SOVIET PHYSICS

USPEKHI

A Translation of Uspekhi Fizicheskikh Nauk

SOVIET PHYSICS USPEKHI (Russian Vol. 96, Nos. 1 and 2) MARCH-APRIL 1969

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PRESENT STATUS OF THE NATURAL SCIENCES AND PHILOSOPHY*

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Usp. Fiz. Nauk 96, 3–19 (September, 1968)

THE development of modern natural sciences has raised a multitude of acute philosophic problems which attract persistent attention of both philosophers and natural scientists. That is why, as a specialist in the domain of astrophysics, I was gratified to accept the gracious invitation to speak before the participants in the 14th International Congress on Philosophy. Of course, I am perfectly aware of the attendant difficulties. First, as Einstein used to say: "If you want theoretical physicists to explain something about the methods they employ, I advise you to strictly adhere to one principle: do not listen to what they say but instead study their actions."[1] This saying can, of course, equally apply to astrophysicists. Second, it should be borne in mind that natural scientists are not always sufficiently well-versed in the manifold subtleties of philosophy, since philosophy is a domain of its own which adjoins the problems of natural sciences only at some "boundary" zone. Nonetheless, since the philosophic problems of natural sciences at present are the subject of fairly frequent discussions among natural scientists, including those in the USSR, I shall take the liberty of expressing my opinion on some of these problems.

1. THE REVOLUTION IN THE TWENTIETH CENTURY NATURAL SCIENCES

A characteristic feature of present-day natural sciences is their penetration into unexplored or previously inaccessible domains of nature. This has led to a revolution in our ideas of nature. Theories previously considered universal proved to be applicable only within definite and fairly narrow limits. Many rooted dogmas, prejudices and superstitions that had been considered "unshakable" have now become relegated to the history of the natural sciences. Modern natural sciences have developed new fundamental concepts and theories, a new natural-scientific picture of the world that reflects more deeply the objective reality of nature.

Many discoveries of modern natural sciences have been extraordinary, intangible, contradicting so-called "common sense." "From the usual to the unusual, the strange," was how Lenin defined the path of the "latest revolution in natural sciences" while analyzing in his "Materialism and Empiriocriticism" the initial stage of this revolution, associated with the rise of modern physics. The subsequent development of the natural sciences proved the validity of this conclusion.

At present, physics, this past and present leader of the natural sciences is developing comparatively more "calmly" than in the early 20th century; for the time being the revolution in physics has come to an end. The outstanding accomplishments of the last three decades are based on the application of the already known concepts, laws, and theories of physics.

At the same time, the penetration of the methods and achievements of modern physics into other sciences—chemistry, biology, etc.—has resulted in their vigorous development, the rise of fundamentally new theories, which is quite correctly regarded as a continuation of the revolution in the natural sciences.

In this connection, it is fairly often stated that even now or in the immediate future biology is taking over or will take over the role of the leader in the natural sciences. But one can hardly agree with this. Of course, it is to be expected that the problems of biology, which currently attract increasing interest, may prove to lie in the focus of attention of the entire natural knowledge, as has at one time been the case with the problems of physics. However, there is no reason to expect that the solution of the extraordinarily complex problems associated with the elucidation of the nature of life requires the development of new fundamental laws and theories of physics.

While it has for the time being given up to biology its place as the most vigorously developing science, physics still retains its primacy of position as the foundation of all the other natural sciences, as a science in which any radical change inevitably affects all the

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*Presented at the 14th International Congress on Philosophy (Vienna, 1968) other sciences of nature.

Now as far as this whole subject of "leadership" is concerned, astronomy has a considerable chance of becoming in the future a genuine leader of modern natural sciences. Until as late as the last few decades the astronomers have been dealing with objects that actually have already been known for millenia: planets, comets, stars, scattered gaseous and dust matter. Now. however, objects of a fundamentally new type have been discovered in the Universe: galactic nuclei in which tremendous explosions are occurring, quasi-stellar radio sources (quasars), etc. Attempts to describe them from the standpoint of the currently known basic theories of physics encounter enormous and possibly insuperable difficulties. I believe that it is precisely of astronomy that we should expect, already in a not distant future, the discovery of new facts requiring the formulation of new theories of physics more general than those known at present. Concerning this subject, more shall be said in Sec. 3.

