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.

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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

worlds. Living matter is a part of nature that follows the same universal physical laws as non-living matter. These laws, in turn, determine certain limits for the properties and features of living beings.

2.2 Energetic Basis (A More Detailed Description of this Topic will be Given in Part 3)

Life is hard work. It is a constant battle fought by organized living systems against the destructive actions of unfavourable factors from external and internal environments, and against the natural expansion of entropy. It is also a task involving permanent massive synthesis of various organic substances needed to maintain structural and metabolic homeostasis. A colossal amount of work also takes place to support the various functions of an organism: motion, respiration, nourishment, reproduction, growth, etc. Therefore, the physical concept of 'work' is applicable to every process in living systems, whether it is at the molecular level or at the level of a whole organism. It is obvious that the implementation of any type of work requires energy, and for the implementation of such a multifarious amount work, a lot of energy is needed.

To this end, all organisms constantly transform, accumulate, and purposefully use free energy obtained from the environment. The inflow of energy gives cells and organisms the opportunity to function and also to support a high level of order and homeostasis for long periods. If the energy intake into the organism decreases or stops, its structure gradually deteriorates, functions become violated, and the organism eventually dies. Liquid, flexible, and vulnerable bodies that live in unfavourable surroundings manage to maintain their organization and properties for many years only by means of constant work against natural forces of destruction.

2.3 Nucleic Basis (A More Detailed Description of this Topic Will be Given in Part IV)

Nucleic acids (NA) are unique molecules that are essential for every organism (from viruses to man) for storage, application, and transmission of genetic information. Nucleic acids are the basis of the structural and functional organization of genomes. They contain genes which determine the synthesis of proteins. These proteins, in turn, determine the character and peculiarity of metabolism, natural laws of growth and development, various functions, etc. The mechanism of NA duplication and transmission of copies to filial organisms lies at the heart of reproduction in the sense that the flows of genetic information determine prearranged transformations of organic substances and the self-organization of material

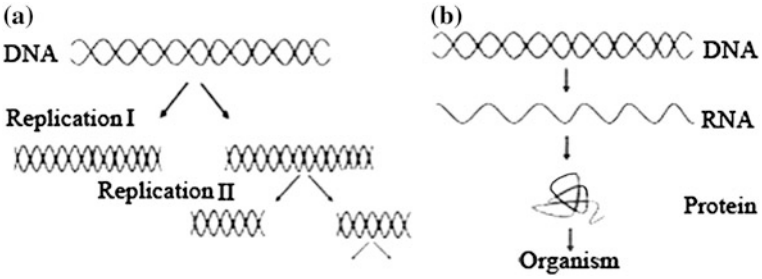


Fig. 2.1 Nucleic acids, the stem molecules of life. (**a**) Molecules of DNA possess an unlimited ability to reproduce themselves. They form the stem of replication or reproduction (horizontal stem). (**b**) Molecules of DNA are the fathers of RNA and proteins, conditioning the appearance of all the necessary molecules in cells. They form the stem of expression or stem of production of living bodies (vertical stem)

space in biosystems. The slightest abnormalities in NA structure may lead to unfavourable consequences or even the death of the organism.

There are two main groups of nucleic acids: DNA and RNA. Both are biopolymers consisting of monomeric nucleotides. DNA and RNA differ in their chemical structures and biological properties. Genetic information is encoded by DNA molecules, and the RNA molecules act as intermediaries that translate the information for the synthesis of corresponding proteins. It has been shown that certain molecules of RNA do not participate directly in protein synthesis. Possessing catalytic abilities, these molecules take part in the regulation of transcription, splicing, translation, and modulation of protein functions and special conformations. These molecules are therefore capable not only of carrying the genetic information, but also catalysing chemical reactions and regulating many cellular processes. RNA seems likely to have been the organizational foundation of life, long before the emergence of DNA and other enzymes. RNA is the only substance known to possess properties of both an informational matrix and a catalyst. The discovery of catalysing RNAs by T. Check and C. Altman is one of the most significant achievements of biology to date.

The foundation of life lies in the abilities of nucleic acids to store and act on information. The main molecule of life, DNA, is the keeper and supplier of genetic information. It is thanks to DNA that living organisms are able to reproduce, grow, and function. By analogy with stem cells, DNA molecules may be called *stem molecules* (see Fig. 2.1), since they are the forefathers of all the trillions of other organic molecules from which every organism is built and through which it functions. RNA is the intermediary in the biological information pathway leading to the production of proteins. Cells, organs, and bodies are built from proteins possessing a wide variety of properties and functions. In this case, the flow of genetic information is directed from the past to the present, from encoded genetic blueprints to realized protein materials.

