On the States of Physical Space

by Vladimir Ivanovich Vernadsky

DOE photo

"In every crystal, we have the manifestation of a particular state of space." These 700-pound fast-growth crystals are produced at Lawrence Livermore National Laboratory for use in the National Ignition Facility laser. Sliced into plates, they convert the infrared laser light beams to ultraviolet, just before the beams strike the laser fusion target.

Fragment I

1. We are currently living through a period in which scientific thought is preeminent in the life of mankind. Presently, in connection with his scientific work, the naturalist quite inevitably turns to a more profound, logical analysis of the very foundations of his knowledge, which it was no trouble for him to leave aside during the last century. The conditions in which he is working in the 20th Century forcibly compel him to do this; it is demanded by his concrete, daily scientific work, and by his methodology of experimentation or observation.

The following circumstances, which are independent of the naturalist's will, require it.

First and foremost among these is a phenomenon, absolutely exceptional in the history of science, which is currently being experienced in the natural sciences—in the broad sense—and is leading to their radical reconstruc-

In this first English translation of a 1938 article draft, Vernadsky proposes that living matter exists as droplets of a Riemannian space, dispersed within the Euclidean space of the inert matter of the biosphere.

tion, opening up for scientific thought completely new pathways of investigation and progress, which science previously lacked.

At present, *scientists,* under the influence of exceptionally important *newly* revealed *facts,* are creating new notions, which go far beyond the limits of all previously existing ideas, beyond the limits of the boldest and most fantastical ideas and constructs of philosophical thought. For the first time in the written history of humanity, science, using new, unprecedented methods, is not merely constructing specific generalizations, founded on and originating from facts. In addition, it is constructing new conceptions of the world, which go far beyond the specific facts, but do not contradict them in the way the facts are contradicted by the scientific and philosophical notions that reigned, unchallenged, during the 19th Century. Those notions were developed by human culture over many centuries, and came into scientific thought as if ready-made. They were honed by the labor of philosophical thought over many centuries. At the present time they are being revised in the course of current scientific work, and are undergoing changes that radically transform our understanding of them. Among such concepts are *time, space, energy, life, geometry,* etc.

In all of this motion that is occurring, *the active source of the change* in basic concepts is not philosophy or religion, but science. Scientific work has barely touched on these concepts before now. It made its way within them, not colliding with them, yet introducing its generalizations into them.

2. This condition of scientific thought has coincided with the absence, in 20th Century philosophy, of any creativity, comparable to what is emerging so clearly in science. Scientific thought is currently influencing philosophy, while the previous belief, that philosophy can fathom reality more deeply than science can, is disappearing.

Philosophy is now living in the past, and it is less and less necessary to take it into account, in the ongoing reconstruction of the fundamental scientific understanding of reality. Science is being deprived of the support, which the philosophical analysis of fundamental scientific concepts provided for it during the past three centuries.

Philosophical thought is now working a great deal on the analysis and criticism of the fundamental propositions of mathematics, including those of mechanics and geometry, and, in the most recent time, also those of theoretical physics pertaining to the atomic nucleus.[1]

The entire, enormous domain of the biological and geological sciences, which is undergoing radical restructuring, remains essentially untouched by philosophical thought, which has offered no independent analysis of the newly revealed phenomena. In certain instances, even within new currents like the realistic philosophies of holism and organicism (Whitehead), for example, philosophical thought is essentially standing on 17th Century ground, failing to realize the impossibility of pouring new phenomena into "old wineskins." Unfortunately, dialectical materialism has also closed its eyes to those new developments, which do not fit the framework of the philosophical conceptions of the 1840s through 1880s, where it lives. With the passage of time, it seems to me, this discrepancy will increase, and dialectical materialism's ability to grasp what is observed, or what is scientifically created, will diminish. New, vital, and creative work is needed, smashing the very foundations of philo-

EDITOR'S NOTE

This article is a sequel to V.I. Vernadsky's 1938 work, "Problems of Biogeochemistry II: On the Fundamental Material-Energetic Distinction Between Living and Non-living Natural Bodies of the Biosphere," which was published in the Winter 2000-2001 issue of *21st Century Science & Technology.* In that work, Vernadsky developed the distinction among the three domains of non-living, living, and noetic, the latter referring to the human mind which, he noted, was capable by its innate power of creativity of becoming a geological force.

In his foreword to that 1938 work, Vernadsky promised "a third issue now in preparation for publication," which "poses the still more general question of the 'states of physical space.'" This promised "third issue" was never completed for publication. However, the article presented here is a translation of two fragments from 1938, both bearing the given title.

It was translated from Russian by Peter Martinson and Sky Shields of the LaRouche Youth Movement, and Rachel Douglas, William C. Jones, and Laurence Hecht. It was dedicated to Lyndon LaRouche on his 85th birthday, Sept. 8, 2007.

The text which we have used as a source is from the work *Filosofskie knigi naturalista* (The Philosophical Books of a Naturalist), Moscow: Nauka, 1988. That text, as reported by the Russian editors on p. 442, is based on the copy held in the USSR Academy of Sciences Archive, f. 518, op. 1, item 152. The Russian editors add:

"The work exists as two fragments with the same title, the first of which is evidently an initial draft. This version was later set aside by the author, which explains its brevity [*sic*; in fact, it is longer] and obvious unfinished character. The second fragment is rather fuller and, together with the notes V.I. Vernadsky made at the Uzkoye Sanatorium in the Summer of 1938, treats the problem fairly comprehensively."

The reference to 1938 writings from Uzkoye Sanatorium refers to the essay published in our Winter 2000-2001 issue.

1. The text included in *Filosofskie knigi naturalista* (The Philosophical Books of a Naturalist), Moscow: Nauka, 1988, inserts here two sentences, typed by Vernadsky on a separate piece of paper, without any indication of where they should go: "But I can omit consideration of this area of physics, which encompasses our most profound notions about the universe, just as it is practically ignored by current scientific work in physics and chemistry, and not only in descriptive natural science. It is at a crossroads, and is changing almost daily."

sophical thought, as is now taking place in creative scientific work. Bold and free searching is required. There must be a shift from interpretation of the old, and adaptation of the old to the new, towards a critical examination of fundamental propositions.

3. Among the new general concepts, prompted by the facts of descriptive natural science, it seems to me that two, in particular, ought to be given attention at this time: [first of all,] the state of space, and, secondly, right-handedness and left-handedness. They are closely connected, and the fundamental one is the state of space.

The first person to touch upon this, in a profound synthetic way, but without giving it an in-depth analytic treatment, was L. Pasteur, not long before his death, in the 1880s. Pierre Curie attempted to approach it later and more deeply, but never yet, as far as I know, has this concept become the object of the systematic thought of both the naturalist and the philosopher.

Space that can be investigated empirically is distinct from the space of geometry. That is a consequence of the inadequate depth of geometrical analysis.

