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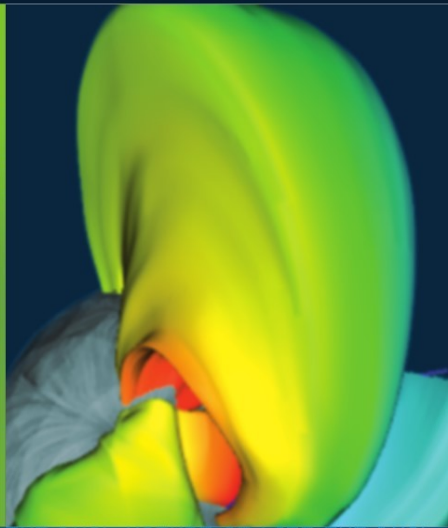

Gennadiy Zhegunov

THE DUAL NATURE OF LIFE

Interplay of the Individual and the Genome

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THE DUAL NATURE OF LIFE

Interplay of the Individual and the Genome

Translated from Russian by
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Springer

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Preface

What is life? Although the origins and nature of life are not yet fully understood, it is a widespread phenomenon on our planet which can be characterized by a number of fundamental attributes that differentiate living bodies from non-living ones in significant ways. It is clear that life is a qualitatively specific manifestation of organized matter. However, due to the fact that all life forms are complex and diverse, there is no complete or clear understanding of this phenomenon or its prevalence.

We will attempt to analyse the mysteries of life from a new perspective. Though the material is based on the classical scientific conception of life, we will consider biological phenomena from a non-standard point of view, developing, among others, the notion of the many *dualities of life*.

In particular, when analysing the nature of life, we proceed from the fact that there are individual and specific physical beings (bodies) which, with all of their characteristics, properties, and functions, represent one manifestation of life in the natural world. On the other hand, life is also a systematic determinant of the iterative interactions of individual organisms leading to the establishment of the living world as an entity (as a global phenomenon of life), and therefore also requires scientific and philosophical comprehension on a global scale.

This duality is also tied to the fact that organisms are physical and visual (phenomic) derivatives of the expression of their genomes. This book suggests and develops a hypothesis about the primary nature of genomes in relation to cells and the living bodies they comprise. Life, in other words, includes complex visible phenotypical components and even more complex invisible genotypical ones. Because this duality is present not only at the level of the individual organism but also in the combined existence of global life, we will attempt to understand the concept of the global phenome, which is a result of the expression of the global genome. A final duality is also seen in the immortality of the global phenomenon of life that is maintained by the mortality and replacement of its discrete components, on both an individual and a global level. It may therefore be possible to surmise that this duality is the essence of evolution, by asking whether it is an effect of the survival of organisms and species or the survival of information, which is transferred and expressed by them.

Because life is a highly complex phenomenon, it is analysed chapter-wise from several points of view. The first part deals with life as a phenomenon of the material world, while the second explores life as the existence of *living bodies* with their inherent properties. Part 3 describes various *processes and mechanisms* that are usually ignored or mixed in with principally different categories. The fourth part delves into the role of *information*, which is a *directive and creative force* of all life processes and mechanisms. The fifth part gives a detailed analysis of the *dualism* of life, followed by a short conclusion that provides a review of the material and gives generalizing summaries.

As a whole, the book provides several key concepts regarding the nature of life. The nature or individual characteristics of humans are not greatly emphasized in the present work, because humans are considered here to be a representative of mammals without any distinct peculiarities which would require a separate and detailed analysis.

Key Concepts

In order to follow and understand the ideas presented in the book, it is necessary to introduce several key concepts that will be used throughout:

1. *Life*. An abstract, collective term that segregates a part of Nature with specific biological properties.

2. *Phenomenon of Life*. One of the forms of organized matter. The process of continuous coexistence of all living bodies which are complementary to the diverse nature of the Earth.

3. *Living Bodies*. A form of manifestation of life. The physical bodies that possess biological properties and peculiarities. These are discrete units of life, which are temporary dissipative self-replicating biological systems. The basis of their rebirth and existence is the relatively permanent genome.

4. *Life of a body* is the dynamic process of the limited existence of discrete units of life from appearance until end.

5. *Gene*. The unit of information that controls the genesis of a certain body characteristic. Genes are segments of NA that carry out specific functions, such as protein synthesis regulation, enhancing or suppressing the actions of other genes, and so on.

6. *Genotype*. The presence of certain genes or their totality in a given individual.

7. *Phenotype*. The presence of certain characteristics or their totality in a given individual.

8. *Genome*. The entirety of genetic information stored in the DNA (or RNA) of living beings. Also, a conceptually defined specific part of a cell that contains a select set of NA and proteins united into an integrated structural and functional

system. This system contains special genetic information as well as mechanisms and instruments of its use.

9. *Phenome*. A visual set of characteristics arising from the expression of genes and from the influence of external factors. Also, a conceptually defined part of a cell that surrounds and integrates a genome, forming a monolithic body. The phenome of a multicullular organism is represented as the combined phenomes of all of its individual cells. In other words, there are highly organized colonies of standard genomes within a combined phenotypic framework.

10. *Genotypic Life*. The totality of the operational processes of all genomic elements for existence and realization of their informational potential.

11. *Phenotypic Life*. Processes of coexistence, functioning and interaction of living bodies, including all their properties and characteristics.

12. *Global Genome System*. The totality of functioning and interacting genomes of all living bodies.

13. *Global Phenome System*. The totality of functioning and interacting phenomes of all living bodies.

14. *World System of Life or Integrated Life System*. The totality of functioning and interrelated genomes and phenomes.

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Chapter 1
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1.1 Key Features of Life

Currently, the Earth is the only stellar body known to contain life as we have defined it (see Fig. 1.1). Despite the fact that life on Earth is a unique phenomenon in our Solar System, it is very widespread and complexly diverse on this planet. It appeared at a definite stage during the Earth's development, approximately 3.5 billion years ago, as a result of spontaneous chemical interactions that led to unique organizations of matter.

