# Living and Nonliving Bodies of the Biosphere

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## I. Basic Concepts

*Living matter, the biosphere as an envelope of the planet. Its new geological state—the noösphere. Natural bodies and the natural phenomena of the biosphere—inert, living, and bio-inert. Their system—the scientific apparatus. Left-handedness and right-handedness in living matter as a manifestation of the state of the space it occupies. The free energy of the biosphere as a manifestation of the biogeochemical energy of the living matter in the biosphere.*

**1** In my biogeochemical work, which I have pursued systematically and without interruption since the beginning of 1916, I have recently framed conclusions, which point to the deep, unbridgeable distinction—energetic-material in character—between the phenomena of life, and all other processes, occurring in the biosphere; a distinction which, on the one hand, can be expressed with quantitative precision, but which, on the other, calls for new mathematical work in the domain of geometry. Revealed before us, is a new area of the study of life phenomena, which uncovers new facets of the phenomena of life and new possibilities for scientific work. I therefore consider it useful to call attention to these conceptions, rather than waiting for the completion of my reworking of biogeochemistry.

**2** The foundations of biogeochemistry are formed from a few basic conceptions, which *do not contain any hypotheses,* but are precise and clear scientific concepts—scientific empirical generalizations of the naturalist's experience and observation. Above all, the very concept *of the living matter of the biosphere* represents such an empirical scientific generalization—one that is as indisputable as a correctly, scientifically established fact. *The living matter of the biosphere is the aggregate of all its living organisms.*

In the following I shall use, instead of the concept *"life,"* the concept *"living matter"* in the indicated sense.

From the standpoint of the biosphere, the individual living organism is usually lost from view; in first place comes the aggregate of organisms—living matter. In biogeochemistry, however—in some strictly defined cases—at times it is necessary to pay attention to the discrete organism, to its individuality. It is indispensable to do this in those cases, where the activity of Man appears as a geological factor, as we see happening now, and the individual personality sometimes becomes vividly apparent and is reflected in large-scale phenomena of a planetary character. The human personality changes, accelerates, and causes geological processes of enormous significance, through its presence in the biosphere.

We are living in a brand new, bright geological epoch. Man, through his labor—and his conscious relationship to life—is transforming the envelope of the Earth—the geological region of life, the *biosphere.* Man is shifting it into a new geological state: Through his labor and his consciousness, the biosphere is in a process of transition to the *noösphere.*[1] Man is creating new biogeochemical processes, which never existed before. The biogeochemical history of the chemical elements—a planetary phenomenon—is drastically changing. Enormous masses of new, free metals and their alloys are being created on Earth, for example, ones which never existed here before, such as aluminum, magnesium, and calcium. Plant and animal life are being changed and disturbed in the most drastic manner. New species and races are being created. The face of the Earth is changing profoundly. The stage of the noösphere is being created. Within the Earth's biosphere, an intense blossoming is in process, the further history of which will be grandiose, it seems to us.

In this geological process—which is fundamentally biogeochemical—a single individual unit of living matter, out of the totality of humanity—a great personality, whether a scientist, an inventor, or a statesman—can be of fundamental, decisive, directing importance, and can manifest himself as a *geological force.* This sort of manifestation of individuality in processes of enormous biogeochemical importance, is a new planetary phenomenon. It emerged, and began to manifest itself ever more sharply and profoundly in the course of time, *during the most recent tens of thousands of years,* on the background of billions of years of the prior history of the biosphere, when this phenomenon did not exist.

In biogeochemical processes—outside the boundaries of these phenomena—the totality of living beings—living matter, continues to play the basic role. It is characterized as the totality of all organisms, mathematically expressed as the

1. Vernadskii, V. *Problemy biogeokhimii. I. Znachenie biogeokhimii dlia poznaniia biosfery. [Problems of Biogeochemistry. I. The importance of biogeochemistry for cognition of the biosphere.]* 2nd ed. (1st ed.—1934). Leningrad, 1935.

totality of *average* living organisms. Biogeochemistry studies, above all, the manifestation of the totality, not of the average indivisible unit. In the majority of the other biological sciences, we chiefly study the average indivisible unit; and, in the sciences of medicine and animal husbandry, the indivisible unit, individuality, or the single personality has been of outstanding significance during the past millennia.