Geometrical space is isotropic; for example, it lacks any manifestation of right-handedness and left-handedness.

This does not flow from how things essentially are, but is a consequence of the insufficiently deep analysis of reality by geometrical thought.

When speaking about space, the naturalist can make only partial use of the achievements of geometry; more and more, he goes beyond its limits in his judgments. This must be borne in mind. Geometric space does not now embrace all of empirically studied space—what Helmholtz called physical space.

In discussing the state of space, I will be dealing with the state of empirical or physical space, which has only in part been assimilated by geometry. Grasping it geometrically is a task for the future.

The state of space is closely connected with the concept of a physical field, which plays such an important role in contemporary theoretical physics. The concept of a physical field is distinguished from the concept of a state of space essentially by its being clearly manifested in three dimensions; that is, it coincides with geometric space. It is also the case, however, that a physical field is not a field in the ordinary sense, since it often has curvature and, in a great number of phenomena, physical fields in which lines of force are distributed—electrical, magnetic, heat, gravitational, and electromagnetic fields—clearly are a part of geometric space that is delimited in an acutely different way. We see dramatic manifestations of such fields on a large scale, in the structure of our planet. Among these are the Earth's electrical and magnetic fields, and the vacuum of the ionosphere, which are delimited by two spherical surfaces of different diameters; another is the magnetic field of the Sun, which encompasses the entire orbit of the Earth, its atmosphere, and the Earth itself.

In all of these cases, we are dealing with states of space, whose properties are manifested not materially, but energetically. In the cases encompassed by the thoughts of Pasteur and Curie, however, we are dealing with a state of space, which is manifested primarily *in matter*.

In essence, we have been dealing with such cases at every step in natural science for a long time, even before Pasteur and Curie. Pasteur began to speak in terms of states of space. Helmholtz distinguished physical space from geometric, as possessing its own properties, such as right-handedness and left-handedness. As far as I know, this idea was not further developed.

4. Crystallographers have been encountering this phenomenon for a long time. In every crystal, in every inert natural body, we have the manifestation of a particular state of space. Inside a crystal we have a three-dimensional physical field, the properties and state of which are determined by the phenomena of crystallization. This is a homogeneous space, filled continuously by pent-up crystalline forces (the chemical forces of matter in the solid state), or atom points, which fill it completely and regularly. The distribution of these forces can very well be grasped as a particular case of the lines of force in a physical field. In essence, in homogeneous crystalline matter—in systems of points or parallelepipeds, continuously, uniformly embracing an entire three-dimensional space without violating its homogeneity—we have the case of a special, *anisotropic state of space,* sharply

Yevgraf Fyodorov (1853-1919)

Arthur Schoenflies (1853-1928)

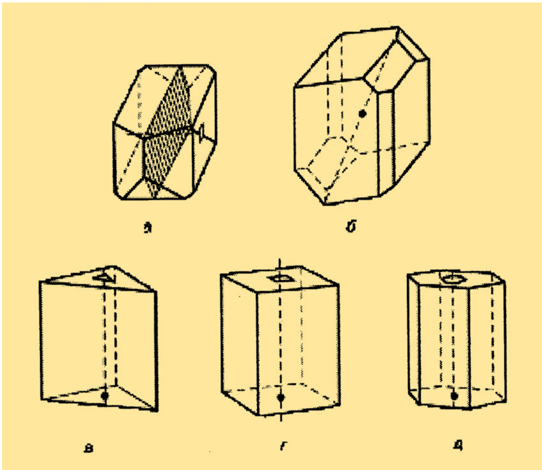
Fyodorov and Schoenflies encompassed "all uniquely possible forms of an anisotropic geometric state of space, manifested in matter," in their studies of crystallography.

distinct from the usual isotropic state of geometric space. Innumerable instances of different such states of space, which are dispersedly[2] expressed in matter, are known and conceivable in geometry.

The geometry of these special states of space is entirely determined by the laws of three-dimensional Euclidean geometry. What is more, it can be said that in these spatial point systems, in their bounded polyhedra—crystals—the laws of geometry emerge for us with the greatest clarity. A. Poincaré expressed this thought very clearly, when he observed that geometry could not have been developed without solids. In crystallographic phenomena, we are located entirely within the bounds of three-dimensional Euclidean geometry. In precisely the same way, we do not go outside of its bounds in physical fields such as magnetic, electromagnetic, and electrical fields.

In reality, in the profound constructions of Fyodorov and Schoenflies, we have a geometric expression of the structures of space, in which the atomic manifestation of the organization of matter can uniquely exist. This is the only geometrically possible expression of the atomic structure of matter, which it expresses clearly, definitively, and precisely. In this solid structure, in its primary manifestation, there is no motion of atoms, such as characterizes the gaseous and liquid states of matter. Taking the general form of this phenomenon, and taking into account that any chemical compound can be manifested in the solid state in our space, we should see, in these great, geometrically expressed generalizations of Fyodorov and Schoenflies, a total encompassment of all uniquely possible forms of an anisotropic geometric state of space, manifested in matter.

"Within the boundaries of the biosphere, which I deal with, in its inert matter, nowhere do we have to go beyond the boundaries of Euclidean geometry."



Some examples of crystalline symmetry.

Eric Hunt

A sulfur crystal from Argent, Sicily.

5. But, in elucidating the more complex processes of the inert natural bodies of the biosphere, it is entirely possible (and fruitful) to use multidimensional space to express the regular patterns that are observed when drawing correlations between matter and its chemical composition (as demonstrated in the works of N.S. Kurnakov and his school, chiefly N.I. Stepanov, et al.). But, even here we do not go outside of Euclidean geometry.

All of these are phenomena, associated with the biosphere or the terrestrial crust.

It appears that Euclidean space may turn out to be insufficient for the geometric expression of phenomena, associated with cosmic space. At the very least, it was necessary to look at those phenomena, when analyzing Einstein's theoretical premises. (Eddington, for example, turned to them—to a certain form of Riemannian space.) But, within the boundaries of the biosphere, which I deal with, in its inert matter, nowhere do we have to go beyond the boundaries of Euclidean geometry.

6. Before continuing, it is necessary to distinguish in what follows, whether we will be dealing in space *with material processes, or with energetic ones*. From the standpoint of the geometric properties of space, it is clearly inevitable that they are manifested differently in space.