During reproduction, genetic information is duplicated by means of DNA replication, and then, as a result of cell division, it is passed to filial organisms. In

this case, genetic information becomes hereditary. This information flow is directed from the present to the future, from parental DNA to filial DNA.

These two pathways for the flow of genetic information are crucial for the existence of living bodies. In their foundation lie structural and functional transformations of nucleic acids. Thus, nucleic acid molecules are the substrates of life, unifying material and informational bases for all living beings. The operation of nucleic acids appears to be the essence of life.

2.4 Protein Basis

Proteins are the foundation of a cell's structure and function. They constitute up to 20 % of the mass of living mammals. Almost all the remaining mass, approximately 70 %, is attributed to water. The final 10 % consists of other organic and inorganic substances including nucleic acids, lipids, and polysaccharides. Proteins define the structure and shape of a cell, determine the functions of organelles and even cells themselves, and act as tools for molecular recognition. Enzyme proteins, for example, participate directly in metabolic processes, energy exchange, and the maintenance of homeostasis.

There can be up to 50,000 different proteins in mammalian organisms. The specific presence of a given set of proteins in a given organism determines its specific features of structure and function. For instance, protein sets that determine morphological, metabolic, and functional features would differ in undifferentiated and differentiated cells, even from the same lineage. In other words, proteins are the primary phenotypic traits.

The totality of structural and functional proteins of a cell is defined as the proteome. It is a complete set of tens of thousands of different proteins that provide myriads of possible processes and functions. The qualitative and quantitative composition of the proteome is determined by the genome—the totality of genes of the given karyotype. The structure and properties of an organism are predetermined and dependent on protein quantity, composition, localization, peculiarities of their structures, and physical and chemical properties.

The major conceptual point here is that proteins are *a nexus between the genome and the phenome*, that is, between the virtual genetic program in the DNA molecules and the real material body created by this program: genome → protein → phenome. Proteins are the intermediaries in the realization of genetic information, the tool and the main element in the creation of living bodies—'a phenotypic framework of the DNA'. Proteins, in other words, are the structural and functional foundations of a phenome.

Life would be impossible without the properties of proteins. It is therefore considered that life on Earth has a protein nature. In this context, the definition of life as a mode of existence of proteinaceous matter, as stated over a 100 years ago, is quite warranted, although today we need to add the known role of nucleic acids and enzymes to this notion.

2.5 Aqueous Basis

Not a single organism is known which can or could have existed without water. Moreover, water is the main substance of most living bodies. As previously stated, water comprises up to 70 % of their total mass on average. The significance of this aqueous substance is determined by its unique physical and chemical properties.

Aqueous molecules associate with each other via hydrogen bonds. They form an integrated phase ('universal ether') in which biosystems exist and all of life's processes occur. Water is a very effective solvent, a property arising from the high polarity of its molecules. The majority of organic and inorganic molecules in cells occur in a dissolved ionized form. Even insoluble substances change to a colloidal or emulsified state, which allows them to interact with the aqueous medium. Such conditions significantly increase their flow dynamics and reaction capabilities, which are extremely important for ensuring proper metabolic and physiological processes. Water and its ionization products (such as H^+, OH^-, and H_3O^+) significantly influence the properties of many cellular components. In particular, they affect the structure of proteins, nucleic acids, enzyme functions, organization of membranes, etc. Aqueous media allow for high velocities to be achieved by molecules in Brownian motion, as required for molecular interactions. Water also participates in many biochemical processes as a substrate, and is generated as an end product in many biochemical reactions. For example, water participates in aqueous photolysis, without which the process of photosynthesis would be impossible, as would the emergence and existence of flora and fauna. Water also exhibits a capillary effect, i.e., fluidity in very thin channels. This is quite important, for example, in the exchange of matter between cells and blood capillaries. The heat capacity of water exceeds the heat capacity of any other biological substance, allowing it to act as a thermal balance regulator in organisms. Water also serves as an environment for millions of different species, and life substrates can only exist temporarily or in a diminished capacity without it.

It should be noted that there is no water in a free state (e.g., a glass of tap water) in living organisms. Most of the water present in cells is in a bound state. Due to the polarity of molecules (proteins, NA, carbohydrates, amino acids, anions, cations, etc.), they bind and orientate a substantial amount of water molecules in several layers at their surface. Therefore, the inner content of cells is represented by a colloidal solution (gel), which is mainly composed of proteins. Colloidal solutions differ significantly from true solutions. In particular, gels have an inner organization due to the ordered orientation of water molecules around proteins that form the intracellular skeleton. Because of this, cells gain dual properties of liquid and solid bodies: density and constancy of shape and structure, as well as high plasticity. It is due to these unique properties that closely connecting mammalian cells form large, almost rigid organisms, despite the 70 % aqueous content of each cell.