Morphologically, living matter is manifested in biogeochemistry as a species, genus, race, etc. We distinguish *homogeneous living matter—belonging to a genus, species, etc.—and heterogeneous living matter,* such as the forest, the steppe, or a biotic community in general, consisting of homogeneous forms of living matter, in certain proportions.[2] The convenience of this approach to the phenomena of life lies in the fact that we do not stray, in our judgments and conceptions, into the shaky domain of hypotheses and philosophical constructs about life, such as dominate the thinking in biology. We do not depart from the domain of scientific facts and scientific empirical generalizations; we stand on their firm ground.

**3** Alongside the concept of living matter, we put forward two other empirical generalizations: the concept of the *medium* of life, as the *biosphere,* and the concept of a *living natural body.* Living matter is found on our planet only in the *biosphere,* which is the domain of life.

This characterization defines the boundaries of the biosphere with absolute precision. According to this definition, the entire *troposphere* of the atmosphere belongs to the biosphere. And now, living organisms—human beings and their inevitable companions: insects, plants, and microorganisms—are penetrating even higher, by themselves or with mechanical assistance, into the *stratosphere.* At the same time, civilized humanity (together with its inevitable living companions) is penetrating several kilometers below the surface of the Earth, deep below the limits of that surface terrain, which is in contact with the troposphere. Today, too, we recognize the planetary significance of the discovery, at the end of last century, that life—chiefly anaerobic, microbial living matter—is to be found in subterranean regions more than three kilometers deep, and probably deeper. The lower boundary of the biosphere thus lies several kilometers below the surface of the geoid.[3] The entire world ocean belongs to the biosphere.

The biosphere constitutes a definite *geological envelope,* sharply differentiated from all other geological envelopes of our planet.[4] This is so, not only because the biosphere is populated by living matter having enormous significance as a geological force, completely reworking the biosphere and transforming its physical, chemical, and mechanical properties. In addition, this is the sole envelope of the planet, penetrated in an appreciable way by cosmic energy, which transforms it even more than living matter does. The main source of this energy is the Sun. The Sun's energy—thermal, light, and chemical [i.e., ultraviolet—trans.] energy—is, together with the energy of the chemical elements, the primary source for the creation of living matter.

Living matter permeates the entire biosphere and to a large extent creates it. Living matter accumulates the energy of the biosphere, mainly the thermal and chemical energy of solar radiation and the chemical energy of the Earth's atoms. It is possible, that radioactive energy plays a certain role in this.[5]

**4** Materially and energetically, the matter constituting the biosphere is acutely heterogeneous. From this standpoint, we must distinguish the main bulk of its matter, which does not belong to living matter, and which I shall call *inert*—nonliving matter. The greater part of this, in terms of weight, consists of solid rocks. But the greatest volume belongs to liquid and gaseous bodies—the ocean and the atmosphere. Here is found—here lives—the totality of the planet's living organisms—its living matter.

Between the living and inert matter of the biosphere, there is a single, continuous material and energetic connection, which is continuously maintained during the processes of respiration, feeding, and reproduction of living matter, and is necessary for its survival: *the biogenic migration of atoms* of the chemical elements, from the inert bodies of the biosphere into the living natural bodies and back again. This appears in the form of *motion*—the departure and arrival of specific chemical compounds and elements to and from living organisms in connection with the processes of feeding, respiration, excretion, and reproduction, characteristic of living matter. These processes define the *biogeochemical energy* of living matter, the chief manifestation of which is the multiplication of living matter.

All of these manifestations of biogenic migration and biogeochemical energy are determined by the dimensions, the chemical composition, and the energy of the biosphere. For this reason, not any arbitrary sorts of organism can exist in the biosphere, but only those organisms strictly determined by the structure of the biosphere. *The living organism and*

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2. Le Roy, E. *L'exigence idéaliste et le fait d'evolution,* Paris, 1927, p. 196.