The principal attributes of modern natural sciences are often said to include their "mathematization," "cybernetization," "cosmization"; the authors who regard terms of this kind as superfluous are sometimes even accused of "conservatism." And yet, the introduction of these currently "fashionable" terms is expedient only in part.

Natural sciences have always strived, whenever possible, to investigate phenomena in their quantitative aspect by describing them mathematically. Of course, as the complexity of the phenomena investigated in the natural sciences increases, increasingly intricate mathematical apparatus is also being employed, and an increasing number of new domains of mathematics is finding application. But this does not signify any fundamental change in the tasks and methods of the natural sciences. Similarly, when they apply the term "cybernetization" to the utilization in natural sciences of the achievements of cybernetic engineering, which themselves are a consequence of the development of natural sciences, the proponents of this "fashionable" term state no real problem and limit themselves to fairly fruitless reasoning. Lastly, there is certainly no doubt that mankind's venture into outer space is a powerful stimulus to the development of all the natural sciences, since they are closely interrelated. But here, too, so far it has not been possible to discern any special tendencies that could be characterized by the term "cosmization."

Instead of using these terms, it is better to stress most emphatically the diversity and variety of the means, methods and orientations of scientific inquiry which in our time characterize all the natural sciences.

2. THE PROBLEM OF THE SUBJECT AND OBJECT OF COGNITION

The natural sciences in the 18th and 19th centuries proceeded from a number of gnosiological premises based, in the final analysis, on the philosophy of metaphysical materialism—on the passive, contemplative nature of the cognitive process, on regarding the external world itself, matter "in itself," as the object of natural sciences, on the possibility of achieving completely adequate, "absolute" knowledge of the objective reality.

In the course of the scientific revolution in the 20th century all these premises had been refuted, thus prompting numerous claims of the "collapse of materialism" and engendering a number of philosophic concepts in the spirit of positivism and subjective and objective idealism. However, metaphysical materialism cannot be identified with any materialism at all. More than 100 years ago Marx devised dialectical materialism, that new, higher form of materalsm, which was subsequently refined by Lenin.

From the standpoint of dialectical materialism, the phenomena of the external world have been existing prior to and independently of the consciousness of the individual and mankind. But the object of cognition is fragments, aspects, parts of the material world isolated by the subject of cognition (a subject construed as the human society regarded from a certain position) in the process of sociohistorical experience and "actively assimilated" by that subject. (Thus, the categories "matter," "object," "consciousness" and "subject" prove to be not identical.) The activity of the subject of cognition ultimately leads to an approximate reflection of the objective reality and knowledge; in the course of the development of science increasingly greater accuracy and adequacy of knowledge are attained.

Many aspects of the problem of the subject and object of cognition have in recent years been further elaborated in Marxist philosophic literature, and primarily in the works of S. L. Rubinshteĭn,[2], P. V. Kopnin,[3] and V. A. Lektorskiĭ.[4] Analysis of the problem of the subject and object of cognition in physics is dealt with in the studies M. A. Markov,[5] V. A. Fock,[6] M. É. Omel'yanovskiĭ,[7] S. G. Suvorov,[8] P. S. Dyshlevoĭ,[9] and others. These studies show convincingly that the ideas expressed by the founders of Marxist philosophy, particularly concerning the problem of the subject and object, have not become obsolete and even make it possible to analyze correctly that "gnosiological lesson" which, according to Bohr, modern physics has taught us.

When the proponents of subjective idealism, proceeding on the premise that the cognition of nature is possible only on the basis of an active interaction between subject and object, began to assert that thereby once and for all an end has been put to objective reality and to its existence independently of the subject, they actually, as elucidated in the studies named above, confused two different questions: 1) does objective reality exist outside the subject and independently of the subject? 2) how can objective reality be reflected in cognition?