Life has a cellular basis and is extremely widely distributed over the entire planet, despite dramatically varied physical and chemical conditions in the external environment. As a result of adaptation and evolution, living beings are very diverse in terms of their size, structural complexity, multicellularity, level of organization, features of metabolism, and vital functions. Such variability allows them to occupy practically any ecological niche on Earth. Living organisms can live above, in, and under the ground, or in water, air, rocks, other organisms, and in extreme conditions such as in ice or hot geysers. They can be found under enormous pressures many kilometres beneath the oceans and at very high altitudes in the anoxic atmosphere at the edge of space. Manifestations of life can also be observed at extremely low temperatures (−50 °C), and at very high temperatures (up to +100 °C). For example, some molds and fungi (*Aspergillus*, *Cladosporium*, *Helmintosporium*) are known to live on the cooling covers of nuclear reactors, surviving colossal doses of radiation.

One can say that the Earth is simply 'contaminated' with so much life that practically nothing can destroy it on our planet. The building blocks of living organisms are nucleic acid molecules (NA) and proteins, the properties and functions of which (in an aqueous environment) account for life's immense diversity. Only a catastrophe of cosmic proportions could annihilate life, such as a cataclysmic event that causes the temperature on the Earth's surface to rise above +100 °C leading to the disappearance of water. Man, despite his global impact on animate and inanimate Nature, cannot destroy the entirety of life. Even nuclear

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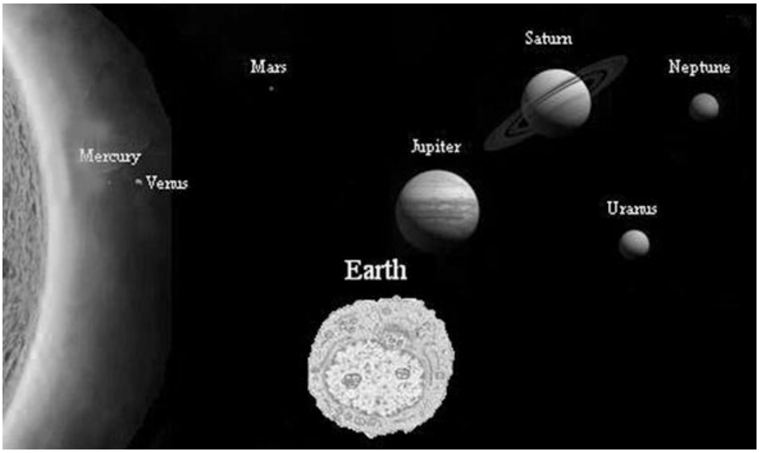

Fig. 1.1 Is there life on other planets? in our solar system, life prospers only on planet Earth which is represented as the component that serves as life's primary constituent: a single cell

war and the consequent nuclear winter could destroy only 'intelligent' life and an indeterminate number of other different types of organisms. Nevertheless, many viruses, microorganisms, and more complex life forms inhabiting the depths of the Earth or the oceans would survive this 'local catastrophe' almost without any problems. Thus, life as a qualitatively special form of matter will exist as long as the conditions required for the formation of nucleic acids and proteins in aqueous solutions remain on Earth.

The fact that life exists only on Earth is due to the Earth's specific location in the Solar System and its size. Only at its current position and distance from the Sun are the temperature and other physical conditions needed for the existence of organic substances, as well as liquid water, optimal. These factors in turn make it possible for 'nucleic-protein bodies' to exist. The size of the Earth is also ideal for gravitational retention of the atmosphere, which ensures the relative stability of the physicochemical surroundings of living organisms. The atmosphere is not only an 'umbrella' against damaging ultraviolet radiation and meteorite bombardment, but it also helps to maintain the Earth's surface temperature between 0 and 100 °C. Water remains liquid (but not solid or gaseous) in this particular temperature range, which is a necessary condition for the manifestation of life. Although the substrates of living things—nucleic acids and proteins—can retain their vital potency at lower temperatures, even at temperatures approaching absolute zero, the commencement, manifestation, and proliferation of life nevertheless requires liquid water.

Some forms of life can be unnoticeable or even completely absent. For example, various primitive organisms can completely halt their vital processes, resulting in a state called anabiosis. Unicellular organisms, small invertebrates, spores, and seeds of plants can remain in this state for many years. Anabiosis makes possible the prolonged preservation of an organism's structure, and more importantly, the maintenance of the structural and functional state of its DNA and proteins during extreme conditions such as low temperatures and complete dehydration. This is why, upon the return of normal conditions, they can restore all the processes of their vital functions and subsequently *revive*. Viruses are also capable of staying in anabiosis for a long time while maintaining the integrity of their DNA, and only manifest their viral properties after entering a host cell. These facts do not eliminate, in principle, the possibility of the existence of 'latent life' on other cosmic bodies (in the form of stable nucleic acids), nor the possibility of Earth's colonization by such beings billions of years ago.

The life of any given organism is a finite, unidirectional process. A process is a course for the development of some phenomenon, a successive change of developmental states and stages. In this case, it is the process of the appearance, development, and extinction of previous generations of individuals and the formation of new ones. The process of life has one-way directionality—from the past, through the present, to the future. This is implemented in the irreversible phase changes of ontogenesis intrinsic to every living being. Generations of organisms are continuously replaced by others. The alternation of generations is a striking phenomenon that is characteristic only of communities of living organisms, and it is an amazing property peculiar to life. It started from the moment of the origin of living bodies and it continues to this day with no tangible end in sight. Life, therefore, is a continuous process, because in the course of reproduction, eternal genomes are transmitted—with slight changes—from one mortal body to the next, and from one generation to another, over millions of years and billions of generations.

Every organism as a carrier of life exists only as a constituent of an ecosystem and its environment. Only in the organism–environment system does the redistribution of matter and energy take place. That is why it is necessary to consider living matter and the sphere of its existence as a large, integrated system. Based on the ongoing processes of constant redistribution of energy and matter within such a system, life can be considered not so much as the existence of autonomous organisms, but rather as a planetary system in which these organisms are just constituents.