3. Vernadskii, V. *Biosfera.* Leningrad, 1926. Vernadskii, V., Tr. *Biogeogeokhim. labor. [Works of the Biogeochemical Laboratory].* 1. Leningrad, 1930. Vernadsky, W. *La biosphère.* Paris, 1930. Vernadskii, V. *Biogeokhimicheskie ocherki.* Moscow, 1939 (in the process of publication [Vernadsky's note]).

4. Vernadskii, V. *O predelakh biosfery. Izvestiia AN SSSR. Seriia geol. [Concerning the boundaries of the biosphere. News of the Academy of Sciences of the U.S.S.R. Geology Series],* 1937.

5. Vernadskii, V. *Biosfera.* Leningrad, 1926; *Ocherki geokhimii [Sketches on Geochemistry].* 2nd ed. Leningrad, 1934 (first published in French in 1924, as *La géochimie*); *Problemy biogeokhimii. I. [Problems of Biogeochemistry. I.]* 2nd ed., Leningrad, 1934.

*living matter are a lawful function of the biosphere.* People usually forget this. And, in an erroneous manner—especially in philosophical discourse, but also in biology—they counterpose the living organism to its environment, as if these were two independent objects. This sort of counterposition is a logical error. It is especially apparent in philosophy, and *undermines at the core a great number of its conclusions.* I shall not pause here to consider this point more fully.

**5** No less important, is the concept of a *natural body.* Strangely enough, this basic concept, which in essence pervades all natural science, is usually ignored and not subjected to serious logical analysis. And yet, scientists use the concept, almost unconsciously, at every step of their work.

In my youth, I had a clear and conscious experience of its importance. My teacher V.V. Dokuchayev, in his creative work on soil science, put forward the proposition, that soil is a *special natural body,* distinct from other rocks. As is well known, he proved this thesis, and thus made it possible for his contemporaries to grasp, through a striking example of a successful synthesis, the bases of creative work in natural science.[6]

But such events are rare in the history of science and in current scientific life. Normally, debates do not address the fundamental assumptions of scientific knowledge. People do not talk about these assumptions; they forget about them.

Reflecting on this, it is easy to convince oneself, *that all natural science is based upon the concept of a natural body, or a natural phenomenon.* In our further discussion, we shall deal only with the biosphere, and shall consider phenomena involving living matter.

Scientists study in the biosphere only those objects, which are created in the biosphere by forces occurring within the biosphere, or phenomena, produced in the biosphere by those forces. The objects they deal with, may conveniently be termed the *natural bodies* of the biosphere, and the phenomena—*its natural phenomena.* The task of science is to enumerate, describe, and identify all the natural bodies and all the natural phenomena, which exist or have existed in the biosphere. This is the work of generations of scientists, and there are billions of billions of scientific facts and scientific generalizations—i.e. natural bodies and natural phenomena—to be grasped in a scientific manner, counted, and brought into a system. These form the basis of science; from them, empirical generalizations are constructed, which can be brought back once again to the natural bodies and natural phenomena.

This work results in the creation of the basic content of science, for which, strangely, there is not yet any generally accepted expression. I have had to name it, and, perhaps, it is convenient to call it *the scientific apparatus.*[7] This apparatus began to be created in astronomy already thousands of years B.C., and was understood—it came down to us—in the form of numerical data on the positions of the Sun, the stars, and the planets in the Hellenistic compendia (Hipparchus, Ptolemy). This work was revived in the Middle Ages in Central Asia. Everywhere, it was done in the chronicles in the form of precise records of comets, fireballs, meteorites, etc. Starting in the 16th century, there was a rapid accumulation of data, the evaluation of which was the basis for making the first major generalizations. But even in astronomy, the basic forward motion, which has been continuous and developing rapidly from that time on, began on a large scale only in the 18th century. In that century—the century of *descriptive natural science*—the effort to precisely enumerate, observe, and describe every natural body and to record every natural phenomenon, became a conscious task of exact natural science.

Linnaeus (1707-1778), basing himself on the work of earlier naturalists, introduced the concept of the *system of Nature* and for the first time calculated the number of species of animals and plants—the species of homogeneous forms of living matter, inhabiting the biosphere. In 1758, he knew a total of 4,162 species of animals (by 1768, the number was 5,936), and in 1768—7,788 species of plants. In all, Linnaeus had distinguished 13,724 species of living organisms by 1768, and even fewer rocks and minerals. Today, the number of species of plants is approaching 200,000, and may possibly exceed 300,000. The number of species of animals is approaching 800,000; in reality, it is probably several million and may reach 10 million. In essence, the *"system of Nature,"* understood in a broad sense, corresponds to what I call the scientific apparatus.