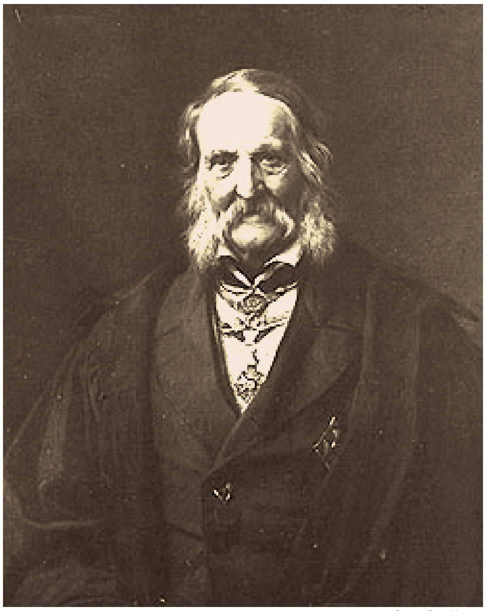
Geometry is not a manifestation of *a priori* human reason. But, it clearly—beyond any doubt, it seems to me—follows from a study of the history of geometry, that it grew out of the investi-

2. Vernadsky uses the terms *"dispersny"* and *"dispersno"* throughout this essay in a sense that is analogous to the chemist's "disperse phase," where particles (as colloidal particles) or droplets of one substance are distributed through another substance, a condition that is also called the "discontinuous phase." We have opted to write "dispersed," rather than possible alternatives such as "quantized" or "discrete," which have their own special connotations.

gation, by scientific thought, of manifestations of solid matter in the biosphere surrounding man. The extension of the laws of the biosphere to energetic phenomena came as a consequence. Such an extension cannot shake this fundamental feature of geometry.

Therefore we ought to view the geometric reflection of the solid state of matter, shown by Schoenflies and Fyodorov in the most profound and general form, as the most profound expression of real three-dimensional Euclidean geometry.

Scientific experimentation and observation have shown that all energetic manifestations of the solid state of matter in space fail to reveal the geometric properties of space as deeply as the atomic structure of matter does. This is a statement, in the language of modern science, of the so-called Neumann principle, named for the noted Königsberg crystallographer, physicist, and mathematician [Franz Ernst Neumann].



Portrait by Carl Steffeck

Franz Ernst Neumann (1798-1895), German crystallographer, physicist, and mathematician, developed the principle that "neither the liquid nor the gaseous state of matter is sensitive enough for detecting the structure of space in its geometric, rather than its dynamic manifestation."

According to this principle, neither the liquid nor the gaseous state of matter is sensitive enough for detecting the structure of space in its geometric, rather than its dynamic manifestation.[3] Not even the weightless fluids, to which the great physicists and philosophers of the 17th Century reduced energetic phenomena—in some cases quite conveniently, from a scientific standpoint—are sufficiently sensitive.

As we are constantly saying, liquids and gases assume the forms of the vessels which contain them, remaining inert with respect to the space of the body. This is another expression of the primacy of solid material bodies for ascertaining the geometry of an environment.

In talking about space in general, we need to broaden Neumann's crystallographic principle. Geometrically, only the study of material phenomena—metamorphic or crystalline—can give us a concept of the structure of space. Energetic phenomena or phenomena occurring in liquids or gases penetrate the geometry of space less deeply, and cannot be used to shed light on this geometry.

Pasteur did not recognize this, when he supposed that it were possible to create a space, characteristic of a living body, by means of circular radiation or electric light. Pasteur proposed to conduct an experiment on abiogenesis in a medium, illuminated by radiation from circular or elliptically polarized light. This experiment was done later, after Pasteur. It reveals the action of these rays upon living phenomena, but, in accordance with Neumann's principle, it in no way alters the structure of space.

The exposition that follows will be based on this geometric nature of material and energetic phenomena in geometric space. *Material phenomena provide a more profound concept of the geometric structure of space than energetic ones do.*

7. Now, we turn our attention to phenomena of right-handedness and left-handedness, as they relate to the laws of symmetry.

We saw that, in three-dimensional Euclidean geometric space, right- and left-handedness are geometrically and physically equivalent in material processes. This equivalence shows itself in the fact that the numbers of crystallographically right- and left-handed polyhedra that are formed during crystallization are identical (in the absence of living organisms in the medium). This number corresponds to the laws of the theory of probability. When there are a sufficient number of cases, the ratio between the quantities of right- and left-handed polyhedra will be equal to unity. The greater the number of cases, the more closely it will approach unity.

The observations done on quartzes by Lemmleyn in our Biogeochemical Laboratory, and an even greater number of cases by Trommsdorf in Göttingen, completely corroborate this.

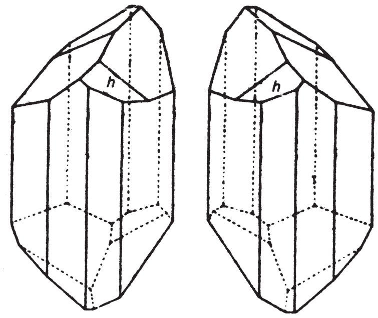
Pasteur's great discovery showed that this never occurs during crystallization phenomena in living organisms, nor, even more profoundly, during the biochemical formation of right- and left-handed molecules in living organisms.

I fully recognize Pasteur's idea of a connection between this phenomenon and the geometrical space of living organisms, as an ingenious intuition. But, failing to distinguish between the material and the energetic properties of space, Pasteur erroneously supposed that life originated on our planet in some past period of geological history, when the Solar System passed through left cosmic space. He furthermore supposed that, in cosmic space, right- and left-handed spaces are separate. As we see, for three-dimensional Euclidean space, and for Euclidean space in general, this cannot be the case with respect to matter. Energetic manifestations in space do not give us the possibility to judge. The division into right and left, corresponding to life, i.e., the inequalities of right-handedness and left-handedness,

3. The text in *Filosofskie knigi naturalista, op. cit.*, here reads *"v vyiavlenii"* (its detection), but the sense and context require *"v proiavlenii"* (its manifestation).

Library of Congress

“It can be clearly seen that between the symmetry of crystalline polyhedra and the symmetry of living organisms, there exists a fundamental, deep distinction.”



Louis Pasteur (1822-1895) discovered left- and right-handed isomers of tartaric acid crystals. (These are his sketches at left.) He found that only the left-handed form is produced in biological processes, such as fermentation, while in laboratory synthesis of the compound, equal quantities of left- and right-handed forms occur.

have to be established not in the energetic, but in the material properties of space.

8. Geometric laws of symmetry were constructed for Euclidean geometry and were expressed with regard to space in a definitive form at the end of the last century by Ye. S. Fyodorov in St. Petersburg and A. Schoenflies in Göttingen. They had many predecessors, such as Frankenhelm, Bravais, and Sohnke, but they were the first to solve the problem definitively: Schoenflies with the aid of group theory, and Fyodorov geometrically, by the continuous displacement of space uniformly, without empty gaps, by parallelohedra. The crystalline polyhedron was discarded, and replaced geometrically by a system of points at the vertices of parallelohedra situated in a lawful way, but not uniformly, within the unbounded space of three-dimensional Euclidean geometry.

Soon thereafter, Paul von Groth in Munich was the first to point out that it flows logically from the work of Fyodorov, that crystals are characterized in their internal structure not by molecules, as crystallographers had thought, but by atoms. Earlier, this had been clearly understood by Gaudin in the first half of the 19th Century. The discovery of X-ray crystallography in 1911, by M. von Laue, Knipping, and Friedrich in Munich, working with Groth, proved it definitively.