Life also has an informational basis, since reproduction, development, function, and evolution are based on info-genetic processes. In particular, throughout their transient existence, individuals transmit a genetic program of development to the next generation in the process of reproduction via the DNA of gametes (sexual propagation) or via the DNA of a body part (asexual propagation). In turn, these new individuals grow and mature on the basis of their DNA programming, and then produce their own gametes and reproduce, establishing a life cycle based on the information stored in nucleic acid sequences. This cycle continues as long as the conditions for survival and reproduction exist. The continuity of genetic material, despite the alternation of generations of individuals, is one of the most important characteristics of life. It accounts for the 'intermittent continuity' of life, despite the mortality of its individual constituents, since they have time to create a transitional form of existence embodied in the genetic material of gametes, spores, cysts, or other compact and stable formations. Thus, it is possible to imagine the flow of life in two dimensions. The first is a form hidden from the eye and is termed genotypic life. This is the dynamic existence of virtually unchanging genomes of all species of living organisms. The second is visible phenotypic life, which is the periodic phenotypic manifestation of genomic activity as various living bodies. One can say that various forms of cells and living bodies serve as distinctive *phenotypic frameworks of genomes*.

Phenotypic life is very changeable and is in a state of constant development. An infinite number of species have changed on the Earth over hundreds of millions of years. At one time fish 'reigned', then came dinosaurs, large predatory mammals, and now humans. In principle, these are all links in one chain of animal evolution. Although the phenotypes of given organisms differ significantly, their genotypes have gone through only modest molecular changes. The qualitative and quantitative composition of the nucleotides, as well as the chromosomal composition of karyotypes, has changed only slightly. In other words, as stated by Timofeev-Resovski, relatively small evolutionary changes in the genetic apparatus are greatly amplified in the process of expression of hereditary information, and manifest themselves in significant modifications in phenotype.

Thus, phenotypic life on our planet is a very old, widespread, diverse, stable, and changeable phenomenon. The reason for the diversity of millions of organisms (phenomes) is the presence of a similarly large number of variations in their genomes. On the basis of common origins and the unified principle of the organization of hereditary mechanisms, it is possible to say that all genomes of a given species and all genomes of all species in general are integrated into the system of the *Global Genome* (GG). This system consolidates discrete genomes of all living organisms into a complete entity. Analogously, the totality of all the phenotypes of all the living beings inhabiting the Earth can be imagined as an integrated system of the *Global Phenome* (GP).

The essence of life is therefore a process of continuous existence, with the development of very stable dynamic complexes of diverse genomes. These genomes contain specific programs for the managed ordering of matter, and the creation of specific incarnations of existence in the form of concrete representatives of distinct types of living bodies. From this point of view, the phenomenon of life can be defined as *a process of the continuous existence of evolving DNA (and in some cases, RNA) with various forms of its phenotypic (bodily) manifestations*.

1.2 Phenotypic Diversity and Genotypic Unity

There are currently several million known species of living organisms that inhabit the Earth, and more and more new species are being discovered each year. These organisms are very diverse in terms of their organization, function, metabolism, motion, habitat, and so on. They range from extremely small bacteria and unicellular organisms, to a multitude of highly organized multicellular plants and fungi, to millions of species of animals. Organisms also differ in terms of the units from which they are formed: the cells of plants, fungi, animals, and bacteria have significant diversity in their structure, properties, and functions as well. Fundamental differences between organisms are linked with peculiarities in the organization of their genomes.

The ‘non cellular’ part of the organic world is represented by a large variety of *viruses*. Viruses can be found in all kinds of shapes: rod-shaped, spherical, oval, etc. Viruses are one of the most widespread forms of existence of organic matter in the world by number. For example, the water in the oceans contains a huge number of bacteriophages—about 250 million particles per milliliter of water, and there are hundreds of thousands of species of viruses, most of which have not been studied.

Viruses are extremely small (15–300 nm) non-cellular parasites that consist of a single molecule of either DNA or RNA, several enzyme molecules, and a capsid. Different virus species vary significantly in their structure and organization, the DNA or RNA content, the host and place of parasitism, and the mechanisms of reproduction and proliferation. Moreover, they do not exhibit any metabolic activities. Some viruses provoke diseases in animals, while others act in fungi, plants, and even bacteria (bacteriophage viruses). Although they can be found everywhere, even outside of the cell, viruses do not display the properties of living things. However, they are capable of mutating, and therefore are also capable of adaptation and evolution. Viruses are the derivatives of cells, the universal carriers of genetic information within the world genome, and they are the representatives of genotypic life.

The most ancient cellular beings that still inhabit our planet are the prokaryotic organisms of *archaea* or *archaebacteria*. They do not have a defined nucleus or membrane-bound organelles, which is why they are considered to be closely related to bacteria. Today, it has been proven that these creatures are equally distant from both pro- and eukaryotes, and they are a unique fragment of the relict micro-world that populated the Earth 2–3 billion years ago.

Although the membranes of archaea are formed by phospholipids, as they are in bacteria and eukaryotes, there are several distinct differences in their composition and properties. Many archaea are capable of photosynthesis, but they lack chlorophyll. Instead, bacteriorhodopsin serves as the photosynthetic pigment. Only archaea are capable of photoheterotrophy, i.e., the use of solar energy for catabolism of foreign organic matter. Unlike bacteria, the genome of archaea contains introns, and this is one piece of evidence that indicates that eukaryotes originated from archaea rather than bacteria. In addition, their ribosomes are similar in size to the ribosomes of both eubacteria and eukaryotes. It is also characteristic for archaea to lack electron-transport chains, and the proton gradient is generated with the help of the bacteriorhodopsin proton pump. A unique peculiarity of some archaea is the possession of a complex of enzymes that are able to carry out methane genesis, something neither eukaryotes nor bacteria are capable of.

The majority of archaea are extremophiles: they have preserved their adaptation to the same conditions that were present on the Earth billions of years ago. Many hot springs, for example, are known to contain archaic thermophiles which are resistant to temperatures from +45 to +113 °C; archaea psychrophiles are capable of propagating at relatively low temperatures (from −10 to +15 °C); archaea acidophiles live in acidic environments (pH 1–4), whereas alkaliphiles prefer basic (alkaline) conditions (pH 9–11). Barophile archaea can even survive pressures of up to 700 atmospheres, and galophilus lives in saline solutions with NaCl contents of up to 20–30 %.

