science as well as molecular biology and neuroscience [99–102]. Noether's theorem [103] shows that a not-contradictive mathematical description of the conservation laws requires including the symmetry features. Consequently, in many theoretical works, it was confirmed that adequate solutions to SRT [28] and GRT [26,104] equations require specific assumptions regarding STS. Applying the relativity principle to the symmetry patterns of EPs reveals that the helicity and chirality of EPs derived from the Dirac equation have a sharply distinct property [105]. The quantum mechanical variables of EPs, like chirality and helicity, exhibit different behaviors (being invariants or depending on the reference frame) for massive (like an electron) and massless (like a photon) particles. For example, the helicity of an electron (spin $\frac{1}{2}$ and velocity less than the velocity of a photon in a vacuum) depends on the reference frame (i.e., exhibit the relativity). The chirality of electrons is Lorentz invariant but is not a constant of motion. Contrastingly, for photon (spin 1), helicity is time-invariant. With this scientific background, it is unsurprising that space-time-related characteristics of EPs, like chirality and helicity, were found to be the critical determinants of the structure and functions of bio-molecular compounds (including DNA, proteins, and lipids). Notably, identifying the gravitational field with the ST curvature has generated the most influential predictions of general relativity, including the quantum structure of ST, the occurrence of the big bang, and the existence of black holes [106,107].

Our consideration of STS in most general terms is aimed at the specific form of symmetry transformation in the space domain—mirror reflection, and their principal role in biological chirality. Growing experimental evidence suggests the chirality of the fundamental physical force may provoke asymmetric imbalance in a chemical system (either racemic or prochiral) [108]. Consequently, it has become apparent that the above-mentioned fundamental principles of the physical world apply to the biological world generally and the phenomena of biochirality specifically. Due to evolution and development, moving

animals gained a sensory perception of time, and space intervals, which in humans were transformed into intellectual reasoning regarding the relativity of movement, STS, and causality. Phenomenology is a philosophy of experience. However, the specific aspects of spontaneous symmetry breaking, and their physical ramifications are dispersed among the specialized literature of multiple subfields, making them not widely known or readily transferred to the area of biological science.

2.3. Fragile Space-Time Symmetry: CPT Theorem

The most surprising twist in the view on the fundamental significance of the Noether theorem is the discovery of symmetry's fragility in physics [109,110] and biology [101,111] considered in the frame of CPT theorem and focused on the phenomena of handedness or chirality. From a geometrical perspective, the objects across diverse spatial scales may be classified as chiral or achiral concerning a specific space-related symmetry transformation—mirror reflection. Chirality as a symmetry element reflecting the property of asymmetry or dissymmetry (lacking all symmetry elements except the trivial identity) is the critical structural feature of natural systems, including EPs, galaxy system and living matter. Chirality as a form of symmetry deficiency is important in the molecular biology of all biological objects, including viruses [112] and higher organisms [113,114].

Quantum field theories predict the set of discrete, fundamental STS which restraint the behavior of all known EPs: charge conjugation symmetry (C-Symmetry), time-reversal symmetry (T-symmetry), and mirror symmetry (P symmetry, space inversion symmetry or parity), collectively known as CPT symmetries [115]. The performance of each of the individual symmetries and its combinations were tested experimentally under all known fundamental forces of nature. The entire family of elementary particles conserves the CPT combination of the summitry transformations (CPT theorem) (see Appendix B). However, violations of individual C, P, and T symmetries and their binary combinations (PT, CT, or CP) were observed in many cases, influencing CPT theorem modifications. In the initial version, the CPT theorem concerning the behavior of EPs states that the STS determinants govern the physical world. CPT hypothesis, in relation to the chemical kinetics, and origin of life, states that STS is a major determinant of the prevalent chirality in biological processes. In its expanded form CPT hypothesis of state: a uniqueness of molecular quantum physiology and psychology only exists in the case of a CPT violation [115,116].