From this we must conclude that in physical space, the atomic state of solid matter inevitably requires, firstly, the inseparability of right-handedness and left-handedness and, secondly, their physical and, consequently, chemical equivalence. The existence of atoms in physical space is, for us, an incontestable fact, upon which our entire scientific conception of reality is constructed. In a solid medium there can be no distinction between right-handedness and left-handedness; moreover, the differences associated with vectors in the direction of the Sun's motion across the sky, and against the Sun, are identical in every other respect. This is *an inevitable logical consequence of the atomic structure of matter* and of three-dimensional Euclidean geometry.

9. This conclusion requires additional consideration. It is again useful to consider the fact that we are dealing here not merely with the properties of crystals, but with the distribution of atoms in spatial lattices. From this it follows geometrically that certain elements of symmetry cannot be manifested in atomic processes. The first crystallographers already pointed out that of the five regular Pythagorean polyhedra, the regular dodecahedron is not encountered among crystals, and a century ago Bravais proved that, accordingly, the axis of five-fold symmetry, which characterizes the dodecahedron, could not occur, because if it were allowed, then the law of rational indices, which has been empirically established for crystals, would have to be recognized as incorrect. This is expressed clearly in the fact that a body composed of atoms, which possesses such an axis of five-fold symmetry, does not allow the possibility of any arbitrary finite distance between two atom points. They will always approach each other to a distance less than the given distance. Physically, we would have to be dealing here with a continuous, non-dispersed state of solid matter. At the same time, we can easily obtain or make a regular dodecahedron out of any solid material. But what's more, from this same fundamental proposition, from the

structure of solid matter, from the homogeneous spatial distribution of atoms having fixed finite dimensions (or possessing forces which do not permit the penetration into their region of the influence of the radius, strictly defined, of another atom)—from all this it follows, on the same basis, that the number of elements of symmetry manifested in crystalline solids is strictly limited. No axes of symmetry greater than six are possible in them, and none is observed. Of the innumerable multitude of the regular polyhedra of geometry, relatively few are encountered in natural bodies, and those consist of homogeneously and regularly distributed atoms in three-dimensional Euclidean space.

10. This is not only a manifestation of the atomic structure of matter, but is also a manifestation of the three-dimensional Euclidean space in which the bodies are located.

From this standpoint, it becomes profoundly significant that such a distribution of atoms is always possible in this space, but then two physically identical varieties of helical spiral distributions of atoms are inevitably formed—right and left. These helical spiral distributions of atoms inevitably should be manifested in crystalline structures, in the absence of elements of complex symmetry, such as a center of symmetry, planes of symmetry, or an axis of four-fold complex symmetry. In ordinary crystallization, the quantity of such differently oriented helical spiral atoms will always be identical, and will be randomly determined.

The violation of this principle in living natural bodies, discovered by Pasteur, poses the question of what the cause of this phenomenon might be.

It cannot, of course, contradict the atomic structure of matter, which is so sharply and definitely manifested in living natural bodies, where, perhaps, atomic properties are manifested even more profoundly than in inert natural bodies.

The cause may lie either in special manifestations of symmetry in living organisms, or in special properties of the space, occupied by bodies of living matter.

These are the theoretically possible premises, which are really associated with the concept of living matter as the totality of living organisms. Thus, I avoid the slippery terrain of the properties of "life." In reality, in the biosphere, this is precisely how we study the phenomena and manifestations of life—only as "living matter."

11. Before going further, it is necessary to pause and consider the phenomena of symmetry as related to the living organism. The very concept of symmetry took shape in the course of studying living organisms. Several centuries B.C., according to tradition, Pythagoras of Rhegium created the concept and the word "symmetry" to express the beauty of the human body, and beauty in general. Here the ancient Greeks had already found lawful numerical patterns, which thereafter, and to this day, have not yielded to the grasp of a generalization in mathematical thought.

When, in the first half of the 19th Century, Bravais approached the concept of symmetry, he proceeded simultaneously from the symmetry of crystals and the symmetry of living organisms. He achieved brilliant results for crystals, thus beginning the discipline of crystalline symmetry, which led, at the end of the century, to a well-formed system of spatial atom points and to the complete description of their geometry.

Illness cut short his work on the symmetry of living organisms. Nobody afterwards investigated it as deeply as Bravais had done, and it has remained in a state of chaos to the present time.

It can be clearly seen, however, that between the symmetry of crystalline polyhedra and the symmetry of living organisms, there exists a fundamental, deep distinction. In the first case, we are dealing with the expression of the atomic structure of solid matter, while the second involves a striving towards organization on the part of living matter, which exists in an isolated and separate way within the alien, inert environment of the biosphere.

Symmetry here is expressed in the external form of that eternally mobile, dispersed element of living matter—a large or a negligibly small living organism—which is created and maintained by the biogenic migration of atoms, and is revealed as a body that is sharply distinct from the nature surrounding it. Symmetry is expressed also in its internal structure, its organization, and its macroscopic and microscopic cross-sections.

12. The laws of this symmetry are completely unknown to us. But, its existence, the existence of morphological regularity, is beyond any doubt. It is clear that this symmetry obeys entirely different laws than those that crystalline symmetry obeys.

Geometrically, two phenomena are immediately striking. First of all, living organisms exhibit five-fold or higher than six-fold axes of symmetry. This indicates that we are not dealing here with the symmetry, or the atomic structure, of a homogeneous solid. The homogeneity of internal structure, which is so characteristic of crystals, is absent here. The inside of a living organism is distinctly heterogeneous, its atoms being in continuous motion, never returning to the same points where they were, unlike crystals, where the atoms do not shift for billions of years, unless external forces cause that to happen. [Secondly,] inside a living organism, we are dealing with an ongoing sequence of dynamic, stable equilibria, regulated by the biogenic migration of atoms. In the symmetry of a living organism, we thus have to consider a new element, motion, which is absent in crystalline symmetry, because the atoms in crystals do not shift, and thus they ideally manifest a solid. It is characteristic, that the biogenic migration of the atoms that create a living organism's form of dynamic equilibrium occurs in a liquid or gaseous medium—in that medium, which is the least pronounced in expressing the geometry of the space occupied by the body of living matter.

Finally, a third, extremely typical feature should be emphasized here, one which is absent in crystals, and is a primary element in the morphological form of a living organism. In the morphology of living organisms, *curved lines and curved surfaces* reign as the

Spirals in mollusk shells. Vernadsky notes the inequality of left and right spirals, and the inadequacy of explanations of the phenomenon.

primary manifestations of their symmetry. In crystalline polyhedra, essentially in the "droplets" corresponding to crystalline spatial lattices, curved surfaces and curved planes are secondary phenomena. They are connected with the action of surface forces during crystallization and in manifestations (of forces) within the space of liquids. Among these are the phenomena of dissolving, and the related dissolution surfaces of crystals. These curved surfaces are even more pronounced in all of the energetic properties of crystals, where the polyhedron disappears and is replaced by a sphere, a hyperboloid, an ellipsoid, etc. These are cases, where, in these phenomena, Neumann's principle states that the geometric structure of space is reflected the least.