The group of life-forms known as *bacteria* includes a great diversity of species of free-living, simply organized, single-celled organisms (bacteria and cyanobacteria) which also tend to lack a well-defined nucleus and membrane-bound organelles. Bacterial genetic material is generally found as single linear or circular molecules of DNA that freely traverse the cytoplasm, as well as in various plasmids. Cytoplasmic organelles include mesosomes, thylakoids, and other diverse vesicles. These organisms have diminutive sizes ranging from 0.3 to 30 μm, and can be found in various shapes such as spheres (cocci), eiloids (*Treponema pallidum*), rods (tubercular bacillus), and so on. Some bacteria are surrounded by a dense capsule and may contain cilia or flagella for locomotion. Bacteria have also mastered multiple forms of energy conversion and synthesis. They are capable of both oxygenic and anoxygenic photosynthesis (i.e., where no oxygen is produced during photosynthesis), synthesis of organic matter from non-organic sources, and use of energy from mineral oxidation (nitrogen, sulfur, iron, or manganese), and they can even act as heterotrophs, although without phagocytosis. Representatives of bacteria are widespread on our planet. As with viruses, they permeate the entire biosphere, from miles down underground to the uppermost layers of the atmosphere. Some bacterial species are pathogenic and can therefore cause infections and diseases.

Prokaryotes, along with protozoa, make up 50 % of the planet's biomass. The geophysical composition of the modern biosphere is primarily attributable to the bacteria and archaea which have been acting on it for over 3 billion years. Eukaryotes and multicellular organisms simply claimed the prokaryotic biosphere as a habitat during all subsequent steps of evolution. Even today, the rest of the living world could not exist without microorganisms, as they remain the foundation of the planet's life maintenance system.

Protista and *protoctista* comprise the largest and most diversified portion of the eukaryotic world. This group contains several hundred genealogical branches of the tree of life that have never quite become true metazoans, with some rare exceptions. Because various protists are not strongly related to one another, phylogenetic taxonomy does not consider them to be a single group, separating them instead into many sub-kingdoms. The unifying feature of protists is that, whether they are unicellular or multicellular, they have a very simple organizational state which differentiates them from other eukaryotes.

The sizes of protista usually range from several dozen micrometers to several millimetres, although some 'achievers' can be gigantic in size. For example, komokinea can be several centimetres long, slime molds can range from 1–5 m in length, and brown algae can grow to as much as 35–70 m. Despite their relatively low level of organizational complexity, protists tend to have a very rich set of intracellular organelles, thousands of different enzymes, and a rather complex metabolism. Many organelles have special locations and characteristics. These include ejectosomes, pyrenoids, spiracles, axostyles, parabasal bodies, etc. Some Protista (foraminifers, diatoms) are encased in an external skeleton, or, on the contrary, have an axial endoskeleton (radiolarians and dictyochales). The composition of such skeletons can also be highly variable, containing such things as silicates, calcium saline, magnesium saline, and even strontium saline. Protista are found in a very wide variety of environments including aqueous media, soil, as well as in the other organisms. However, because the majority of them require water in some form, only a few are capable of living directly on the land or in the air.

Fungi or *mycota* are a large group of eukaryotes that currently includes about 100,000 species, although it is assumed that there are at least 10–15 times more. These are relatively simply built unicellular and multicellular organisms which differ in various osmoheterotrophic ways of feeding: they absorb nutritious material through their surface (like plants), but they are not capable of synthesizing organic matter from non-organic sources (like animals).

Cells of true fungi possess the majority of traditional eukaryotic organelles (except for plastids), as well as a number of specific ones. Fungi have cell walls which are composed of chitin and β-1,3-glycan. They also utilize the polysaccharide glycogen as a reserve energy source, the metabolic product of which is urea. Fungi have an excellent enzymatic composition, allowing them to dissolve lignin, keratin, and cellulose. They can also absorb and dissolve glass, rubber, and plastic. The scope of the fungal genome is the smallest among eukaryotes. Fungi can be found living in all kinds of environments and can be seen deep in the sea, in the soil, in the atmosphere, and even in many animals, plants, and other fungi.

The body of most fungi is composed of mycelium that consists of thin branching filaments called hyphae. The mycelium of pileate fungi is located in the soil, and forms a biomass on the surface known as the carposome. Fungi multiply asexually with mycelia and sexually with spores, and can be segregated into higher and lower distinctions. The hyphae of lower fungi, for example, do not have a multicellular structure (coenocytic), but are instead giant and intensively branched single cells with numerous nuclei (e.g., mucor, which forms mold on spoiled products). The hyphae of higher fungi, on the other hand, have a multicellular structure (septate), which consists of very long cells with multiple nuclei and a set of organelles typical of eukaryotes. The genetic material of fungi is also more complex than that of protista.

Plantae comprise hundreds of thousands of species of colonial, unicellular, and multicellular organisms. They are capable of oxygenic photosynthesis, during which they absorb photons of light and transform their energy into the energy stored in the chemical bonds of ATP molecules. These molecules are further used for the synthesis of primary organic molecules along with CO_2 and H_2O from the environment. However, it is important to note that, at the present time, only organisms that contain chlorophyll *b* are considered unequivocally to be plants. These include green algae and vascular plants. The rest of the photosynthesizing eukaryotes are a part of the diverse world of the protists. True plant cells also characteristically have a double membrane (while photosynthesizing protista can have 1, 3, or 4 membranes) and a cellular wall composed of cellulose (in protista it can be lacking, or can incorporate β -1,3-glycan, β -1,4-glycan, proteins, and minerals). Furthermore, vascular plants do not have centrioles, although green algae do.

Plants have the largest biosynthetic potential in the organic world. They are found both in water and on land, and have the ability to regulate the water content in their bodies (poikilohydry). Plants also possess a rich system of symbiosis with other organisms such as bacteria (nodule diazotrophy), fungi (lichen and mycorhiza), and animals (pollination and dissemination).

Plants can also be further differentiated by their levels of complexity. Higher order plants possess complex organ/tissue structures, while inferior plants, represented by various algae and lichens, do not have tissues or organs, and usually exist as single cells, a cell colony, or a frond.