Bound water also has the ability to participate in chemical and physical processes, which allows for practically unimpeded migrations and interactions of

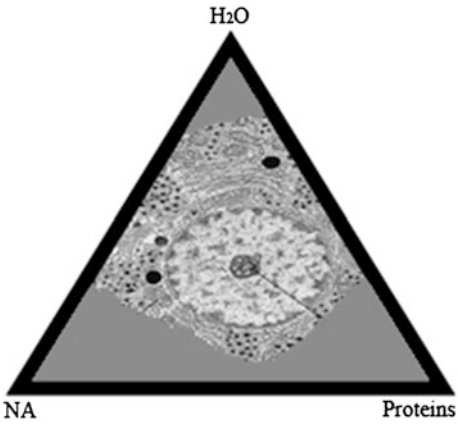


Fig. 2.2 The triangle of life. The basis of life lies in the existence of aqueous solutions of proteins and nucleic acids. From the aqueous point of view, living organisms are highly organized, long-living colloidal solutions

substrates and metabolites. Moreover, the intracellular organization of water has required the formation of special 'cytosolic channels' that participate in the purposeful displacement of certain hydrated molecules across the cell interior. The displacement of various molecules such as nucleotides, ions, amino acids, etc., is achieved through the use of these channels. There is also experimental evidence to suggest the presence of controlled local phase transitions (gel to liquid and vice versa) of certain cytoplasmic areas that are capable of directed substance transfer. Such properties of intracellular water establish internal mobility, which may be the basis of all processes and mechanisms in living bodies (see Fig. 2.2).

Therefore, the importance of intracellular water is highlighted by the unique duality of its existence as an ordered liquid crystal structure with the simultaneous retention of liquid properties.

Life has emerged, progressed, and exists in aquatic environments. Not a single manifestation of life is known to exist without water. Water thus plays a crucially important role in the establishment and perseverance of life. It is for this very reason that scientists search so carefully for H_2O on other planets and satellites of the Solar System, because it appears to be the main criterion for the emergence of nucleic-protein life.

2.6 Cellular Basis

Cells are very complicated biological systems that possess a high degree of order and the capacity to develop, maintain integrity, and reproduce. Cells are mobile, open, non-equilibrated systems that represent the integration of structure and function. The content of cells is so dynamic that they can be considered rather as continuous processes than physical bodies. The basis of cellular life is grounded in the incredible orderliness of macromolecules which create complex supramolecular structures (membranes, organelles) possessing certain functions. Protein molecules

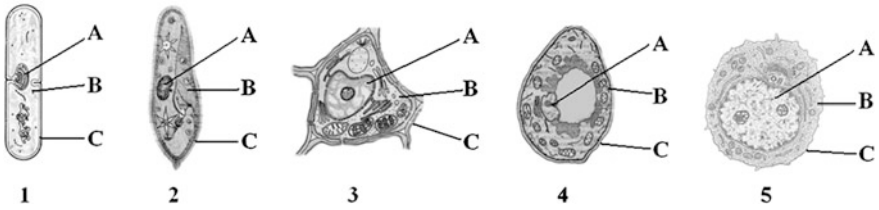


Fig. 2.3 The common principle of cellular organization. (*A*) Genome. (*B*) Colloidal matrix based on proteins. (*C*) Membrane. (*1*) Cell of a bacteria. (*2*) Cell of a protozoa. (*3*) Cell of a plant. (*4*) Cell of a fungus. (*5*) Cell of an animal

are the basic units, from which cellular structures are built, and enzymes are the fundamental participants in metabolism and all its associated functions. Likewise, qualitative and quantitative cellular compositions are controlled and regulated by nucleic acid molecules.

Cells are the basic structures of unicellular organisms, prokaryotes, fungi, plants, and animals. Despite the differences in structure, metabolism, and function of cells from the various kingdoms, all of them share many common principles of structure and organization (see Fig. 2.3). For bacteria, protozoa, certain algae, and fungi, the definitions of a cell, organism, and body coincide, since they are unicellular creatures. However, vast species of other fungi, plants, and animals are multicellular, because they consist of thousands, millions, or even trillions of cells. Many of these organisms have tissues and organs which arise from collections of cells with similar functions and structures. The coordinated performance of trillions of cells and tissues in animals, for example, has led to the development of various vital bodily structures such as the neural networks of the brain and the endocrine and immune systems.