13. In the symmetry of living organisms, right-handedness and left-handedness are extremely pronounced, while in crystals they are a special case, whose occurrence is associated with the absence of complex symmetry.

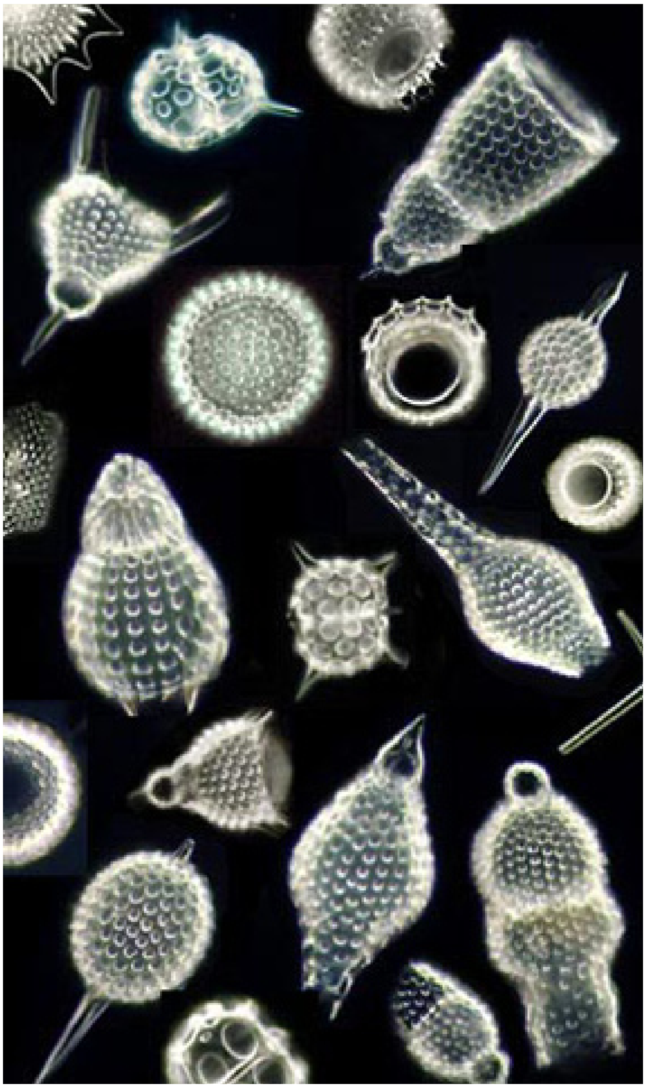
But there is a fundamental distinction, as I have already indicated, between the manifestation of right-handedness and left-handedness, with respect to symmetry, in organisms and its manifestation in crystals. This distinction consists in the physical-chemical equivalence of right-handedness and left-handedness in crystals, which is manifested in their occurrence in equal numbers during the crystallization of right and left forms. This always happens and, as I indicated in Section 8, may be viewed as a manifestation of the atomic structure of matter in the solid state in three-dimensional Euclidean space. *This is as much a property of symmetry, as it is a property of three-dimensional Euclidean space.*

We observe something else entirely, in living matter.

Here *the inequality of right-handedness and left-handedness* is acutely manifested. There is an enormous accumulation of material that has still not been worked through critically, but it seems to me that it can be firmly established on the basis of this material, that in organisms—in living matter—this inequality is extremely pronounced for a whole range of diverse properties. It is transmitted hereditarily and is a species marker. All proteins exhibit a left rotation of the plane of light, both in animals and in plants. This means that, in the complex matter of living bodies, only left isomers in protein bodies—the principle component of protoplasm—are stable. Right isomers are absent. As Pasteur demonstrated, all crystalline compounds—alkaloids, glucoses, sugars, etc., which make up eggs or grains, i.e., which are the most essential for life—are left-handed. This last assertion would require more detailed discussion, which I cannot go into in this short article. But, in general, it seems to me to be true, and sometimes difficulties may occur only because the complex organic compounds in bodies of living matter have right and left complexes simultaneously as their components. This situation requires verification, beginning with the critical processing of all the material.

No less pronounced is the chemical distinction of the action of right and left isomers upon cell protoplasm.

A series of precise experiments in this area, designed by G.F. Gause partly in connection with the work of our laboratory, has recently demonstrated this beyond the shadow of a doubt. Right and left chemical compounds act here in an identical setting and under identical conditions, in the complex thermodynamic environment of living matter, as bodies that are *chemically* acutely different. They point to a unique geometric structure, which is dynamically manifested differently for right and left [isomers] in a living organism, and in a



© Michael W. Davidson/Florida State University

Radiolaria are single-celled marine organisms with intricately detailed glass-like exoskeletons. These mixed radiolaria were microphotographed with darkfield illumination.

cell, in particular.

The inequality of right-handedness and left-handedness is expressed not only in their chemical and physical manifestations. It embraces the entire morphology of the organism and, moreover, its dynamics. Extraordinarily characteristic is the significance of spirals in the form of organisms, and the inequality of right and left *spirals*. This is expressed in the inequality of the right and left coils in shells, bacteria, seeds, plant tendrils, etc. It is seen in the rare occurrence of "left-handed" organisms although, for certain organisms, they predominate and can be taken as a species marker.

I am leaving completely aside the numerous and various explanations of this general phenomenon. They are formulated from case to case and, in general, it seems to me that they explain nothing.

Fragment II

1. The state of space is closely associated with the concept of a *physical field,* but is distinguished from the latter, in that it is clearly manifested in three dimensions. But a physical field, too, for example an electromagnetic field, actually has curvature, and phenomena within it do not occur on a plane. In the ionosphere, we have a very pronounced, peculiar state of the space of this terrestrial envelope, a special physical field—the field of a physical vacuum in the form of a three-dimensional space, bounded by spherical surfaces of different radii.

In reality, we encounter different *states of space* at every step. Thus, inside a crystal we have a three-dimensional physical field, whose properties are determined by the phenomena of crystallization. This is a homogeneous space, filled continuously by pent-up crystalline forces (the chemical forces of matter in the solid state), by atom points, which fill it completely and regularly. In essence, in homogeneous crystalline matter—in systems of points or parallelepipeds, continuously, uniformly embracing an entire three-dimensional space without violating its homogeneity—we have the case of a special, *anisotropic state of space,* sharply distinct from the usual isotropic state of geometric space. Hundreds of such different states of space, expressed in different ways in dispersed matter, can be distinguished geometrically. But the geometry of these special states of space is entirely determined by the laws of Euclidean geometry. Likewise, in magnetic, electrical, and electromagnetic fields we do not go outside the boundaries of Euclidean geometry, and remain in three-dimensional space.