Animalia is the largest group of eukaryotes, and is represented by 1.5 million different species of multicellular organisms, as well as by a small group of their unicellular ancestors, the choanoflagellates. Animals are mostly phago-heterotrophic, which means that they are capable of absorbing organic matter from the environment through ingestion. Most also possess the ability to move autonomously, have a well-defined growth capacity, and produce urea, ammonia, or uric acid as the final product of protein metabolism.

Animal cells have a limited set of specialized organelles. They do not have rigid walls, which allows them to be elastic and movable, and they do not contain plastids or mineral inclusions. Most animals possess highly complex and specialized organ/tissue systems such as the nervous, endocrine, and immune systems, as well as others. They also have complex behavioural reactions, which are structurally conditioned due to the presence of neural networks.

Animals possess a tremendous variety of different types of cells that participate and specialize in distinct functions. Compared to the other life forms previously mentioned, animal cells possess an extremely complex and enormous genetic apparatus with many chromosomes. The various types of animalia are categorized on the basis of their structural and vital peculiarities (e.g., coelenterates, worms, mollusks, arthropoda, chordates), and every type of animal (e.g., mammals) has many different species within the greater classifications.

It should be noted that during the 3.5 billion year period of life on Earth, many millions of other species of living beings have inhabited our planet, as attested by their numerous fossil remains. All these organisms had the same ‘nucleic-protein’ foundations of organization as modern organisms, and every currently living organism appears to be a derivative of those from the past. Each one appears to be a link in a never-ending branching chain that stretches back over billions of years to the moment when life’s processes first became associated with organized material systems. This chain continues to develop into an unpredictable and

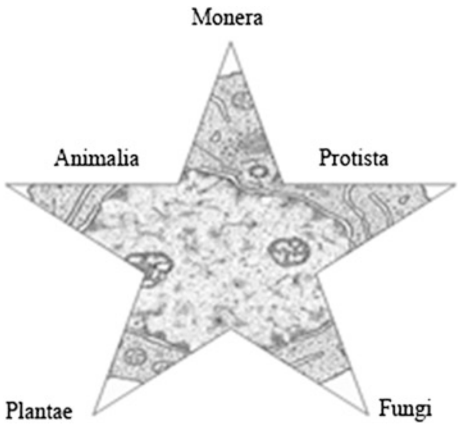

Fig. 1.2 The life star. A cellular concept of life's organization provides the foundation for the five kingdoms of living organisms

impossible to imagine future. Reproduction of the first cells and their derivatives formed the continuous chain of living organisms, capable of passing on their structures and processes of life to the next generation. Colonies of new cells were formed from certain types of particular cells. These new colonies possessed properties distinctive to animals or plants. After millions of years, such colonies originated the great number of living organisms with properties that arose from their adaptation to environmental conditions. As a result of these processes, various organisms emerged on our planet wherever conditions provided aqueous solutions of NA and proteins.

Despite their tremendous diversity, all living organisms have possessed (and still possess) common general characteristics of organization and function. In particular, all organisms are composed of cells (see Fig. 1.2). Every cell has a membrane, cytoplasm, genome, a common mechanism of genetic expression, similar rules governing inheritance and mutability, and analogous biochemical processes. All cells transform energy, synthesize comparable compounds, and maintain homeostasis. Cells of all organisms have similar molecular compositions and metabolic mechanisms. Therefore, life appears to be a totality of structures and processes that are identical in essence for all living bodies. Although the structures and mechanisms may vary significantly depending on the species of the organism, they do so within the confined parameters necessary for life. Basic unity within the diversity of organisms indicates the identity of life in all its manifestations, a common source of origin, and its consecutive complications according to the process of progressive evolution.

However, the major similarity between all living bodies is that every organism appears to be the unity of genotype and phenotype, or, better to say *genome* and *phenome*. In other words, a living body (phenome) is the final 'product' of the realization of the mechanisms of a genetic program. The great diversity of DNA and RNA molecules allows for infinite amounts of genetic information. Functioning separately or in various combinations, these molecules form the vast number of genomic options. By means of protein molecules, genomes organize the

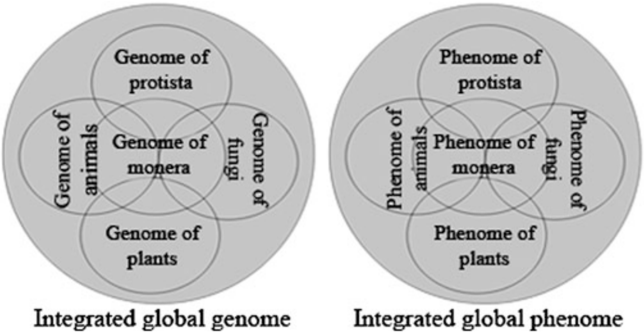

Fig. 1.3 Two integral constituents of the integrated life system. The totality of all the genomes of all living creatures on the planet constitutes an integrated system of the global genome. It can be displayed as a nucleic net (genet) that covers the whole planet. Everything is interrelated within this net, and modifications in any part of it may cause unpredictable fluctuations in many other parts. The totality of phenomes of all the living creatures constitutes an integrated system of the global phenome, represented by the integrated protein net (phenet)

surrounding material space, creating specific phenomes that establish the individual representatives of a species of living organisms.

Thus, it is convenient to notice again that the totality of all the genomes of the different species on Earth can be interpreted as the integrated system of the Global Genome (Fig. 1.3). The expression of its separate discrete parts (genomes of individuals) leads to the specific manifestation of living bodies—phenomes. Therefore, the totality of all organisms of living nature presents itself as the integrated system of the Global Phenome. Thus, 'all life on Earth' appears as the global phenome which, in turn, is the product of the expression of the global genome. This statement indicates the integrity and unity of the phenomenon of life, despite the diversity of the individual discrete forms of its genotypic existence and phenotypic manifestations.

1.3 Expediency, Universality, and Similarity

The expediency of structural and functional organizations of living organisms is rooted in the correspondence between metabolism, physiology, morphology, behaviour, environmental factors, and the interaction between and interdependence of the environment and all kinds of different species. Besides that, every single organism shows an amazing logic in the organization, structure, and functions of all organs, tissues, and body parts, and also an amazing correspondence of the inner and outer structures with the external natural environment. For example, the constitution of fish is expedient exactly for the aqueous medium in which they live. These organisms have gills, fins, and streamlined bodies. Likewise, flying birds have adapted wings, fast responses, acute eyesight, light bones, and so on. Such apt correspondences represent the complementarity between form and function, between planet and life.