The colossal quantity of numerical data, corresponding to chemical and physical properties of matter—growing like a snowball, always increasing over the course of time, obtained mainly by *scientific experiment,* rather than from observation of the biosphere, and first created in the biosphere by scientific work, exceeding by many times the quantity of living natural bodies and living matter, and having no limits—in my opinion, makes it logically unclear, inconvenient, and practically useless to term these data a system of Nature. Therefore, the concept of *the scientific apparatus,* which we can appreciate, only because it has been reduced to a scientific system, is simpler. It includes both the system of Nature and the scientific apparatus of the humanities, which is encompassable by a scientific system, albeit thoroughly permeated by individuality.

**6** Every object of natural science is a natural body or natural phenomenon, created by processes of Nature. At the

6. Vernadskii, V. *Ocherki geokhimii [Sketches on Geochemistry].* Leningrad, 1934; *Biogeokhimicheskie ocherki [Biogeochemical Sketches].* Moscow, 1939 (in the process of publication).

7. Vernadskii, V. *Ocherki i Rechi [Sketches and Speeches].* Prague, 1922, p. 77. *Problemy biogeokhimii. I. [Problems of Biogeochemistry. I.]* Leningrad, 1934.

present time many quadrillions, if not more, of natural bodies and phenomena have been scientifically collected, enumerated, and scientifically defined in the system of the scientific apparatus. The number of bodies and phenomena continuously increases, and the system of the scientific apparatus is also continuously being perfected. Thanks to this, we are confronted, ever more acutely, with an infinite quantity of scientific facts to examine. The basic content of science is located in them. Reworked by means of scientific generalization, provisional scientific hypotheses and theories, and embraced by mathematical deduction and analysis, these become *scientific truth,* the precision and profundity of which increases *with each generation.*

This is what distinguishes exact science from philosophy, religion, and art, where *there is no scientific apparatus* and where the scientific truth, sometimes discovered by intuitive creativity, can be recognized as such only when it has been scientifically validated. This creative intuition sometimes comes far in advance of its scientific comprehension, and it is in these domains of human creativity that the scientific truths of the future are hidden, which are unclear to contemporaries. But, we cannot make precise sense of them without science, without grounding them in the scientific apparatus.

**7** It is possible to distinguish three types of natural bodies in the biosphere: *living* bodies (for example, a plant, a beetle, etc.), *inert bodies* (for example, rock, quartz, etc.), and *bio-inert* bodies (such as soil, lake water, etc.).

The biosphere consists of sharply bounded domains, formed by living, inert, and bio-inert bodies—waters, living matter, rocks, air, and so forth. A transition from living bodies to inert bodies takes place when they die; when a living body ceases to exist as such, it is transformed into organogenic rock (for example, bioliths) and inert bodies such as gases.[8] Bioliths are often bio-inert bodies. The direct generation of a living organism from inert bodies is never observed: the principle of F. Redi (all life comes from life) [*omne vivum ex vivo*], is never violated.[9]

*The concept of inert (dead) and living natural bodies* as sharply distinct natural objects, is a commonplace, ancient notion, inculcated over millennia of history—a concept of "common sense." It cannot provoke any doubts, being clear and intelligible to all.

In scientific work, even over centuries, only a few cases can be found, in which there were doubts about whether a specific natural object should be reckoned a living being or an inert body—whether that given natural phenomenon were a manifestation of the living or the nonliving. One such doubtful case—perhaps the most profound one—is the question of viruses.[10]

Other cases may be the questions J.C. Bose has raised in Calcutta, about whether *life* is not manifest in both living and inert matter, but to different degrees. These are, however, philosophical problems, which Bose tried to solve using the scientific method, as G.T. Fechner had posed the matter less precisely, in philosophical terms, earlier in the 19th century in Europe. In this case, the question of biogeochemistry's living matter is not involved, since in biogeochemistry, living matter is the totality of living organisms, whereas Fechner and Bose were trying to delve into the material-energetic substance, which is common to the living and the inert body.