The predictable consequence of symmetry violation at the level of elementary particles is breaking thermodynamic equilibrium between pairs of molecular enantiomers leading to selective bio-chirality. Commonly discussed links between space STS symmetry and biochirality require additional theoretical clarifications associated with experimental verifications within concepts of indivisible and undistinguishable particles. The most trackable connection between STS in physics and biology occurs through space inversion symmetry. Consequently, we will narrow our consideration to P-symmetry in physics which is strongly linked to bio-molecular chirality [117–120]. Among many aspects of spatial symmetry, chirality gradually gained sharp attention. As mentioned, chirality is one of the most common space-related (geometrical) characteristic of natural objects appearing in our universe at many levels of space size, from the EPs world to the galaxy world. The idea that the non-interrupting chain of chirality transfer comprises of distinct links between overlapping domains of spatial dimension has a long period of clarification. However, even now, we have lack or limited information regarding many links in this chain. In the history of science, we can see the corresponding continuity in the chain of logical conclusions. Ancient philosophers beginning with Democritus considered hypothetical atoms' shape (i.e., symmetry) determinants of material world diversity. Later, the intuitive symmetry consideration was used by Mendeleev for establishing periodic tables of elements. The symmetry arguments in physics and chemistry were traditionally used to find the solution to puzzles of symmetry transfer from atoms to molecules [118,121,122]. Consequently, molecular chirality was found to be a determining factor in the external and internal symmetry of non-organic crystals and biological macromolecules [123]. From a

different perspective, an increasing line of convincing evidence suggests that stereo-specific chemical evolution may originate before the origin of terrestrial life from the contribution of the symmetry patterns of the macroscale galaxy dynamics [124,125]. Essentially, we have a bidirectional chain of chirality transfer across the space scale (see Figure 2) as a causal factor of biochirality.

Notably, formally opposing converse pathways indicate the decisive role of fundamental forces of nature in the origin of bio-chirality. However, the phenomenological similarity and differences underlying the mechanisms of the succession of such events are not the mainstream of the scientific discussion. The progress in this direction should be grounded in more systematic and goal-oriented studies. The unifying view on the evolution of the time-space concept, covering the areas of spinors, quaternions, tensors, and differential forms, can be found in many published courses [49,126–129].

3. Bio-Chirality

Conservation quantities (conservation laws) in all domains of physics, including quantum mechanics of indistinguishable EPs particles (fermions and bosons), are always related to the symmetries of the system [130,131]. The symmetries determinants, critical in classical and quantum information processing [132], are recognized as the mechanisms underlying biological information processing at the molecular and cellular levels [133,134]. We have primarily focused on the phenomena of symmetry transfer across the levels of biological organization. According to current knowledge, "the mechanisms which ensure invariant left-right asymmetry of the heart, viscera, and brain represent a thread connecting biomolecular chirality to human cognition, along the way involving fundamental aspects of cell biology, biophysics, and evolutionary biology" [135]. The hieratical chain of chirality transfer bears the occurrence of such a connection [123]. Notably, the stereo-divergent chain of chirality transfer between hierarchical levels of biological organization was observed experimentally, including in Bottom UP and Top-Down directions [136–140].

3.1. Hierarchical Levels

> "*All forms of life, from single-cell eukaryotes to complex, highly differentiated multicellular"organisms, exhibit a property referred to as symmetry*" [141].