The successful combination of molecules, cells, tissues, organs, organizational patterns, and biochemical and physiological processes that came into existence millions of years ago after sorting through natural selection is characteristic of the majority of modern living organisms with different levels of organization. Such universality is typical for various biological structures, functional complexes, and biochemical and physiological mechanisms. The similar organization of living bodies is determined by the natural selection of the most auspicious combinations of molecules and molecular complexes, the most thermodynamically efficient and economical biochemical processes, structural shapes, concepts of interaction with the environment, and so on.

The significant influence of the range of constant environmental factors (such as gravity, photoperiodism, electromagnetic radiation, media, temperature, etc.) has come to be an important element of selection of universal principles of organization in biological systems. Given the above factors, nature uses optimal algorithms of organization based on the similarity principle. The evidence for this notion is the existence of a large scale of semblance and universality at all levels of the evolutionary hierarchy of organisms. It is apparent in similar plans of construction, metabolic processes, functions, and similar mechanisms for maintaining homeostasis.

The phenomenon of similarity in evolutionary biology is reflected in the definitions of homology and analogy of structures. Structures that have a genealogically common basis but are capable of performing various functions are called homologous. In contrast, analogous structures have a different basis and their similarity is determined by solidarity of performed functions. In this context it should be noted that the genomes of all living beings are homologous to each other, since, despite the diversity of performed functions and individual distinctions, they all have a common basis. At the same time, the phenomenon of analogy is widespread in the world of phenomes, which is prone to environmental pressures.

In particular, homology is found in the fundamental processes of life where nature uses the same limited standard set of molecules to build all life forms. The successful composition of substances composed of organic monomers and the formation of multifunctional polymers (nucleic acids and proteins) is typical for all living organisms. The presence of unified membranes, the principle of compartmentalization of living bodies, and the principle of autonomy are inherent for single cells as well as for multicellular organisms. The emergence of the cell as a result of evolution represents the universal standard unit of organization of all living beings.

Enzymes are the major characters in all micro and large scale (macro) processes. The identity of many molecular mechanisms and functions has remained without significant changes at all levels of organization in living systems from single-celled algae to modern mammals. As an example of the universality of life's mechanisms, controlled cellular events such as ATP formation and the transfer of electrons in various organisms rely on principles of selective catalysis, which are operated by virtually identical membrane proteins and enzymes.

Genetic likeness is determined by the presence of genomes as keepers and operators of genetic information, and by the presence of unified mechanisms of realization of this information. Without exception, the genetic material of all organisms is presented by nucleic acids that have unified concepts of organization, properties, and functions. Nucleic acids differ from one organism to another only by the sequence of the standard nucleotides and their relative abundance. A gene arises when the information stored in genomic sequences leads to the production of some other nucleic acid (such as mRNA) or protein product. The stipulation of a phenotype arising from the genotype is a key principle for all living things.

Living nature uses a quite limited number of metabolic pathways. The majority of them are conventional for most organisms (e.g., glycolysis, tricarbonic acid cycle, protein synthesis, etc.). Similar functions and roles are maintained by hundreds of similar enzymes. Nature also uses a limited amount of standard regulatory molecules (e.g., the somatotropic hormone has an identical molecular structure and mechanism of action for all mammals). All organisms are self-regulating systems; they are built and function according to the information found in their makeup and surroundings, which they can perceive, process, and exchange with the environment and other systems. These and many other universal principles of the way living matter is organized were chosen by nature billions of years ago and are typical for most modern organisms.

The expedience of the semblance of properties of different living bodies is determined by the necessity for every one of them to achieve the same strategic life tasks: survival, reproduction, and distribution. Successful versions of organization were fixed in various genomes, and due to the unity between the global genome and DNA continuity, these versions spread to all kingdoms of living organisms. These facts testify to the common nature and close relation of all living things and to the common origins of life. Life, therefore, exists as an integrated global network with molecules of nucleic acids as the connecting links and threads.

It is amazing how all living beings are perfectly complete organisms. For example, whether looking at single cells, worms, amphibians, or mammals, all of them, regardless of their level of organization, are rather rationally structured and excellently adapted in spite of the difference in quality and quantity of genetic material. This difference only affects the complexity of bodily structures, but does not affect the ability to adapt, survive, and multiply. Absolutely all the functions and metabolic processes necessary for survival in certain environmental conditions are available at all levels. Basically, every genome is sufficient for the living body that it creates, and this body, in turn, is perfect to sustain the life of its owner.

1.4 Probability and Life

Cells are very complex, highly organized molecular systems that have strictly defined processes occurring within them. These processes take place in specific locations and directions. The probability of the emergence and existence of such systematic processes is extremely low, because the appearance of defined molecules in constrained qualitative and quantitative ratios in an accurate hierarchic order coupled with a proper location in a microscopic space that is separated from the environment is highly improbable.

However, improbable does not mean impossible or motiveless. Genetic and other informational programs considerably raise the probability of such material events. Because of this, low-probability events do not just happen once in a while, but steadily reproduce over and over again in living systems. In particular, specific structural and functional proteins and enzymes are synthesized according to specified genetic information. Structural proteins and other molecules become organized into certain probabilistic cellular macrostructures (e.g., organelles) according to the laws of chemistry and physics. It is these functional proteins and enzymes that direct biochemical processes from millions of possible directions to just those that are necessary for the cell to exist.

It is important to realize that the incredible complexity of multicellular bodies does not happen miraculously, but is formed during the developmental process. These 'incredible constructions' are built step by step from the fertilized ovum under the laws of development, based on the genetic programs and molecular mechanisms necessary for their realization. It is the mechanism of development that allows the realization of low-probability events that determine the existence and appearance of extremely complex living bodies.