**8** The concept of *a bio-inert natural body* is a new concept—defined in exact biogeochemical terms and in distinction from the concepts of inert and living natural bodies. Natural bodies of this sort are clearly expressed in the biosphere and play a big role in how it is organized.[11] *Bio-inert bodies are characteristic of the biosphere.* These are lawful structures, consisting of inert and living bodies simultaneously (for example, soils), all of *the physico-chemical properties* of which have to be adjusted—with sometimes very large corrections—if, in studying them, the activity of the living matter located within them is not taken into account.

The biogenic migration of chemical elements (atoms) plays a big role in their properties—very often the dominant role.

Any soil is a typical bio-inert body. V.V. Dokuchayev had already recognized this clearly.

The overwhelming majority of *terrestrial waters* are bio-inert bodies. There are only isolated instances, in which living matter does not play a fundamental role in them. This is not the case, for example, in hot volcanic waters, which are rich in sulphuric and hydrochloric acid, nor is it the case in strongly saline waters. Nonetheless, even in the Dead Sea there is microbial living matter, although it does not play a decisive role. Rain water is free of living matter in its first moments. All the waters of the oceans and seas, of rivers and lakes, and all of their *bottoms,* are bio-inert bodies. The gas balance, the chemical composition, and the silts of all these waters—their chemistry—is basically determined by living matter.

The role of bio-inert natural bodies is extraordinary, and

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8. I have to introduce a new word for this old concept, although the enormous significance of the concept it embraces is clear to everyone, as is the exclusive importance of work on the scientific apparatus, in terms of both the time and the labor, spent on it by scientific researchers. This is a consequence of vestiges of the past, of a time when work in philosophy—rightly so, at that time—was considered more fundamental than scientific work.

9. Samoilov, Ia. *Biolity [Bioliths].* Moscow, 1929.

10. On Redi's principle, see Vernadskii, V. *Ocherki geokhimii [Sketches on Geochemistry],* 4th ed., Leningrad, 1934, p. 209.

11. For viruses, it is still unclear whether we are dealing with a new form of organism ("living protein"), or with a protein, which contains the spores of miniscule organisms. It is thought that *the proteins cannot be cleansed of these spores by crystallization.*

12. Vernadskii, V. *Problemy biogeokhimii [Problems of Biogeochemistry].* Leningrad, 1935. Vol. 1., 8 f.

has not yet been properly taken into account in how the biosphere is organized.

The process of *the weathering of rocks* is a bio-inert process—a fact that is usually not considered. This circumstance, I think, explains the backwardness of this area of chemical geology (the weathering of the Earth's crust) relative to the contemporary level of knowledge. The biogeochemical approach should contribute much to the solution of this problem.

**9** So far, I have not gone beyond the concepts: living matter, the biosphere, natural bodies, and natural phenomena (inert, living, and bio-inert)—concepts based on the enormous empirical, precise material of experience and observation. These concepts cannot arouse any theoretical doubts whatsoever, nor do they require any new scientific hypotheses or theoretical scientific constructions to be understood. One can calmly proceed with the work, so fruitful for science, of systematizing the accumulated scientific facts and generalizing from them.

But, for an understanding of the matters that now follow, I must necessarily touch upon two new phenomena of great importance, the scientific investigation of which cannot be carried out on the basis of the mere generalization of scientific facts, but requires introducing new concepts and finding a new form of comprehension of the facts. Both of these phenomena are extremely poorly understood from a theoretical standpoint, and their scientific significance has not been appreciated. They are now on the frontier of contemporary scientific knowledge. These are, first, the concept of *right- and left-handedness* and, second, the concept of *biogeochemical energy.*

*Right- and left-handedness* is an everyday concept, existing since the earliest times, which has hardly been comprehended in a scientific and philosophical way. It was Louis Pasteur, who first drew attention to its paramount importance for understanding the phenomena of life—the living organism, or living matter. Independently of Pasteur, and somewhat earlier, Bechamps had realized this, but Pasteur grasped the question more deeply, and identified within it phenomena, which permit us to penetrate in a precise scientific way into this immense domain of problems, the full significance of which Pasteur himself could not foresee.