If the activity of the subject at the empirical level of cognition is considered, then, of course, by organizing increasingly sophisticated experiments and observations, we are posing to nature an increasing number of questions, with the orientation of these questions depending both on the subject's scope of interests and on the existing system of knowledge. Thus an incalculable number of experiments is organized so as to receive an affirmative or negative answer concerning the prediction of one theory or another. This may be excellently exemplified by the observations during total solar eclipses, performed in order to discover the effect of the curvature of light rays in the gravitational field of the Sun, predicted by Einstein's general theory of relativity. There is no doubt that the orientation of our questions posed to nature should also definitely affect the nature of the general theories of nature, which are formulated on the basis of the answers received. However, it is well known that in the course of experiments and observations nature, on its own part, poses to the subject an increasing number of questions, some of them quite unexpected. For example, an astrophysicist studying the structure of distant galaxies wants to know of what star types familiar to us in our Galaxy they consist. Then suddenly these observations reveal bursts of supernovae, thus leading to the discovery of not only a new type of stellar "population" but also new processes of the liberation of gigantic amounts of energy in nature, processes whose actual nature represents a completely new problem. Another example: now we no longer are surprised to know that new types of elementary particles have been discovered in cosmic rays, and it is possible that some of them still remain undiscovered. But the first discovery of this kind—the discovery of the positron in 1932—was completely unexpected, as until then only two elementary particles, the proton and the electron, had been known. It seemed that no other particles could exist and the investigators of cosmic rays had not intended it as a goal to discover any new particles. Those who are poorly acquainted with the history of science may object that the existence of the positron had been predicted by Dirac and that physicists had been searching precisely for that predicted particle. But the discovery of the positron proved to be unexpected, because Dirac in his study erroneously identified with protons the "holes" he predicted and, until the discovery of the positron, theoreticians disputed the question of what, in that event, would account for such a great difference in the mass of the particle and the antiparticle.

These instances, fairly random as they may be, demonstrate how unexpected—from the standpoint of the original interests of the subject of cognition—may sometimes be the questions posed by nature. It also can happen that, in reply to fairly vague questions that we pose, nature answers by asking other, highly specific but difficult questions. Thus, when astronomers began to observe with the aid of radiotelescopes the monochromatic lines of hydroxyl in order to elucidate the spatial distribution of OH molecules in the Galaxy, almost at once they encountered extremely compact sources emitting radio waves in the same spectral lines, and thus there unexpectedly arose the highly interesting and difficult question of the nature of these objects.

Of course, the result of any correctly organized experiment is of definite value to science, but still it must be admitted that cases where nature provided answers unexpected by the investigator or itself asked even more unexpected questions have been cases representing the greatest impetus to scientific progress.

As for the theoretical level of cognition, mention should be primarily made of the change in the method of the description of nature which has occurred in modern physics. Quantum physics has shown that perturbances in the state of a microobject due to its interaction with a macroinstrument cannot be infinitesimally reduced. Hence the quantum system is simply not amenable to a classical description. In this connection, Bohr substantiated the need for a fundamentally new, quantum-mechanical (complementary) method of description.[10] This method of description was subsequently elaborated by V. A. Fock. The quantum-mechanical method of description is an enormous achievement of not only physics but the entire natural science, since it has made it possible with respect to an extremely broad range of qualitatively new phenomena to dispense with prejudices stemming from naive ideas based on everyday experience.

Thus, in this field, too, the attempts of natural scientists to apprehend a new domain of phenomena have not only produced unexpected answers but also led to an unexpected new form of the description of these phenomena. Physicists were yet again prompted to realize the persistence with which nature can compel us to abandon old theories and adopt new theories predicted by observation and experiment.