Another reason and condition for the implementation of low-probability events in living organisms is the purposeful utilization of energy. The fact of the matter is that processes of destruction are more probable according to the laws of thermodynamics, because they do not require energy consumption. But any processes that serve to order matter for creation require certain forces and energy applications. Therefore, definite material structures and processes require an energy supply for the creation and maintenance of ordered biological systems. The utilization and employment of the energy is achieved by purposeful enzymes that target only the necessary biochemical reactions with energy. Therefore, an organized biological system can provide the conditions required for low-probability events to occur by exploiting effective and selective applications of energy.

The probability of specific chemical reactions in cells is significantly raised by the genetic selection of enzymes. These molecular machines do several important things: they catalyse strictly defined processes, elevating their probability several million fold, as well as increasing the speed of otherwise improbable processes many thousands of times. In this case the 'all or nothing' law is followed: where the enzyme is present, a well expressed random process is observed, while no enzyme means no process.

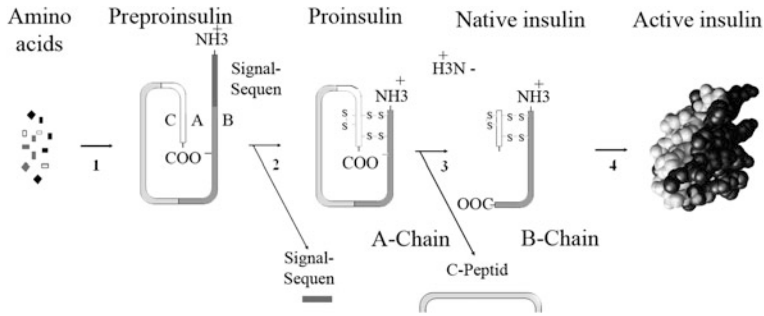

Fig. 1.4 Main steps in the formation of active insulin molecules. (*1*) Polypeptide chain formation from 51 amino acids, (*2*) Signal peptide is cut from synthesized polypeptide preproinsulin, and the molecule is folded by two disulphide bonds, (*3*) Another peptide is cut from proinsulin, (*4*) Subsequently, polypeptide chains are spatially folded. The result is the active form of insulin

Various DNA mutations and recombinations that constantly occur in cells are examples of random events. Mutations can be caused by various factors that unpredictably influence any of the trillions of nucleotide pairs. The results of such mutations are also barely predictable and may be neutral, lethal, positive, or negative. Since mutations are the source of new characteristics for natural selection, it is clear that the direction of evolutionary processes is totally random and unpredictable, and would most likely correspond with certain environmental conditions.

We have already mentioned that the probability of formation of concrete macromolecules within cells is extremely low. Let us have a look at the formation of one of the smallest proteins—insulin (Fig. 1.4). It consists of 51 amino acids, so the probability of their conjunction is only possible on the order of one in 20^{51}. And this is just one option of the 2.6×10^{66} possibilities! Moreover, in order to be activated, insulin must obtain a well-defined structure with a spatial form during the process of post-translational modification. In order to achieve the active form of insulin, the initial polypeptide has to be cut by enzymes into several distinct parts, two of which are afterwards joined in a specified location by disulfide bonds. Only then does insulin assume its specific, biologically active form. The probability of obtaining such a unique variation is extremely low—just one in a trillion. Therefore, the probability of existence of every one of the tens of thousands of proteins in living organisms is close to zero. However, these proteins, even those that consist of hundreds of amino acids, exist happily and plentifully. Moreover, they are constantly reproduced with great speed, and are successfully inherited by new generations over millions of years.

The individuals of various species are also matters of chance. For example, let us evaluate the probability of the birth of a human individual. To do so, we will take into account only the following conditions[1]:

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[1] *Numbers are rather approximate, but reflect the essence.*

The chance of meeting of the partners. The probability of a relationship between a specific man and woman in a two-million person megalopolis (if the sexual ratio is equal) is one in 10^{12} possible outcomes.

The chance of insemination of the egg by the spermatozoa. Women have in their ovaries tens of millions of allele-varying egg cells, every one of which can mature and be fertilized. Every man produces 10^{10} variations of allele-varying spermatozoa during the 50 years of his reproductive activity. Therefore, the probability of fertilization from two individual gametes is also a one in 10^{17} chance.

The chance of crossover events during meiotic formation of gametes. Human haploid chromosomes consist of approximately 3.2×10^9 nucleotide pairs. Therefore, the possibility of their recombination during contact with homologous chromosomes (taking into account only a single crossover) corresponds to a chance of one in 10^{19}.

The chance of chromosome combination and disjunction into separate gametes during meiosis. The number of possible combinations can be as high as 10^5.

Therefore, taking only these circumstances into account, the probability of the birth of Gennadiy Zhegunov is one in 10^{43}. This makes such an event highly improbable (the total number of human individuals that have inhabited the Earth so far is approximately 10^{10}). Meanwhile, in reality, each living person does in fact exist, despite the almost absolute improbability of this happening. These probabilities are similar for all other living organisms with sexual reproduction. Individuals, therefore, seem to appear by chance, unscheduled, without permission, and against their will.

Nevertheless, unlikely events in biology are quite substantial, having their own reasons, conditions, and circumstances. It is absolutely clear that random events can occur under certain conditions, but based without exception on the laws of nature. Furthermore, the probability of the implementation of the random processes of self-organization and evolution rises with time, so that randomness may indeed be realized over some prolonged period.

In summary, it can be stated that cells and organisms are biological systems that develop conditions for transformations of random events into ordered events—acting as *extraordinary enhancers of probability and chance*.

1.5 Temperature and Life

Thermal motion, as one of the forms of existence and transformation of matter and energy, is of particular importance for living bodies. And the temperature is a quantitative measure of this kind of motion, which determines the boundaries of life.

The temperature range of the universe is extremely wide. It varies from absolute zero (−273.15 °C) to many millions of degrees Celsius. On Earth, such limits are much narrower, ranging from −88 in the Antarctic to 5,000 °C in the

Earth's core. The boundaries of the temperature range of the oceans, seas and rivers, and groundwater are considerably narrower, and range from 0 to 100 °C. This is the temperature range where all the living bodies exist.