The concept of *biogeochemical energy* was introduced by me in 1925, in my report to the Rosenthal Foundation in Paris, which was never published in full. In my book, I deal with this question to the extent possible today. Let us first examine the question of right- and left-handedness in its relation to living matter and to the biosphere.

**10** We do not need, here, to deal with the profound naturalist and experimenter A. Bechamps—an older contemporary of Pasteur, his enemy and rival, who outlived Pasteur by many years, but was unable to obtain the conditions needed for systematic work. He started out from exactly the same fact, as did Pasteur—from the discovery, made at the beginning of the 19th century, in a small enterprise in Alsace, of the transformation of racemic acid or its salts into left-tartaric acid during the development of wine mold in it. On this basis, a new way of producing left-tartaric acid was established. Pasteur and Bechamps—both profound chemists—saw in this chemical action of the mold as living matter, a remarkable, exclusive property of life—living matter; something not understood, unusual, unknown and, apparently, impossible in ordinary chemical reactions. To reflect upon this and to take note of it—to see the problem involved—was already a big accomplishment, but it was only the first step. It was necessary to investigate the phenomenon, and express it, in specific scientific facts.

Bechamps's circumstances of life did not permit him to do this. But Pasteur connected the new phenomenon with a very special property of enantiomorphous crystals, characterizing—under the influence of living matter—the racemic acids and salts. As a result of that action, an isomer was produced—only the left- or the right-handed one, but not the other, which had perhaps been consumed by the organism. Pasteur correctly saw in this a drastic violation of the law of crystalline symmetry. This violation appeared in the fact, that the right- and left-handed forms manifest completely different degrees of stability in living matter, exhibiting *far from identical chemical behavior*—something never observed with them in inert natural bodies. Evidently, the latter could not occur.

He called this phenomenon *dissymmetry,* but did not draw attention to, and did not connect this with the normal right- and left-handedness of living matter, in its morphological and physiological structures. He studied the phenomenon as a crystallographer and a chemist, but not as a biologist. Pasteur himself did not provide a more precise definition of dissymmetry and did not consider the changes, which had occurred in crystallography, when he returned to these problems again in the last years of his life.

Much more important, was Pasteur's discovery of *molecular dissymmetry,* completely analogous to the dissymmetry of polyhedral crystals. He thereby initiated a whole new science—stereochemistry. Because of it, chemistry was enriched by the concept of *asymmetry* (i.e. the absence of symmetry in the spatial configuration *in the vicinity* of a carbon atom). This term is used simultaneously in chemistry and physics in completely different senses, generating confusion.

**11** The muddle that arose interfered with the work. The molecular dissymmetry, discovered by Pasteur, showed, that the presence of living matter is reflected in the chemical formula, including in solutions, and that *right- and left-handed atomic structures* are found to be non-equivalent in chemical reactions. *They are chemically distinct in living matter, but chemically identical in inert chemical media.* Pasteur did not know, that (as was discovered after his death) this was

essentially the same phenomenon he himself had discovered in crystals. For in crystals, he had a spatial distribution of right- and left-handed spiral arrangements of *atoms,* analogous to the atomic structure in molecules. This conclusion emerged in a precise way from the notion of *crystalline space*—speaking in contemporary language—geometrically constructed by Ye.S. Fyodorov and A. Schoenflies at the end of the last century. In the coincidence of the 230 groups he identified (there are actually 219), with the arrangements of atoms in crystalline space, Ye.S. Fyodorov saw proof of the atomic construction of chemical compounds. Finally, this was experimentally demonstrated in the 20th century by the X-ray analysis of crystals. The contemporaries of Pasteur—Seeber, Ampère, and Godin—had foreseen this, but Pasteur remained outside the influence of their ideas.