Modern theoretical physics operates with a growing number of domains of mathematics. Many of the domains of mathematics that have been conceived owing to the inherent developmental logic of mathematics itself, outside any relationship to physics, have in time proved necessary to the construction of the fundamental theories of modern physics (non-Eucliden geometry, tensor analysis, group theory). This development has sometimes been regarded as the "imposition" on nature of a number of intricate mathematical laws by the subject. It is obvious, however, that it is exactly the countless multitude of the new phenomena being discovered in nature and the resulting need to generalize the results of observations and experiments that necessitate an increasingly powerful and complex mathematical apparatus. It would be strange if a converse picture had been observed, i.e., if the increasing diversity of the investigated phenomena and laws of nature could fit a comparatively limited number of possible elementary mathematical schemes. Hence it is quite natural that certain types of mathematical theories which had originally been evolved within the framework of "pure" mathematics have in time begun to find various practical applications. A major factor here also is that mathematics is used by physics to develop increasingly broader theories and schemes. However, not every general mathematical scheme can find application in physics or in other branches of the natural sciences. For example, Riemannian geometry is only one of the many generalizations of the geometry of Euclid, yet it was precisely this particular geometry that has found application in the general theory of relativity, while the many other known generalizations of this kind have remained purely mathematical constructs. It is probable that many of the "hypothetical" geometries will simply remain just that, "free creations of human intellect."

Nevertheless, all this is no reason for underestimating the heuristic role of mathematics. Suffice it to mention, e.g., the works of Schrödinger who, proceeding from the empirically established spectrum of the values of energy of the atom, grasped that it is possible to find a differential equation for which this spectrum represents the solution of the eigenvalue problem. He derived the specific form of that equation from a number of additional considerations which may perhaps have been insufficiently rigorous from the standpoint of present-day theories of physics, but the heuristic role of mathematics in this discovery was highly significant. Nonetheless, what was decisive was the empirical fact that the spectrum of the eigenvalues of the energy of the atom directly resembled the spectrum of the eigenvalues of a differential equation. Even more interesting was Dirac's formulation of his electron equation, on the basis of which not only known properties were described but also, as was pointed out above, the antiparticle problem was raised for the first time (although, I repeat, originally Dirac had thought that the antiparticle with respect to the electron was the proton). Here we are dealing with a case where mathematical theory, unexpectedly to its author himself, proved capable of accounting for a previously unforeseeable group of phenomena.

Even more striking instances of the discovery of new phenomena on the basis of mathematical laws describing nature can probably be given. But does it mean that physics theories can as a rule develop without consulting experience and should find their "experiential" justification only "in the final analysis"? No conclusion could be more mistaken. In fact, consider again the instances examined above. The Schrödinger equation, like all the laws of quantum mechanics, made allowance for an enormous amount of the empirical data of atomic physics and represented their generalization. Dirac's equation was derived from the relativistic Schrödinger equation and some additional requirements imposed by the need to allow for the electron spin and to preclude all higher derivatives of time. This last requirement, in the final analysis, was also conditioned by experimental data. Hence Dirac's equation was a new, more accurate and logically more valid generalized description of properties of the electron. And there is nothing surprising in that this new generalization of a law of nature led to consequences which could not have been foreseen during the compilation of this equation. Thus history repeated itself, in a way; Newton's law was at first derived for the solar system which, as is known, has a highly distinctive structure, but it turned out to be also applicable to distant stellar systems.

Thus, the point is not that physical theories should be developed invariably on the soil of the method of "mathematical hypotheses," but that the laws of nature sometimes display a universality that greatly transcends the limited scope of the phenomena from whose investigation they happen to be derived. Numerous instances can be cited to show how the principal laws and patterns of nature have been derived exactly from the generalization of experimental data rather than from the construction of mathematical hypotheses. Consider also Heisenberg's testimony concerning Bohr's methods of research: "To Bohr the recognition of interrelationships proceeded not from a mathematical analysis of the *premises* on which theory was based but from an intense investigation of the phenomena themselves, which enabled him to sense these interrelationships intuitively rather than to derive them formally."[11]

The role of intuition in natural-scientific research is a question of great interest. Sometimes it is implied that intuition represents some kind of a special "vision" that lacks any objective basis. However, "prophetic" conclusions in natural sciences that are far ahead of their time most often are based on a thorough consideration of the available factual data and the ability to select from the broad gamut of possible explanations that explanation which is of some just barely perceptible interest compared with the others, being closer to truth. It is this ability to correctly assess the situation that represents intuition in the natural scientist.