The common belief that molecular chirality is a central feature in the origin and evolution of biological systems is reflected in many reviews [66,117,123,142]. The emergence of the chirality of life is associated with the break of symmetry at the molecular level. However, the cause of biomolecular asymmetry so far is characterized as an "unanswered question" [12,143]. The most common of those questions are: "Did life begin by using both forms of chirality, and then one of the forms disappeared" and "Did the choice of homochirality precede the formation of biomolecules"? Resolving such uncertainty calls for a broader outlook on biochirality phenomena. The science tracing the links between biological events, including the prevalent bio-molecular chirality with the laterality of perceptual, cognitive, and psychiatric functions, gains the name biological chirality or bio-chirality [144]. The chain of chirality transfer within the biological world, ranging from molecular chirality to cognitive brain laterality (bio-chirality), is a well-studied phenomenon for animals [123,137,145] and is discussed in detail in several comprehensive reviews [12,13,146]. A hierarchical chain of chirality transfer within the bio-molecular system is experimentally observed for amino acid's spontaneous and induced self-assembly into chiral aggregates [137,147]. The essential feature of the chain of chirality transfer in biology is bi-directionality, meaning that each link (and any sequence of the links) experiences the asymmetric impact from the left- and right- neighborhoods. The molecular chirality of plants and animals has many recurrent features. Animals and plants originated from a common, single-celled, and motile eukaryote probably 1.5 billion years ago. The corresponding complex of the experimentally observations supports the hypothesis regarding the chain of chirality transfer from molecular structures to the morphological and functional characteristics of the organism [123]. The evolution of morphogenesis of moving animals is

driven by the fluctuating asymmetry (FA) representing the small, random developmental differences between the right and left sides [148]. A well-known example of chirality transfer from the molecular to the cellular level is that major cytoskeleton components of eukaryotic cells, like actin microfilaments and microtubules, produce polar filaments of one chirality responsible for cell handedness [149]. The opposite chain of chirality transfer to the biological world originates from the macro-domains of space, apparent in the structure of GW. The solar system containing the planet Earth encapsulating the biological world is just one of many other intermediates (Figure 2).

The predominance of molecular handedness in biological objects is frequently considered a unique signature or property of life. This widespread perspective (being encouraging for many biologists) contains two essential destructive elements generating deviation from objective reality. First, the word unique is compromising the truth of this statement. Second, it is misleading in the search for the origin of biomolecular chirality and laterality of cognitive functions. The escape from such a dead end is possible only based on a broad perspective on the attention to the advances in understanding the fundamental laws of nature, showing the significance of the symmetry concept. Our attempt is the generalized (i.e., philosophical) transection of organism bio-chirality considering the internal, external, and behavioral aspects. The human's brain information processing mechanism of is challenged with the task of discriminating the event across space and time domains, examined by sensory perception and reasoning [50]. As we mentioned, sensory perception of moving objects differentiates itself into the chain of more specialized patterns: perception of time-space intervals, symmetry, and causality. On another side, spontaneous emergence and breaking of symmetry in space-time events are two alternative processes underlying the mechanisms of many physical phenomena ranging from condensed matter physics and the Higgs mechanism in the SM of elementary particles to biology [79,80]. The external and internal determinants of the organism's bio-chirality are rooted in quantum physics. The quantum hydrodynamic approach to particle physics justifies the continuous spontaneous formation and annihilation of virtual particles and antiparticles (vortex-antivortex pair) in a quantum vacuum. The handedness of EPs, combined with the experimentally observed asymmetry in spiral galaxies, originating from chirality from giant vortices of the central black hole [72,150], suggests that the left-handed bias of weak nuclear force and the rotation of the cosmic superfluid explain the left-handed bias in biological molecules (bio-chirality) [151]. Bio-chirality of the living organism has its internal determinants at the atomic and molecular levels. At the atomic level of events, coupling the symmetry parameters of sub-atomic components, including protons, electrons, and photons is critical. In agreement with Lorentz-Poincare symmetry transformations and Noether's theorem [103,152], the dynamic changes of local quantities of the electromagnetic field associated with the helicity and chirality of spin and orbital components momentum of electrons are coupled with the energy state through helicity and chirality of emission/absorption of photons. The underlying physical laws are considered the fundamental determinants of light-matter interaction [89,153,154]. The interaction between chiral matter and circularly polarized light (as events occurring in both space and time domains) is determined by the combination of physical parameters influencing the degree of stereo-specific effects [155].