Single-celled creatures, primitive multicellulars, fungi, plants, and poikilotherms cannot maintain a constant body temperature. However, they are still capable of possessing viability and activity within the aforementioned temperature limits, since their enzymes operate stably in the specified range. Birds and mammals are able to maintain a constant body temperature automatically in a very narrow range from 32 to 40 °C. Under such conditions, biochemical and biophysical processes in living systems possess stable behavior regardless of environmental conditions, which gives these classes of animals significant advantages.

Temperature plays a significant role both for the existence of living bodies, and for the existence of the phenomena of life. Both occur in the same temperature range from 0 to 100 °C, which is the range of liquid water. The substrates of life, the NAs and proteins, may also exist for a long period in a frozen state at temperatures down to absolute zero. Under such conditions they do not manifest their biological properties and do not possess the phenomena of life, but retain the structure and ability to realize their life potential. In this form the "seeds of life" could travel in outer space on the fragments of planets for millions of years. But at temperatures above 100 °C, there is no phenomenon of life, because the existence of living bodies becomes impossible. Most of the macromolecules of cells become destroyed under such conditions. And what is most important, there is a phase transition of water into a gaseous state, which is not propitious for life.

Thus, it should be emphasized that most of life is realized within the narrow confines of temperatures which are close to the lower boundaries possible in nature (0–40 °C). At such low temperatures, many biochemical reactions are thermodynamically impossible or can only occur at very low rates which cannot provide for the manifestations of life. Only the presence of enzymes, which accelerate reactions a thousand fold, can enable the implementation of the necessary biochemical processes. Only with the help of biological catalysts is the world of biochemical reactions determined, leading to the manifestation of life. By means of high rates and specificity of action, enzymes distinguish only a limited set from an unlimited number of possible reactions between the countless molecules. Thus, the enzymes increase the probability of the processes, which are otherwise unlikely within the vital temperature range, thereby providing for the incredible phenomenon of life.

The upshot of this is that low temperatures constitute a very important condition for the emergence and manifestation of life. Only against the background of a "slowed-down" environment, where the transformation of matter and energy flow sluggishly, can specifically made and naturally embedded enzyme molecules clearly distinguish a limited number of interconnected chemical reactions. Chemical reactions then become biochemical and life is generated from the non-living.

Chapter 2
Material Basis of Life

2.1 Material Nature

Living beings, as a part of nature, are derivatives of the developing material world. All biological processes, including those that constitute the existence of living beings, occur within the limits imposed by natural laws.

Virtually all the elements of the periodic table have been found in various representatives of living organisms. The main elements of living organisms are: carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus. These elements are widely spread around our planet and it is exactly these elements that form organic compounds and basic macromolecules: proteins, nucleic acids, carbohydrates, and lipids. Moreover, 70–80 % of the mass of most living bodies consists of water and various mineral and organic salts. Thus, all living organisms consist of the same elements and organic and inorganic molecules as non-living bodies.

The properties of various separate molecules that compose cells and organisms do not differ from the properties of the same molecules in non-living systems. However, specially arranged and organized complexes of macromolecules (such as cell compartments) possess completely new 'biological' properties. As a result, biological objects differ significantly from non-living bodies, having unique properties that are only typical for living beings. For example, they are able to reproduce, take in nutrients, respire, and so on. These functions, as a matter of fact, are stipulated by the arranged interaction of molecules and cells that compose an organism.

It is known that organisms possess a set of physicochemical features. In particular, they have a discreteness and hierarchy of structure, and an interaction and interdependency of parts which establish the concept of integrity. An organism's structure has a molecular basis, and it converts and uses energy for accomplishing work, etc. Due to the physicochemical foundations of life, the study of biological objects can be accomplished with the application of powerful modern physical and chemical methods. This has led to the discovery of many molecular and cytogenetic mechanisms of the phenomenon of life.

G. Zhegunov, *The Dual Nature of Life*, The Frontiers Collection,
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Thousands of biochemical reactions occur in all organisms on the basis of chemical laws (e.g., the law of conservation of mass and energy). The majority of substances in an organism are dissolved in water, and the mechanisms and behaviours of dissolved substances are the same in a cell or in a test tube. The presence of enzymes is necessary for almost all biochemical processes. Enzymes act as chemical catalysts. Various factors, such as light, temperature, pressure, etc., affect biochemical reactions the same way they affect chemical reactions outside biological systems.

Hormones and neurotransmitters are chemical molecules of a certain nature and structure. They transmit definite signals and information by associating with receptor molecules on the surface of cells and changing physical states of a membrane and/or other molecular complexes. Through this process, the cells of multicellular organisms communicate using a physicochemical language.

The chemical interactions of various molecules are the foundation of life. Features and properties of living organisms, recorded in their DNA molecules, are stored and transmitted by chemical means. Biochemical transformation (that is, the transformation of certain molecules leading to the formation of others) appears to be the essence of the majority of biological processes, these being founded on the mechanisms of chemical bond breakage and formation. These mechanisms are linked with the interaction and exchange of elementary particles (protons and electrons) and atoms between the reacting molecules.

Motions and interactions of molecules in living systems involve physical processes such as diffusion and osmosis. These processes are the result of thermal motion. The basis for all types of movement in living bodies is the thermal motion of molecules that appeared along with matter during the Big Bang. Living organisms, like all other material bodies, exist in a certain time and space. They are complex systems that exist due to the global properties of all their constituents in motion.

Molecules and supramolecular cellular structures also possess various functionally significant physical properties (e.g., polarity and hydrophobicity). Cellular membranes have electric potentials, as exemplified by neural cells which function on electrical impulses. Blood movement occurs according to the laws of rheology. Joints, skeletal bones, and muscles act on the basis of mechanics. Energy transformation occurs according to the laws of thermodynamics. All of the processes and elements of an organism such as vision, hearing, nerve impulse conduction, permeability of different substances, and so on, are dictated by physical laws.

It is important to stress that all living bodies possess physicochemical characteristics and that all the processes in living organisms obey the laws of physics and chemistry. To put it another way, the laws of physics and chemistry are not violated in biological objects.

The major difference between the scientific and non-scientific (religion, mysticism, etc.) points of view is that scientists do not consider life to be a separate (or different) manifestation from the rest of the material world. They consider it to be a particularly organized part of nature that has the same material basis as the rest of the world. Therefore, a strong integration occurs between the biological and physical