Despite being a vital component of a tissue or an organ, every cell, first and foremost, lives its own life. The organization and metabolism of a cell is primarily directed towards the maintenance of its own homeostasis. This requires the expenditure of the majority of the cell's energy reserves, leading to low energy utilization for the needs of an organ or the organism. It is therefore legitimate to consider multicellular organisms as a complex community of tiny living bodies that are united for the purpose of mutually beneficial coexistence. This is a qualitatively new concept of the organization of biosystems and cellular existence, where cells must act as part of a large specialized colony. The cells must work in accordance with this, following the interests of an organism and maintaining its integrity and functional diversity while balancing their own needs in the process. The entire organism and all of its interrelated components are regulated and coordinated by the genetic programs of its unified genome. In other words, a multicellular organism is the product of the selectively expressed genome of different cells which exchange matter, energy, and information with the external environment.

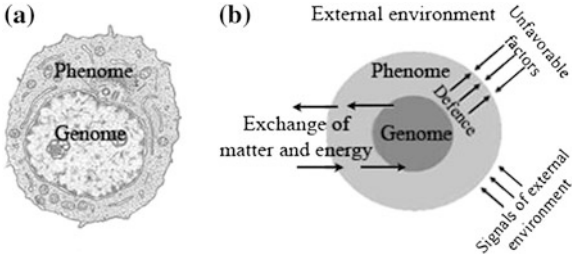


Fig. 2.4 Schematic view of cellular organization from the standpoint of the genome in a phenomic frame. (**a**) Picture of a cell. (**b**) Interactions of the genome and its phenotypic frame with the external environment. The phenome is an active intermediary between the genome and the environment. Various cellular components accept signals from the environment and maintain the homeostasis of the genome. The phenome of multicellular organisms is composed of organized cellular masses and non-cellular substances. The external membrane of a cell body and the totality of metabolic and physiological processes of an organism withstand environmental factors, maintaining homeostasis of the body which incubates numerous genomes

Thus, every cell is an autonomous body that represents a dynamic solidarity of interacting macromolecules, organelles, and compartments, which form a highly organized and self-maintaining system on the basis of genomic programming.

The separate nucleic acids and proteins cannot alone set the conditions for life without a special medium where material transformation can occur. That is, separate molecules of nucleic acids and proteins cannot be considered alive unless they form a system that is integrated into the complex colloidal matrix of the protoplasm. The colloidal system of protoplasm, which consists of structured and compartmentalized elements, may be considered as a matrix. This matrix can be characterized as being 'cybernetic', meaning that it is defined as a complex of interconnected structure-informational elements (see Fig. 3.3). This matrix (nucleoplasm and cytoplasm) serves as an effective environment where genomic processes can occur to ensure accurate and directed movements of energy and matter and their controlled interactions for life. The functions and activities of the molecular matrix are directed by the genome via protein synthesis. The genome acts as a sort of biological microprocessor. It is therefore clear that the minimal components of living systems include not only nucleic acids and proteins, but also a complex aqueous-colloidal protoplasmic matrix.

Genetic information is an organizing and directing force which leads to high levels of order and functionality within a given cell. Genomes create around them an ordered environment called the phenome (see Fig. 2.4), which allows for the maintenance of genomic homeostasis necessary for the purposes of self-preservation, reproduction, and growth. A cell's composition is a reservoir for the genome, and has a set of properties and functions for the cell's successful existence and reproduction. Although the cell is an autonomously acting structure, its activities depend totally on genomic directions. The creation, appearance, and processes of new cells occur only on the basis of the genetic information stored

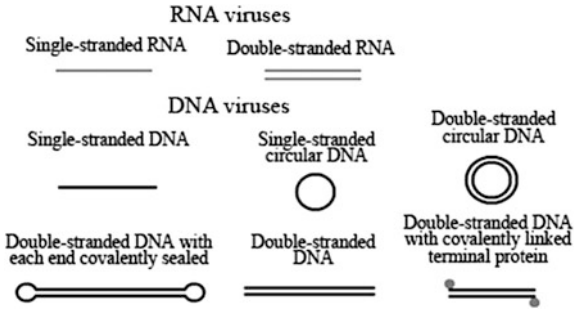


Fig. 2.5 Several types of viral NA. Viruses may contain single- or double-stranded NA molecules. DNA molecules of certain viruses may also be annular. Prokaryotic as well as eukaryotic organisms may be hosts of all these types of viruses. Some examples are: single-stranded RNA—bacteriophage R17, poliovirus; double-stranded RNA—reovirus; single-stranded DNA—parvovirus; single-stranded circular DNA—M13 and X174 bacteriophages; double-stranded circular DNA—SV40 and polyomaviroses; double-stranded DNA—T4 bacteriophage, herpes virus; double-stranded DNA with covalently linked terminal proteins—adenovirus; double-stranded DNA with covalently sealed ends—poxvirus

within their genomes. The genome, therefore, creates the phenome as an intermediary between genotypic life and the external environment.