After Pasteur, P. Curie generalized the concept of dissymmetry, considering the phenomenon, discovered by Pasteur in living organisms, as a special case, and applying the concept of dissymmetry to physical phenomena in general—electric and magnetic fields, etc.—as a fundamental postulate of physics. But Curie was not able to complete the development of his ideas; his work was interrupted in full swing, by his sudden death. No coherent presentation of the results he had obtained was left in his papers. It should only be noted, that Curie demonstrated the existence of different forms of "dissymmetry," and logically concluded that a phenomenon, connected with any given form of dissymmetry, must have a cause that possesses the same form of dissymmetry. It is convenient to call this conclusion *P. Curie's principle.*

In view of this state of the matter, I think it will be more correct to leave aside the concept and the word "dissymmetry," and instead employ the older, generally familiar idea of the distinction between right- and left-handedness in organisms, which is so starkly manifested in Man. But since there exists a theory (an erroneous one, it seems to me) that right-handedness in Man emerged only in the Neolithic period, the correct way to proceed will be to substitute for right- and left-handedness, the more general concept, which Curie employed before his death, of *distinct states of space.* He did not manage to prepare a formal presentation of this concept before his death, but it essentially corresponds, of course, to the different forms of dissymmetry, one on which Curie and Pasteur were working.

This concept was widely known among naturalists in the domain of descriptive natural science, and is rooted far back in the 18th century. Here the subject was often the variable state of space on our planet, connected with its orbital motion around the Sun; that certain motions and phenomena were different, according to whether they took place on a part of the planet moving in the direction of the Sun, or in the opposite direction. Pasteur recognized the possibility of *different states* of cosmic space, by which he explained his discovery that living matter exhibits dissymmetry. Indeed, we should see in the state of space, the basic *geometrical substrate* for all of its material, temporal, and energetic manifestations.

In the present case, there will be a state of space, in which right- and left-handedness, expressed as right- or left-handed spiral structures of atoms, are chemically identical in inert bodies and distinct in living ones. This, one of the most profound geometrical properties of natural bodies, has been given insufficient attention, in philosophy, mathematics, and natural science. But we are all very familiar with it in daily life. We know it from childhood, since a human being is a living body, in which right- and left-handedness are sharply distinguished from one another (including in chemical terms). For example, one person out of 16,000 [sic] is left-handed. In recent times these phenomena have begun to attract greater, but in my opinion still insufficient, attention in biology.

Mathematicians—especially geometers—can no longer ignore this, but need to elaborate this fundamental *geometrical phenomenon.*

I shall return to the question of the state of space, in general, and in connection with its particular manifestation in the non-equivalence of right- and left-handedness, in my next study on the problems of biogeochemistry. Here I cannot go into it further. It seems to me that it is convenient to speak, in this context, about physical space, as Helmholtz proposed.

**12** It is necessary to discuss yet another phenomenon, which has hardly been comprehended by scientific generalizations—*the active energy of living matter in the biosphere.* R. Mayer, almost 100 years ago, took this manifestation of living matter under consideration. He showed that in organogenic minerals—in coal deposits—we have an accumulator of free energy, captured in this form by the living matter of the Carboniferous period, and we use the fossilized solar rays of that time. But the idea in general form—the creation and accumulation of *free energy in the biosphere by living matter* and by the natural processes associated with living matter—arose in the minds of many in the middle of the 19th century, when the concept of energy itself was developed.

Now I want to address this more concretely: not as the basic question of the energetics of the planet, but as a biogeochemical problem. In 1925, I designated the free energy exhibited by living matter in the biosphere, which essentially amounts to the work, associated with the motion of atoms, and is manifested in the movements of living matter, as *biogeochemical energy* (See Section 15, V). Since biogeochemical energy sharply distinguishes living matter from inert matter, it is indispensable to mention its basic features here.

**13** The biogeochemical energy of living matter is closely linked with three fundamental characteristics of living matter in the biosphere: first, with *the unity of all living matter in the biosphere;* second, with the continuous generation, by living matter in the biosphere, of *free energy, capable of performing work;* and third, with *the colonization of the biosphere by living matter.*

In all three of these cases, the manifestation of biogeochemical energy is different; *taken as a whole, biogeochemical energy is inhomogeneous.* In the final analysis, it is connected with the movement of living matter in the biosphere, with passive or active displacements (relative to living matter), associated with the mobility of masses of living matter in the biosphere, and ultimately reducible to the motion of atoms or chemical elements.