Thus the present-day development of the sciences of nature and in particular of physics convinces us that, despite the steadily rising activity of the subject of cognition, the conclusions of these sciences, now as before, correspond to the objective reality existing outside and independently of the subject or, more accurately, they correspond to certain aspects of that reality.

Nature is infinitely varied in its manifestations, and the selection of the paths toward its study displays, as has been pointed out above, a definite ambiguity. Under these conditions natural sciences during every stage of their development can encompass only some particular domains of the phenomena of nature or rather, as a rule, particular aspects and features of these phenomena. True enough, the object of cognition in research into the natural sciences is steadily broadening and our knowledge of nature is becoming increasingly adequate, but this does not alter the fact that at any given moment natural sciences have been dealing only with a limited number of aspects of that part of the objective reality which has been isolated by the available empirical and theoretical means and represents the "world" of the natural scientist. The selection of these aspects of the study of nature is conditioned by the practical sociohistorical needs of mankind and by the conditions and logic of scientific progress.

The aspects of objective reality with which physics is concerned can be conveniently termed physical reality. In the field of quantum effects the concept of physical reality includes not only the microobject but also the conditions of cognition, as here we must allow for the finite extent of the interaction between the macroinstrument and the microobject. Many authors, referring to Bohr's previous works, speak of the presence of a "fundamental uncontrollability" of the interaction between the microobject and the macroinstrument. It should be noted that the term "uncontrollability" is not felicitous in this case, as it produces the impression that there may exist interactions not amenable to physical investigation. In fact, as Fock[12] has emphasized, what is concerned is the logical interrelationship between quantum-mechanical and classical methods of description, and conversion from the quantum to the classical language results in, as it were, loss of precision. This exactly was meant by Bohr when he spoke of "uncontrollable interaction." In his very last works he no longer employed this term.

In the domain of astrophysical phenomena the precision of information on the state of the investigated objects is virtually unaffected by the effect produced on this state by the instrument or observer. However, astronomy, along with such objects as the planets, stars and galaxies, is concerned with the entire system of galaxies, whose limits we have not yet reached. Therefore, both the various quantitative characteristics ascribed to this field and all of its theoretical descriptions provided by various cosmological theories are extrapolations which, while sometimes very bold, are not yet sufficiently fruitful. The special feature of the situation that has arisen in modern cosmology lies in that mathematical models constructed on the basis of the general theory of relativity are being introduced to describe the Metagalaxy, with the Metagalaxy itself being identified with the Universe as a whole.

It turns out that models of this kind can describe, to a certain approximation, some already known properties of the Metagalaxy. Recently they even have made it possible to describe a new fact—the presence of "relict" microwave radiation in the Metagalaxy and the energy distribution therein. We wish to lay special stress on this accomplishment, since only quite recently it still may have appeared that these models describe nothing outside the data that were used in their construction. Thus the ability of theory to describe even a single new fact should not be underestimated. At the same time this demonstrates that the aforementioned models represent not conclusive theories but merely the first attempts to construct a general theory of the Metagalaxy.

As for the question of the uniqueness of the Metagalaxy, it cannot be considered resolved. The data of modern astrophysics do not preclude the postulate of the existence of other metagalaxies. The only thing that can be stated is that so far we have no data on them nor on the methods of their relationship and interaction with our Metagalaxy. It is probable that these methods will prove to be completely different from the methods that we can conceive of as clearly as, e.g., we conceive of the interaction between two systems spaced a certain distance apart in euclidean space.

The problem of constructing and interpreting cosmological models leads us to the broader problem of the role of these models in cognition and of their adequacy to the object being modeled.

A given model may display formal perfection yet it may often turn out that it does not at all correspond to the object being modeled or that it satisfactorily describes only individual, inessential aspects of that object. This happens whenever the starting premises adopted for constructing the model are remote from the conditions corresponding to the real object. An interesting sample of this may be the model of the "Bohr atom" which, being based on a somewhat modified form of classical mechanics, described a specific and fairly narrow range of atomic phenomena. Strictly speaking, however, it did not adequately describe these phenomena, since the principles on which it was constructed were inapplicable to the conditions of the microuniverse. The possibility of constructing models very closely describing atomic phenomena arose only after the rise of quantum mechanics.