Electron-photon coupling is an illustrative example of stereo-selective (chirality-dependent) interaction between mass carriers (fermions) and massless EPs (bosons) [156,157]. The subjects of particular interest are the laws common to the non-biological and biological worlds. In other words, the question is what kind of universal phenomena embrace the domains of non-organic and organic nature. The broad-view picture suggests that the emergence and evolution of the biological world on the Earth occurs under the collective impact of the galaxy world and the world of EPs. Consequently, the most fundamental biological world law, associated with the spatial domain of existence, is biological chirality or bio-chirality.

3.2. Bilateral Symmetry

Left-right morphological handedness and prevalent chirality of biological molecules are incidents/examples of geometrical similarity among chiral (not-superimposed) objects of differential hierarchical complexity. The morphology of plants and animals exhibits different forms of symmetries, including bilateral, rotational, translational, and fractal (see Appendices C and D) [158]. The evolutionary origin of mobile multicellular bilateral organisms is linked to prevalent molecular chirality, determining the animal cell motility, polarity, and proliferation. The best-studied examples of the interplay of symmetry and asymmetry in biology are the bilaterality (symmetry) and handedness (hemi-lateral asymmetry) in morphology and functions of the human body, nervous, sensory, and cognitive systems. Left–right asymmetry in body morphogenesis occurs at the early stages of embryonic development [135] followed by moto- and cognitive laterality. Organisms' bilateral symmetry is characterized by body shapes divided along a plane of mirror reflection (suggesting the link to mirror reflection symmetry at the molecular level. Movement, associated with competition for food and predation, generates elaborating sensory systems, contractile muscles, and a fast-reactive, bilaterally asymmetric nervous system. These features enabled survival. In the human brain, functional hemispheric asymmetry is evident in the division of labor between language (left hemisphere) and motor (right hemisphere) functions [159,160].

3.3. Molecular Level

The internal determinants of cellular and organismic bio-chirality are molecular complexes, including proteins, DNA, and lipids. Corresponding external determinants are related to the geo-centric realm of existence, such as the local environment and biosphere, as a whole (Figure 2). Apparently, the distinction between determinants as internal and external is not absolute because the impact of fundamental forces of nature is essentially bidirectional. The spectrum of hypotheses considering the origin of biological homochirality is consistently expanding. Some analysts appeal to parity violation due to the energy difference in the chiral molecules attributed to parity violation energy difference (PVED) [12,13,161]. Others link the origin of prevalent bio-molecular chirality to the impact of external organism factors such as the handedness of the axial and orbital rotations of the Earth, the asymmetric fluctuation of the atmospheric and oceanic media [162], and the spiral structure of galaxies. However, they all focus on considering the spatial symmetry attributes of the corresponding objects. Molecular chirality (i.e., an association with symmetry constraints) originates from the symmetry of atomic constituents, including electrons and protons, inherent to all periodic table elements. Experimentally observed CISS effects in α- helical proteins and DNA structures attract attention to the theoretical consideration of the mechanism of electron spin-selective transport in biological molecules [155]. The emergence of biochirality mechanisms is generally classified as biotic or abiotic. The discrimination between them should not shadow the fact that chirality linked to fundamental STS is the common feature of living and non-living (soft and solid) matter. The experimental observation of various spin-dependent molecular processes driven by the external and internal chiral physical force supports this view [154,163–170]. Notably, all organic molecules contain a limited member of evolutionary selected chemical elements (carbon, hydrogen, oxygen, sulfur, nitrogen, and phosphorus). The primary cause of such selection is the unique symmetry of atomic orbitals, allowing the ribosomal synthesis of homochiral proteins and vital stereo-selective interactions within the DNA-proteins-lipids complexes. The biological systems, representing thermodynamically open non-equilibrium states characterized by the bio-molecular phase transitions, are commonly associated with symmetry transformations (symmetry changes or "breaking") [165–168] and not trivial bi-directional behavior of entropy [123,171]. Notably, the evolution of galaxy clusters exhibits similar bi-directional (decreasing and increasing stages) entropy patterns [43,172–174]. The fundamental significance of biochirality at the molecular and cellular levels assumes the mechanisms of the organism/brain morphology, behavior, cognition, and consciousness are grounded on basic principles of spatial organization and function. The biochirality