We can conclude that the *genome* is a conceptually defined specific portion 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 for its use. Analogously, the *phenome* is a conceptually defined portion of a cell that surrounds and integrates the genome, forming a monolithic body. For unicellular organisms, these are whole cells with the exception of a genome. For multicellular organisms, these are whole bodies, which are highly organized colonies of standard genomes in a phenotypic framework.

2.7 Non-Cellular Forms of Life?

Our planet is inhabited by millions of different species of living organisms. An overwhelming majority of these organisms have a cellular structure, but the rule does have exceptions. Some scientists believe that non-cellular forms of life are represented by viruses. This is a vast group of 'microscopic beings' that possess biological properties, but do not have a cellular structure. Viruses are tiny bodies composed of some sequence of nucleic acids (DNA or RNA) (Fig. 2.5), which is usually surrounded by a coat formed from several different protein molecules (capsid). Some complex viruses are additionally covered with a membrane derived from lipids, proteins, and carbohydrates (supercapsid). The genomes of the simplest viruses consist of only three genes: a gene for a protein that causes the rupture of a host cell's membrane, a gene for an enzyme that provides for the replication of the

viral genome, and a gene for a capsule protein. The NA content of different viruses can differ greatly. RNA from *bacteriophage* Qβ that infects *Escherichia coli*, for example, contains only 3,500 nucleotides. Other larger viruses may contain up to 200–300 genes and up to several hundred thousand nucleotides.

Viruses are capable of existing outside of cells without manifesting any vital activity. In this condition they are passive and incapable of reproduction. However, when they penetrate a cell, they become very active, and acquire such properties as reproduction and development. During viral infection of a cell, the nucleic acid of a virus is transported through the cell membrane by various means, depending on the type of virus. For example, this can occur through the binding of the virus to membrane receptors on a host, followed by endocytosis (*Semliki forest virus*), or by means of injection (*bacteriophage lambda*). Nucleic acids of many viruses interact directly with the genome of a cell. Other viruses are replicated and translated in the cytoplasm (though indirect interaction with the genome of a host cannot be excluded). The genomic component of many viruses can integrate into the host cell's genome due to its intrinsic similarity to the host's NA constitution; it can be reproduced, transcribed, and translated using its endogenous cytogenetic machinery. New viruses are then assembled in the cytoplasm from the newly synthesized viral proteins and nucleic acids. Thus, viruses are 'alive' when they are inside a cell, but outside they do not display such properties, thereby demonstrating a form of intermittent life. In fact, it is more correct to describe a virus as a very active 'nucleic acid molecule' than as an actual living being inside the cell, since only the NA penetrates the cell, accompanied by a few proteins.

Viruses are, ultimately, intracellular molecular parasites that are capable of infecting nearly all representatives of living organisms. The internalized NA modifies the inner space of a host cell, making its genome and phenome serve the virus, or rather, serve the global process of genetic information realization as a part of the integrated life system.

While not all viruses cause diseases, some are highly pathogenic and cause very serious ailments such as influenza, smallpox, parotitis, poliomyelitis, and HIV infection. Some viruses can infect bacteria and kill them. These are called *bacteriophages*. In a mechanism akin to viruses, the chromosomes of various plant cells can be parasitized by *viroids*—very small bare molecules of annular RNA that consist of just a few hundred nucleotides. These tiny RNA molecules essentially represent a minimal manifestation of a living body which has both a phenotype (a certain quantity of nucleic acids and an annular structure) and a genotype (a certain set of genes).

The origins of such a specific parasitic form of life are probably connected with the early stages of prokaryotic evolution. Certain nucleic acids of nascent cells are likely to have originated plasmid-like 'beings' that adapted and proliferated using cellular resources for their own autonomous existence and reproduction. After certain evolutionary pressures, these beings gradually gained the ability to penetrate other cells and exist in the external environment. Thus, viruses are derivatives of cells rather than independent organisms. Let us examine several considerations to support this claim.