But with more complex phenomena, it is convenient and possible to use geometrical representations of multidimensional spaces in Euclidean geometry.[4]

It can be stated that in all of these phenomena, we never go beyond the limits of the inert natural bodies of the biosphere. In this domain of phenomena, we are located entirely within Euclidean geometries. These Euclidean geometries are expressed in three-dimensional geometry in the anisotropic spaces of crystallography, while in expressions of the correlation of chemical properties and matter in the conceptions of Kurnakov, they are expressed in three-dimensional, four-dimensional, five-dimensional, and more complex geometries.

One might think, that nowhere within the limits of the inert natural bodies and phenomena of the biosphere do we currently go outside the domain of Euclidean geometry. We do not go beyond it, until we touch upon planetary phenomena.

Evidently, these conceptions are insufficient, when we go beyond the limits of our planetary world into cosmic space.

But these phenomena, which are associated with Einstein's ideas, lie outside of my purview, insofar as I am dealing with the inert and living natural bodies of the biosphere, which is one small envelope of our planet.

4. Author's note: This current of thought has been applied with great success for correlating chemical compounds in the work of N.S. Kurnakov, N.I. Stepanov, and the school of N.S. Kurnakov.

2. Yet, as soon as we approach living natural bodies, we encounter a fundamental change in the geometric phenomena, which, it seems to me, does not fit into the confines of Euclidean geometry of any number of dimensions.

Basic here is the marked violation of, firstly, *symmetry,* and, secondly, the manifestations of *right-handedness* and *left-handedness.*

Geometrically, the laws of symmetry were constructed for Euclidean geometry, and they were expressed not only geometrically, but also algebraically, in the theory of groups, and the same results were obtained by these two independent logical paths. Geometrically, they came out of the distribution of the points of space, where these points always had a certain parameter, a certain interval, closer than which they could never approach each other. In the phenomena around us, which can be reduced to points, i.e., to the atoms which comprise matter, nowhere do we encounter any violation of the laws of symmetry.

These laws are violated within the boundaries of the space occupied by *living matter,* where by "living matter" I mean the totality of all living organisms. This violation is most vividly expressed by the acutely different manifestation, inside the bodies of living organisms, of right-handed and left-handed crystal lattices (having right-handed and left-handed internal atomic structure) for one and the same chemical compound, and these turn out to be chemically very different.

3. Unfortunately, these phenomena of symmetry and the phenomena of right-handedness and left-handedness—the former encompassing all of the basic geometric and physical patterns of solid matter, and the latter characterizing the bodies of living organisms—remained for a long time, and in part still do remain, outside the purview of mathematicians and philosophers.

One might say that there has been no philosophical analysis. But, mathematical analysis (both geometric and algebraic) of dispersed regular systems of atom points was done brilliantly, one might say definitively, in the work of Ye. S. Fyodorov in St. Petersburg and A. Schoenflies in Göttingen at the end of the 19th Century. In the course of this work, incidentally, it was determined that far from all of the geometrically conceivable polyhedra are encountered among the inert natural bodies of our planet. In particular, one of the five Pythagorean solids, the regular dodecahedron, is not and cannot be observed among the inert natural bodies of the Earth's crust. This is a consequence of the dispersed structure of solid chemical compounds: they are composed of atoms which can never approach one another to a distance less than a given magnitude, which is different for each isotope. Another geometric consequence of that same basic phenomenon is that in the geometric structures of matter—in crystals and molecules—five-fold, seven-fold, and higher-order axes of rotational symmetry cannot exist.

Auguste Bravais (1811-1863), a geometer and naturalist, studied the question of symmetry from the perspective of biology, but illness cut short his life and work. "It seems to me that nobody has gone beyond Bravais," Vernadsky writes.

The phenomenon of symmetry, which has only partly been grasped by mathematical thought, came into science in connection with the sense of beauty that developed in humanity many thousands of years ago. This concept was a creation of Hellenic thought in the first millennium B.C. Tradition has preserved the name of Pythagoras of Rhegium, who first identified it. But in science, the concept of symmetry arose in the 17th Century and, in a more general form, in the 18th and 19th centuries. It had two roots. On the one side, it emerged from the observation of inert natural bodies of the biosphere—snowflakes and crystals—and, on the other side, chiefly with Bravais in the middle of the 19th Century, from observation of the forms of living organisms. Bravais, who approached the study of crystals from the standpoint of his primary scientific interest in biology, laid the basis for the geometric study of crystalline symmetry, and, at the same time, demonstrated the essentially different character of the symmetry of organisms, compared with crystals. But his work, the work of a profound geometer and naturalist, was interrupted in its prime by an incurable illness. The thread that he let go was not picked up by anyone. As far as geometry is concerned, the symmetry of living organisms is in a state of chaos. The assembled facts have not been embraced by geometric thought. It seems to me that nobody has gone beyond Bravais.

Amazingly, the concept of symmetry has remained outside the reach of philosophical thought, and it seems to me that its significance has been insufficiently deeply considered in science, despite its fundamental significance being clear to many, and despite the obvious possibility of further mathematical investigation.

4. Matters are even worse with the concept of right-handedness and left-handedness, whose enormous significance and very different manifestation in living and inert natural bodies were clearly brought out in the middle of the last century by Louis Pasteur. Essentially, no one has gone deeper than he did. Geometers

have ignored this concept. Crystallographers ascertained that it is expressed in the right-handed and left-handed helical spirals, in which the isotopes [sic] are distributed in crystalline structures. Pasteur was the first to prove that the same phenomenon must be observed in certain chemical compounds in molecules. From his observations, he drew the correct conclusion that there is a pronounced difference in how these phenomena are expressed in living and inert natural bodies. The laws of symmetry, derived on the basis of the study of crystals, are sharply violated in living natural bodies.

Pasteur, like Bechamps somewhat before him, understood the significance of right- and left-handedness, based on the observations made by technicians in Alsace, who had obtained left tartaric acid and its salts through the action of living mold on racemic acid and its salts. Most likely Pasteur was right (unfortunately, this has not yet been conclusively verified), that, contrary to the laws of symmetry, all of the main compounds necessary for life, when crystallized (compounds that are components of seeds, eggs, spores, and so forth), are observed only in the form of left isomers. Non-crystalline—colloidal or mesomorphic—proteins are always left-handed. To date, right-handed isomers of proteins and the main crystalline products of their decomposition have been obtained only in the laboratory. In the plant and animal worlds, only the left isomers are observed.

This is expressed in the special characteristic of living organisms, namely, feeding on, and converting into their bodies, right-handed isomers. Only left-handed isomers enter into the composition of a living body. This explanation is a simple statement of fact and, essentially, cannot be considered an explanation. It is just as incomprehensible to us as the fact itself.