Another example. When A. A. Belopol'skii made his renowned discovery of the periodic variation in the radial velocities of the cepheids, a model attributing the observed phenomena to the binariness of these stars was proposed almost immediately afterward. Later, however, this model was found to differ completely from the statistical data on the variations in the radial velocities of the cepheids, established from observations. The inspired idea of the pulsations of the cepheids had to be conceived before it became possible to come closer to a real understanding of the processes occurring in these stars. The first models of the pulsations, based on the assumption of their linear nature, were very rough models describing only isolated aspects of the investigated phenomenon. Only the nonlinear theory of pulsations, which was developed in the most recent years, made it possible to describe them fairly adequately. But at this stage the pulsation theory was refined so markedly and, at the same time, it made it possible to turn attention such a large number of new facts that yet have to be interpreted, that astrophysicists now are talking not so much of models as of a mathematical description of the highly intricate phenomena occurring in the cepheids.

So far, the point has been that the assumptions underlying a model should be, insofar as possible, more appropriate to real conditions in the object being modeled. But the success of modeling decisively depends on whether the physical laws, patterns and theories that we employ, including the fundamental laws and theories of physics, are sufficient under the conditions being investigated.

The currently accepted form of the fundamental laws of physics is based on the study of the properties of matter over a broad but limited range of physical conditions. Under conditions that differ sharply from those already known, these laws may prove to be inapplicable and must be further refined and generalized, which will only enhance their significance and broaden the range of their applicability. And indeed, the laws of physics represent a generalization of a specific totality of factual data, expressed in a maximally elementary and terse form. However, this should not be interpreted as meaning that the system of the laws of theoretical physics, developed at some particular stage of scientific progress, is absolutely exact, complete and not subject to further generalization. These laws reflect only incompletely and roughly the objective reality and they can and should be further refined and generalized. (The refinement and generalization of the laws of nature usually both represent a unified process. For example, the transition from classical mechanics to the special theory of relativity represented both a refinement of classical mechanics and its generalization (extension) to the case of high velocities.)

Such a view derives from the analysis of the development of modern natural sciences which, as time goes on, uncover an increasing diversity of new, previously unknown phenomena that are qualitatively different from the phenomena with which these sciences had been concerned previously. To describe them we have already more than once been compelled to generalize physical laws and theories.

I wish to be correctly understood. When we are speaking of the possibility that even such well-substantiated physical theories as quantum mechanics and the special and general theory of relativity have only a limited range of applicability, this provides grounds for rejoicing to the people to whom these theories are too "strange" and greatly deviating from conventional concepts. Actually, however, we want to say that beyond the confines of the range of applicability of the currently known fundamental theories of physics there must exist even more extraordinary conditions whose description requires the creation of more general fundamental theories that are even more decisively divorced from the classical theories instead of representing some "return" to them.

When we criticize certain aspects of the application of the method of models in natural sciences, particularly in the form in which it is applied in astrophysics and cosmology, we, of course, do not wish to cast aspersions on that method itself. The point is simply that quite often the models are constructed without a preliminary (or parallel) analysis of their starting premises. It should be borne in mind that the construction of models is useful when it is based on a thorough investigation of factual data and, insofar as possible, sufficiently reliable postulates. The more accurately the degree of adequacy of the starting premises to the conditions in which a phenomenon occurs can be assured, the more valuable the model can be. The value of the model manifests itself most completely in that it makes possible the prediction of some new effects. It is known, for example, that astrophysicists have already for tens of years been working out models of the internal structure of the main-sequence stars on the Hertzsprung-Russell diagram—models based on premises that seem fairly reasonable to us all. But despite the gigantic volume of this work, although astrophysics is literally replete with unexpected discoveries, the modern theory of the internal structure of stars has not predicted any fundamentally new phenomenon that was later confirmed by observations. On the other hand, after new facts were discovered, they usually could be "reconciled" with theory by introducing more or less arbitrary complementary hypotheses. All this deprives the currently developed models of the internal structure of stars of a large part of their value and points to their inadequacy. This applies even more so to the "models of the Universe" in cosmology.