Viral genes have a cellular origin, because they encode proteins that are common for both cells and viruses, but they are able to reproduce and develop only inside cells. For example, bird flu viruses contain neuraminidase, an enzyme which demolishes the glycocalyx of epithelial cells in an animal's respiratory tract. This activity is understandable, because these are the cells in which the cycle of formation for this particular virus occurs. Many viruses are also known to have capsules that are derivatives of the cellular membrane of the host. During their lifetimes within cells, viruses may mutate, evolve, change their properties, and alter their pathogenic sites (e.g., swine flu). Viruses are very selective in choosing which cell types to infect. Their penetration only into certain cells of a particular lineage leads to a successful production of multitudes of new virus particles, which can directly or indirectly result in the illness attributed to the virus. Lastly, although there is a similarity between viral and eukaryotic genomic elements called introns and transposons, the virus requires cellular machinery to realize its functions. It is therefore obvious that despite significant phenotypic differences, both viruses and cells have some common molecular foundations and mechanisms, which testifies to their genetic affinity.

But viruses do not possess one of the main characteristics of living beings—autonomy. Viruses depend totally on cellular structures and processes for their activities. Their molecular compounds correspond in many respects to those of their potential hosts. It can be surmised that cells began to 'produce' viruses at a certain period of evolution. The absence of sexual processes in prokaryotes and ancient eukaryotes could have been 'deliberately' compensated by viral transformation. Subsequently, some population of the viruses went out of control and gained the ability to reproduce independently of the organism they were formed by. This was very likely at a time when only prokaryotes existed, which utilized derivatives of their own genomes as a way of exchanging genetic information. In other words, viruses and their analogues (viruses, viroids, phages, and plasmids) formed as the global mechanism of transfer and exchange of genetic information between the genomes of various cells and within an individual cell as well (transposons, IS elements). Mobile genetic elements unite all discrete genomes into the *integrated information space*, where any NA segment can be transferred to any part of the global genome. Thus, viruses and their analogs are the instruments of the infinite evolutionary process (see Fig. 2.6).

Viruses are very labile. They evolve constantly in concourse with the development of living organisms. At the present time, many mobile genetic elements are probably the competent representatives of discrete genomes of all the cells and organisms that inhabit the Earth. For example, according to different sources, between 8 and 20 % of ordered nucleic acids in the human genome are similar to those found in retroviruses. This leads to the assumption that many viruses primarily exist as *episomes* within cells, while outside they are found in a transitional form as peculiar cysts (see Fig. 2.7).

It is interesting to note that cells on their own are not too strongly opposed to the viruses living inside them, since they do not seem to make any type of protection against them and even have special corresponding receptors. The exact

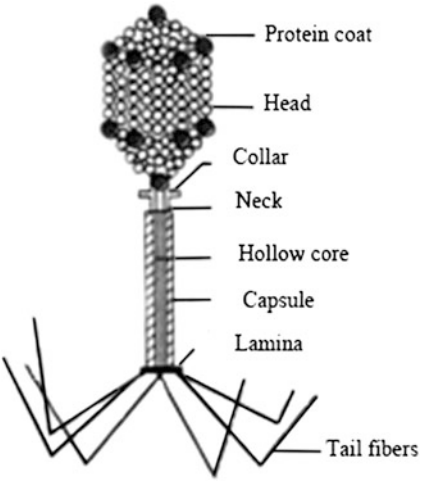


Fig. 2.6 The structure of a phage gives evidence that it is a special instrument for manipulating the molecules of membranes and DNA. The phage attaches to the surface of bacteria by its tail fibers. The hollow core then penetrates through the membrane and forms a channel through which the viral DNA is injected into the cellular cytosol

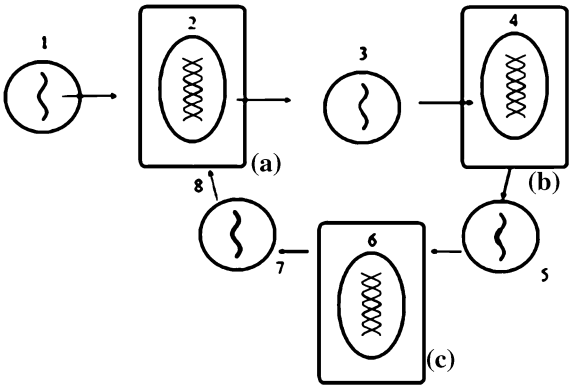


Fig. 2.7 Stages of viral existence—the stages of transformation and transitions of information. 2, 4, and 6: stationary stage (episome) in the genome of one of its hosts. 1, 3, 5, and 7: transitory stage in the external environment. (*1*) Virus in the external environment. (*2*) Virus as part of a human cell genome. (*3*) Mutating virus with 'stolen' segments of host DNA. (*4*) Virus inside the genome of a chicken cell. (*5*) Repeatedly mutated virus that contains segments of chicken DNA. (*6*) Virus inside the genome of a pig cell. (*7*) Repeatedly mutating virus that contains segments of chicken and pig DNA. (*8*) Further infection of human cells. This circulation of viruses among several genomes of different hosts allows it to deceive the protection systems of these organisms. (*A*) Human cell. (*B*) Chicken cell. (*C*) Pig cell