From what I have said, it is clear that biogeochemical energy is not some special form of energy pertaining to life; it is not the *vital energy* that W. Ostwald was looking for—analogous to thermal, chemical, light, electrical energy, etc. It does not affect the law of conservation of energy, but appears in that context as *already known forms of energy.*

We can now trace the real sources of biogeochemical energy with precision. They are, ultimately, the radiant energy of the Sun (light, heat, chemical, and the energy of the chemical elements, from which bodies of living matter are constituted (chemical and thermal energy). There is probably a contribution from radioactive elements.

An exact quantitative calculation of the caloric effect in life processes, I believe, establishes beyond any doubt that such is its origin. It is, essentially, a result of *the organization of the biosphere and the organization of the living matter* that inhabits the biosphere.

I cannot go into this matter further here. I shall only mention the main forms of manifestation of that organization. The most important is *the biogeochemical energy, connected with the colonization of the planet.* I attempted to calculate it in the form of a definite, for each species of living matter, maximum *velocity of that species' transmission of life*—the perhaps unsuccessful definition I gave it earlier; that is, *the velocity of colonization of the entire planet by a given organism.* This is energy, connected with the *reproduction of living organisms.* Each form of living matter can in this way spread throughout the planet and, within a certain period of time, which is different for each form of living matter, theoretically colonize the entire planet. In the most rapid cases, for bacteria, this process of colonization can occur within one to one-and-a-half days; while for the elephant—one of the slowest-reproducing of all organisms—it would take 1,000 to 1,100 years. At full colonization, the living matter would cover the entire surface of the planet, i.e., it would fill all of its actually existing lines and areas. One of these curved lines, the line of the Earth's equator, i.e. the precisely defined terrestrial line (curve) of maximum length, may be taken as a single parameter for comparison, common to all forms of living matter.

When I speak here about the colonization of the planet, I assume that this process of colonization were to occur under such conditions, as would permit it to proceed normally into the future, if it were not hindered by lack of space—of surface area for colonization. The velocity of colonization, expressed as a magnitude *V,* may fluctuate within limits ranging from close to the speed of sound in air, more than 33,000 centimeters per second (for some bacteria), to hundredths of a centimeter per second (for the elephant).

In other words, we are talking about the long-term, durable colonization of the planet by an organism under its normal conditions of life, in which it can exist over generations; and not about *explosions* of life, in which the excess of organisms born, dies out due to insufficient food or living space.

These conceptions have not yet entered into the consciousness of science. I am convinced that their employment is a matter for the future. It should be noted, that the velocity of sound corresponds to the real condition, wherein the normal composition of the atmospheric medium, in which the organism lives—even in the case of aquatic organisms (natural waters have their own underwater atmosphere)—, is not destroyed. This shows that biogeochemical energy, so expressed, has nearly reached its physical limits. The velocities obtained in this way may be quantitatively compared with one another; it can be asserted, for example, that the velocity of colonization for the elephant is $10^7$ times less than for bacteria.

But the biogeochemical energy of colonization does not subsume all the manifestations of that energy. I shall mention two more of its forms here.

First, the creation of *a mass of a living matter* and *its maintenance,* by the metabolic process, *at a constant value* during the period of the organism's existence.

And, second, the enormous new form of biogeochemical energy, constituted in the biosphere by the technical *work process of the human race,* which is directed in a complex manner by human thought—consciousness. It is remarkable, that the growth of machines within the structure of human society, also proceeds in a geometrical progression over the course of time, just as does the proliferation of any living matter, including human beings.

These manifestations of biogeochemical energy have not been scientifically investigated at all.

It is imperative to direct scientific work into these areas of biogeochemistry, not only because of their great theoretical significance, but also, it seems to me, with a view towards their certain importance for the tasks of the state. In biogeochemistry, it is necessary to make a deliberate approach to the spontaneous process of the biosphere's transformation into the noösphere, which is now taking place.

For this, the paramount task is to assemble facts and study the problems connected with biogeochemical energy. I have no doubt that this will be done sooner or later. I hope to come back to it in my book.

The basic, distinctive feature of biogeochemical energy is clearly and forcefully demonstrated in the increase of *the free energy of the biosphere* over the course of geological time, and is evident in an especially drastic manner in the transition from the biosphere to the noösphere, which is now apparent.