5. Since the right-handedness and left-handedness of crystalline solids in three-dimensional Euclidean space are chemically identical, the question inevitably arises of whether or not the fact, grasped by Bechamps and Pasteur, and independently demonstrated earlier by Bechamps, is explained by assuming that living organisms have a special, poorly understood property, by which they violate the equivalence of right-handedness and left-handedness, and construct their bodies from left isomers of the basic molecules necessary for life. Isn't that a tautology? And would it not be more correct to turn, as Pasteur did, to the properties of the spaces, in which life takes place and in which it originated?

Certainly *right-handedness* and *left-handedness* in Euclidean space are a geometric property of that space. That is evident from the geometrical finding, shown long ago, that right-handedness and left-handedness are not manifested in the fourth dimension of Euclidean space. Kant already studied this phenomenon, and he emphasized that right and left hands coincide in four-dimensional Euclidean space. It is clear that right-handedness and left-handedness are characteristic of *Euclidean spaces of odd-numbered dimensionality.*

It is clear from the properties of symmetry mentioned earlier, that it is not only a physical-chemical property, since the equivalence of right-handedness and left-handedness in all of their manifestations, whether those be geometric or physical-chemical, is found for a homogeneous system of points, continuously filling all of three-dimensional Euclidean space. This follows inevitably from the constructions of Schoenflies and Fyodorov. Pasteur did not know this. But with the intuition of genius, he understood the profundity of the phenomenon he was dealing with. And he looked for a way out, in the properties of cosmic space. He suggested that in some past period of geological history, the Solar System had passed through left cosmic space, and that life had originated at that time, and reflected this phenomenon. But Pasteur did not know the geometrical consequences, which follow from the work of Schoenflies and Fyodorov—the geometrical equivalence of right-handedness and left-handedness in three-dimensional Euclidean space—and which are geometrically expressed in spatial lattices of atom points. From this it follows that *the equivalence of right-handedness and left-handedness* may be considered to be a geometrical property of three-dimensional Euclidean space.

6. In order to explain the inequality of right-handedness and left-handedness and the pronounced manifestation of left-handedness in chemical compounds within the bodies of living organisms, we have to suppose either that we are not dealing with Euclidean space in this case, or that organisms possess a special ability to utilize[5] right isomers when constructing their bodies, while left isomers are deposited inside the bodies of living organisms.

It seems to me to be simpler, before assuming the existence of a phenomenon we don't understand and looking for it among the properties of "life," to be persuaded of the possibility of there existing a space, in which geometrically right isomers would be chemically stable, while left isomers could agglomerate in chemical processes.

L. Pasteur supposed the existence of such a space. Essentially he supposed, that in this instance there exist *separately* two analogous spaces—two isomers, in a sense—in the Cosmos: right, and left. He took this space to be Euclidean.

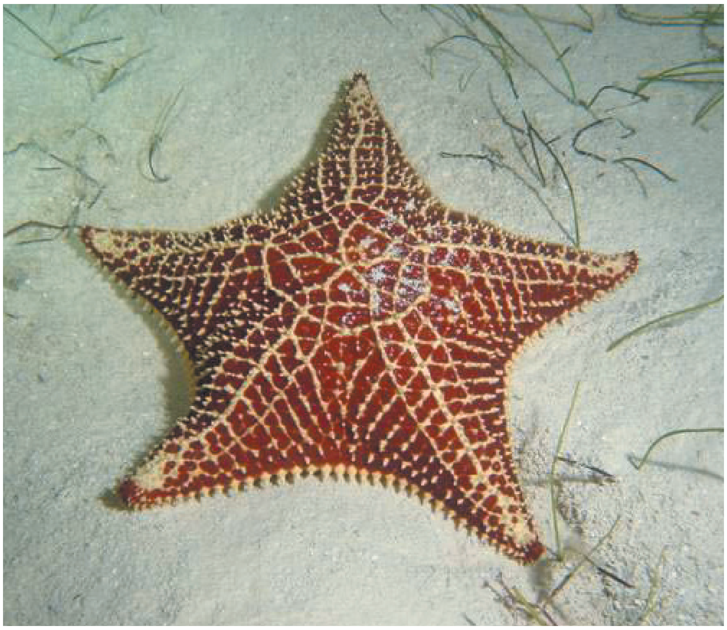
But, right-handedness and left-handedness are inevitably geometrically equivalent in Euclidean space. There would have to be some cause for the division of space into right and left as two independent spaces. Pasteur proceeded empirically, beginning with how racemic crystals and molecules break down into optical isomers. But, to this day, we know of this phenomenon only within living organisms or in their presence. Indeed, in his last work, Pasteur attributed the spontaneous breakdown of racemic acid into right and left tartaric acid during crystallization, to the presence of invisible organisms in the solution. He thought that experiments, such as no one had yet done, needed to be designed to resolve this question.

The notion of such a thing being possible in Euclidean space of an odd number of dimensions seems improbable, for reasons

5. One of the editions we consulted changes "utilize" to "ignore," but Vernadsky's manuscript says *"ispol'zovat,"* which means "to use."

that follow, if we assume that the identity of right-handedness and left-handedness is a geometric property of three-dimensional space. This is demonstrated by the identical stability of structures of matter made from the same chemical compound, with either right or left helical spirals of homologous atom points, completely filling the space. As long as right-handedness and left-handedness have not been studied as a geometric property of three-dimensional Euclidean space, I believe I may take this proposition as a premise in my reasoning.

But for radiation of a non-material nature, we have instances of three-dimensional space, in which such a division of right and left spaces easily occurs. Pasteur already drew attention to them, and thought that they could be used to create a medium for abiogenesis. A gaseous medium or a vacuum, illuminated by light with right or left elliptical or circular polarization, would be such a state of space. Here we are dealing with two separate media—right, or left. But living beings involve a material medium, not an energetic one. Only experiment can resolve the matter. Unfortunately, these relatively easily accessible phenomena have not been studied experimentally at all.



The five-fold symmetry of the starfish Ophiuroidea. *This photo was taken on the sea floor with an underwater camera.*

This being the state of our knowledge, it seems to me to be logically more correct, in geometric problems that have been basically empirically validated throughout the entire existence of humanity, and were constructed by humanity, not to equate, for solids, the material and energetic states of space with respect to their logical consequences.

Thus, I shall proceed from the assumption that the equivalent manifestation of right-handedness and left-handedness for natural bodies in the space they occupy is a geometric property of three-dimensional Euclidean space.

The absence of this equivalence, and the pronounced manifestation of left-handedness in the material substrate of living matter and of right-handedness in its functions, indicate that the space occupied by living matter may not correspond to Euclidean geometry.

Before taking up this subject, we must discuss the problem of the symmetry, characteristic of living matter.

7. The problem of the symmetry, characteristic of living organisms, absolutely cannot be solved within the bounds of the symmetry that was developed for crystalline bodies. This symmetry, which is so striking, must be expressed essentially in some other way.