correspondence of molecular mechanisms of viral penetration into a cell suggests that these mechanisms are created by the cell itself. However, a multicellular organism is generally opposed to viral life inside itself, because there is a threat of destruction of certain body parts due to the abnormal functions of the contaminated cells. Long before emergence of multicellular organisms, single-celled creatures probably existed in symbiosis with viruses and their analogues, and this is likely to have been a mutually beneficial coexistence. The cells allowed viruses to reproduce, and in turn they got the opportunity to use the additional genetic material procured by viruses. The formation of colonies and, later, multicellular organisms, led to a contradiction with such symbiosis, because the penetration of some pathogenic viruses resulted in damage to the integrity of multicellular systems. In response to such a threat, multicellular organisms have developed special immune cells for protection. The battle between organisms and viruses has lasted for a billion years, and continues to this today. Despite this, however, many viruses and multicellular organisms have found compromises that imply that the development of a majority of viruses does not lead to the death of the host organism, while in turn the immune system of the host cannot cause significant damage to viruses.

We have shown that viruses are a legitimate part of living nature's global genome system. In our opinion, viruses are the *discrete units of genotypic life*—bodies that thrive at the molecular level. Their life is invisible to the naked eye, and may only be discovered in cases where pathogenic parasitism causes phenotypic changes in a host. We may also conclude that the definition of 'non-cellular forms of life' is quite relative, since the main stage of viral existence occurs in cells. This expression relates only to the definition of the existence of inactive viral bodies outside of cells, because every possible form of life has a cellular basis, including the manifestation of viral activity.

As inhabitants of the molecular world, viruses demonstrate the minimal biological body (one NA molecule), the minimal qualitative and quantitative composition of a living body (NA molecule + several proteins), and the minimal set of processes and mechanisms necessary for living (replication, transcription, reverse transcription, translation, catalysis, and self-organization).

Thus, viruses are probably the ancient derivatives of single-celled organisms that reigned on Earth during the first 1.5 billion years of life's existence. Then and now, their main purpose is the varied transfer of genetic information within the *integrated information space* of the Global Genome (see Fig. 4.8).

2.8 Informational Basis *(A more detailed discussion of this issue can be found in Part 4)*

It is known that living organisms are complex open systems that exist on the basis of energy and matter exchanges with their environment. However, an exceptional significance has lately been attached to the role of information on the basis of

which organisms are born, survive, improve, and interact with the environment. Here is a list of the main informational flows found in biological systems:

1. *Flow of External Information*. Organisms exist in an 'ocean' of information from the external material world. Absolutely everything around us carries information. It could be in the form of various physical, chemical, and biological phenomena, various types of movement and changes, diverse waves, fields, corpuscular streams, and so on. Living bodies perceive a certain part (a very limited part) of this external information. Organisms are only able to process the information they can sense through special analysers, receptors, and internal systems which can understand and apply the information. Such a specific system of perception and informational analysis in living beings is called the *thesaurus*. The term 'thesaurus' is used in the theory of information for the identification of a package of all the information that a given individual has in its possession. Organisms of different types and species exhibit differences in the way they organize their thesaurus, therefore possessing unique distinctions in perception as well as in the quality and quantity of the information processed. Organisms adapt and live in those informational conditions which correspond to their unique thesaurus in such a way as to ensure their survival.
2. *Flows of Intracellular Information*
    a) Genetic Information. Genetic information is stored in DNA and RNA. During realization, information provides for the synthesis of the necessary proteins. The proteins then participate in their respective cellular functions. The transformation and transmission of information is provided by the processes of replication, transcription, translation, and expression. This type of information is used for reproduction, development, and support of the structural and functional organization of living beings.
    b) Molecular Information. Intracellular structures, as the elements of a complex system, function in an interrelated and synchronous way due to their regulation by biologically active molecules. These molecules carry signals for activation and cessation of metabolic processes, mass transfer, enzyme activation and inhibition, etc. For example, there are several specialized protein factors that regulate protein synthesis, and the end products of biochemical pathways are usually allosteric regulators of key pathway enzymes.
    c) Information in Orderliness. It is obvious that the orderliness of the intracellular content itself constitutes a complex informational system. Inherited by means of cell division, this predetermined orderliness of the cytoplasm defines info-structural conditions for the behaviour of standard biochemical and biophysical processes.
3. *Flows of Intercellular Information*. The body of a mammal consists of hundreds of different types of cells. They form diverse and specialized groups that have specific spatial locations. These cells form tissues, organs, and their functional