concept is closely associated with all vital events of the organism, including fertilization, asymmetric cell division, organism development (bi-laterality), biological information processing (brain functional asymmetry), and ageing [166–168,175–180]. The study of the mechanism of human consciousness and cognitive functions traditionally concern the sensory perception of space-time geometry [181–185]. The view that "time and space are tightly blended in the brain" is supported by most advanced perceptual and cognitive function studies [186–189]. Notably, the functions of place cells are attributed to the pyramidal neuron populations, presumably serving as a gravity-based three-dimensional compass in the brain [190]. Understanding molecular chirality as a unique characteristic of biological structures is misleading.

Three-dimensional shapes of both biological and non-biological constructs exhibit intrinsic chirality at the molecular level. The intrinsic determinant of molecular chirality is the symmetry of quasi-stable atomic complexes, which, in turn, are driven/governed by the symmetry of sun-atomic elementary particles. An illustrative example of symmetry constraints, common to organic and non-organic molecules, is chiral-icosahedral shells observed for Au60 spere and capsids (icosahedral shells of proteins around a single RNA molecule) of many icosahedral viruses [191–193].

4. After Words

The commutative power of experimental results and theoretical developments suggests that the Universe's non-equilibrium state, characterized by the entropy's increase, is inevitably linked to the compensatory processes of self-organization (decrease of entropy). At the molecular level, such compensatory events are associated with the mechanism of chirality-dependent protein folding as a distinct phenomenon of life. Notably, from a theoretical perspective, self-organization is considered a new form of global STS, that is scale-invariance reflecting the dynamics of energy/matter at all levels of organizational hierarchy, from elementary particles through cells and organisms to the universe as a whole [194,195].

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Abbreviation

Deoxyribonucleic acid (DNA). Charge symmetry (C-summitry). Elementary particles (EPs). General theory of relativity (GTR). Physical world (PW). Parity symmetry (P-symmetry). Parity violation energy difference (PVED). Quantum theory of elementary particles (QPT), Standard model (SM). String Theory (StrT). Space-time (ST). Space-times symmetry (STS). Space-time relativity (STR). Special theory of relativity (SRT). Time reversal symmetry (T-symmetry).

Appendix A

The tetrahedral coordination sphere of carbon, nitrogen, and oxygen, accompanied by the four-bondedness of a saturated carbon atom, are critical determinants of protein-ligand interaction [196].

It should be noted that the prevalence of L-amino acids accompanied by the small amount of D-amino acids is not the only factor contributing to the diversity of stereospecific bio-molecular compounds. Recent surveys of protein data bank (PDB) structures show the possibility of right-handed and left-handed variants in helical and beta-sheet conformations [197].

Appendix B

In a generalized theoretical view, the arbitrary symmetry transformation results in the combination of the invariant and differing parts of the physical state. In addition, each of these parts can be observable and not observable [198,199].

An example is the physical symmetry of the initial disposition of chess figures, which is invariant under a horizontal reflection passing through the center of a chessboard. However, the colors of the figures are switched under this reflection. Here, relative positions of the figures are the invariant part of the physical states, and the figures' coloers are the differing parts of the physical states.

Appendix C

C, P, and T symmetries stand for the charge conjugation (C), parity or mirror-image symmetry (P) and time-reversal symmetry (T).

Appendix D

Many natural phenomena exhibit repeating patterns of similarity at every spatial scale. This similarity causes a new notion of symmetry called "fractal" and is referred to as "scale-symmetry," "self-similarity," "similarity, or symmetry up to scale," and "similarity in the small and in the large."

Scale-symmetry is observable in the evolution of galaxy shape, molecular structures, and various intermediate scales, including all biological organization domains [194]. Considering fractals in space-time physics is necessary for a deeper understanding of the GTR [194]. Fractals in biology are studied in the morphology of plans and animal organs [200–203].

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