The point is that in the morphology of living organisms, we do not see straight lines. Where we do encounter them, for example, in sponges or *Radiolaria,* it is when crystallization phenomena are involved. At the same time, we encounter here instances of five-fold symmetry, such as in starfish or *Ophiuroidea*.

This entire domain of phenomena, which clearly involves geometry and symmetry, remains at a standstill, and we have not found ways to express it mathematically.

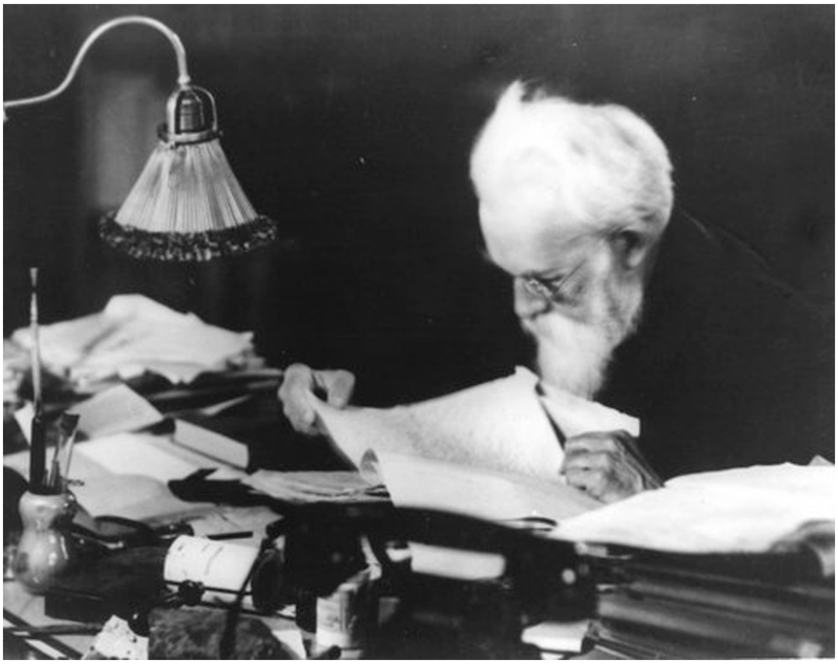
All investigators interested in the form of living organisms have turned their attention to two extraordinarily characteristic phenomena. The first is their dispersedness, meaning their sharp delimitation from their environment, in which they seem to represent bodies that are independent, constantly moving, and set sharply apart from their surroundings. It is as if they were special little alien worlds. Their sizes range from 10^{-6} centimeters to 10^{3} centimeters. Their delimitation from their environment is unusually pronounced, and is beyond any doubt. The states of space, occupied by the bodies of living organisms, differ fundamentally from the states of space of the inert natural bodies of the biosphere around them. Living organisms are created in the biosphere only from living organisms. Never from inert bodies of the biosphere.

The form of their delimitation is clearly regular and symmetrical, and they are always delimited by curved surfaces. There have been attempts to explain this form as a manifestation of particle forces, developing at the boundary of the gaseous and liquid medium in which the organisms exist and with which they are connected by the continuously occurring biogenic migration of atoms. Their form is unusually constant, extremely stable over historical time and unchanging in the course of geological time; for some living matter, it has remained unchanged for hundreds of millions of years.

This stability of form, which essentially expresses for us, in living matter, the continuous motion of atoms, and the dynamic equilibrium of atoms that is continuously maintained by that motion—in the form of an organism, rather than a mechanism—cannot be entirely determined, in a fundamental respect, by surface forces, but, rather, depends fundamentally upon deeper properties of matter (at the level of atoms or even isotopes). The general similarity with the way in which particle forces are manifested has to do with the fact that the matter of a living organism, in which liquid water predominates, is in a colloidal or mesomorphic state; only a portion of the dispersed particles within it are composed of crystalline matter, though these may play a very great role.

The symmetry that is observed, and the stability of minute morphological peculiarities over geological time, which is unusual in our experimental work, clearly show that deeper phenomena than particle forces are fundamental here.

It is therefore entirely legitimate to think that we are dealing here with a manifestation of deeper properties of matter, or, rather, with a form of manifestation of matter, other than the properties of atoms and isotopes, or physical-chemical properties in general.



Vernadsky in his office in Moscow in 1940.

It is also legitimate to advance and investigate the working hypothesis, that bodies of living matter are fundamentally determined by the geometric state of the space they occupy, which differs from the Euclidean space of the inert natural bodies of the biosphere.

This space cannot be Euclidean, if only because it lacks the equivalence between right-handedness and left-handedness that is inevitable for Euclidean three-dimensional space.

8. We may try to detect the geometric properties of this space. The following properties of Riemannian space suggest that it will correspond to one or several of the states of this space. Firstly, the fact that an infinite number of Riemannian spaces can exist. Secondly, that any Riemannian space is as if closed, but appears to be unbounded. In three-dimensional Euclidean space, it will appear as a sphere. Thus, it has no straight lines nor plane surfaces, but only curved lines and curved surfaces can exist.

As we know, the symmetry of living matter reveals itself geometrically in exactly this way within the inert three-dimensional Euclidean space of the biosphere.

The dispersedness of living matter, and the widespread occurrence of closed curved surfaces that are nearly spherical or geometrically related forms, entirely support the hypothesis.

But we can deepen the geometric representation of these Riemannian spaces that are characteristic of living matter.

9. Their characteristics must be:

(1) In forms corresponding to this geometry of bodies, straight lines and plane surfaces are relegated to a secondary level. At the fore are curved surfaces and curved lines. Obviously, in the simplest cases in three-dimensional Euclidean space, it is convenient to proceed from lines on the surface of a sphere and, instead of plane surfaces, sections of its curved surface.

(2) Vectors in this space must be polar and enantiomorphous.

(3) Right-handedness and left-handedness must be pronounced, and they are not equivalent geometrically or physical-chemically. Evidently, left-handedness predominates in the internal structure of living bodies.

(4) In such a space, time—just as much as physical-chemical processes—must be expressed geometrically by a polar vector.

(5) A number of very important consequences follow, which sharply distinguish the substrate of living matter, i.e., the state of its space, from the state of space of inert bodies. Expressed by a polar vector, time is irreversible in the physical-chemical and biological processes of this space; it does not go backwards. Consequently, entropy will not occur in matter here.

(6) But a vector in this space must not only be polar, since it is expressed in the physical-chemical and biological properties associated with matter. It must also be enantiomorphous, or else right-handedness and left-handedness would be impossible.

(7) This enantiomorphism is markedly different in phenomena that are "in the direction of the Sun's motion or against the Sun, which is connected to the inequality of right-handedness and left-handedness.

(8) The biosphere represents an envelope of the Earth, in which innumerable minute Riemannian spaces of living matter are included, in a dispersed way and a dispersed form, in the states of space of inert natural bodies with their three-dimensional Euclidean geometry. The connection between them is maintained only by the continuous biogenic flow of atoms.