elements. A vast amount of cells in a multicellular organism require informational exchanges for the coordination of various metabolic and physiological processes, division, growth, etc. Several distinct forms of intercellular communication are presented below:

a) Distant Chemical Signalling. This occurs through liquids of the internal environment by means of active molecules secreted by special cells. For example, in the case of endocrine regulation, hormones are carried by the blood and affect cells that are located in different parts of an organism.
b) Contact Chemical Signalling Between Proximal Cells. This occurs by means of special signalling molecules. In this case, cells secrete chemical mediators locally, and they are absorbed and used up so fast that they have time to affect only the producer cell or nearest-neighbour cells. Signalling can occur through direct cellular contact by means of gap junction channels formed between neighbouring cells. These channels are the only known direct method of intercellular communication, and are variably expressed in nearly all animal cells and tissues. Among many vital roles, gap junctions are extremely important for proper heart contractions, as they allow all the cardiomyocytes to maintain a close functional contact that provides synchrony and power. Likewise, during synaptic transmission, neurons secrete mediators into special intercellular regions called synapses. These chemical substances traverse a very short distance and affect only neighbouring pre-synaptic target cells.
c) Electrical Signalling. This function in the neural system, where signal passage within a single cell (neuron) is regulated by electrical mechanisms and the transfer of excitation from cell to cell may occur through chemical, electrical, or combined means.

In all cases, chemical substances are the carriers of information. They are all molecules with a definite structure. Even for neural tissues which generate and transmit electrical signals, it is typical that the final stage of communication with a target cell is mediated by chemical means as a result of electrical propagation. After completing their roles, the signalling molecules quickly become altered or degraded. Not all of the cells in a multicellular organism respond to chemical signals, but only those that have special receptors. These receptors associate with the signaling molecule and cause a directed response, leading to the signalling cascade. The various pathways of informational exchanges via intercellular communication provide a well-coordinated system for the billions of separate cells of an organism to act as a single entity.

4. *Flows of Information Between Organisms*

a) Between Individuals of the Same Species. Various concepts of communication also exist between individuals of the same species. They may be based on certain behavioural standards, forms, particular postures, facial expressions, signs, scents, emissions, sounds, chemical signals, etc. Through basic informational exchanges, animals of the same species coexist well in

their territory, survive, and reproduce. More complex methods of recording, storing, and transferring information appear at the level of human beings by the use of language.

b) Between Individuals of Different Species. Many communicational elements can be common to several different species. These may include sounds, movements, or other actions. Many prey animals, for example, possess an inherent ability to recognize their predators by their appearance, scent, or behaviour. Many animals understand the 'language' of marking a habitation territory with excrement or secretions from special glands. The flows of information between individuals of different species direct their co-existence and co-dependence, leading to the establishment of different ecosystems.

5. *Flows of Hereditary (Genealogical) Information*. Besides the intracellular flow of genetic information, life is associated with the use and storage of information within the changing generations of cells and organisms. In this case, genetic information becomes hereditary. Analogous to the way the flow of information is directed from the DNA of one cell to the DNA of daughter cells, it is also directed from one organism to another. This flow is connected with the process of reproduction, and ensures the long-term existence of populations of cells, organisms, and species.
6. *Intragenomic and Intergenomic Information Flows*. Intragenomic transformation and transfer of information occurs during reproduction, and is associated with the infinite number of possible integrations of a father's and mother's genome, the great number of variations of DNA recombination during meiosis, and many variations of chromosome disjunction.

The complex of discrete genomes of living organisms composes the integrated system of the global genome. Though separate genomes belong to representatives of diverse species and vary significantly in their qualitative and quantitative compositions, all of them have the same origin and common concepts of organization and function. Therefore, structural and functional ties still exist, even between distant genomes. Integrating factors for all the discrete genomes include viruses, phages, plasmids, transposons, etc.

We can conclude that there is evidence of continuous informational exchanges at all levels in the organization of biosystems. The first four flows of information we mentioned provide for the life of material bodies (phenotypic life), and the fifth and the sixth flows provide for the continuity of life (genotypic life, or, in other words, life as a natural phenomenon). Living organisms are therefore structured on the basis of information, exist in tight informational surroundings, and live and survive through the ability to generate, perceive, analyse, and use the information around them.



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