Thus, nature again proves to be richer and more varied than the ideas of nature evolved by the modern natural sciences, and the countless "surprises" which it springs on investigators cause the study of nature to be of surpassing interest.

3. THE PROBLEM OF THE UNITY OF THE PICTURE OF THE WORLD IN THE NATURAL SCIENCES

Until the early 20th century the idea of the universality of the laws of classical mechanics and the "reducibility" of all the other laws of nature to these laws was commonly accepted in the natural sciences. It was on the basis of this idea that the mechanistic picture of the world was constructed. Anything that, in quite a few natural phenomena, was not amenable to a mechanistic explanation was regarded as essentially unimportant and temporary.

The 20th century scientific revolution in the 20th century demolished these metaphysical views: it became perfectly obvious that the diversity of known natural phenomena cannot be constricted within the narrow mechanistic framework. On the other hand, the grandiose achievements of modern physics and its impressive applications have led to the conceit of believing that a somewhat new but again complete—at least in its general outline—unity in the natural-scientific picture of the world can be attained on the basis of the fundamental laws of modern physics, i.e., that the totality of known natural phenomena—physical, astrophysical, chemical, geological, biological, etc.—both those already known and those yet to be discovered, can be reduced to these laws.

Yet it is clear that although in the study of, e.g., the phenomena of life by methods of physics we are dealing with conventional physical processes, the extraordinarily intricate structure of the molecules and proteins as well as of the heredity substance of the chromosomes and of the cell as a whole determines a number of specific new qualities of living matter, qualities with which biology is concerned. (The application to these systems of Bohr's complementarity principle incurs major difficulties so far as the description of the state of these systems is concerned; their further investigation may lead to new methods of description adequate to systems of this type.)

To further consider the question of the possibility of "reducing" the phenomena of life to physics, we will dwell on two principal tendencies in the development of modern natural sciences. The first, which may be termed analytic or inductive, lies in reducing the investigated complex phenomena to elementary phenomena and, further, in finding the most elementary and at the same time maximally general laws of nature. For example, the diversity of the motions and perturbations of the planets has successfully been reduced to Newton's law of gravitation. Many properties of matter could be explained by the theory that in all of its three states of aggregation—solid, liquid and gaseous—it consists of molecules and atoms. The highly intricate structure of atomic and molecular spectra has been described on the basis of comparatively simple and general laws of quantum mechanics. The entire diversity of chemical compounds could be reduced to a mere hundred odd elements of Mendeleev's periodic table. Thus the analytic method has achieved victory after victory (sometimes prompting us, natural scientists, to believe that it alone is a genuinely scientific method for the cognition of nature).

But the history of the natural sciences in the last hundred years demonstrates that brilliant accomplishments in understanding nature often have also resulted from the use of the synthetic method, which originates from the tendency to deduce the laws of complex phenomena from the knowledge of elementary (often termed fundamental) laws of nature. This may be readily exemplified by the development of the kinetic theory of gases. It is patently obvious that examination of the behavior of an individual molecule is not a means of deducing the laws of ideal gases, whereas the statistical examination of an ensemble of molecules makes it possible to construct the kinetic theory of not only ideal but also real gases. Moreover, the ensemble, consisting of a large number of particles, displays new properties as a consequence of not only the properties of the individual molecule but also, to a much greater extent, of the statistical laws inherent only in the emsemble of particles (diffusion, heat conduction, etc.). From this simple example we see that the system is governed by laws that qualitatively differ from the laws governing its discrete components. Even more striking are the properties of bodies with ordered particle arrangements, as evidenced, in particular, by the phenomena of conduction, superconductivity, ferromagnetism. (And it would be incorrect to assume that research based on the synthetic method is not science but, so to speak, already the applications of science.) The synthetic method play a highly important role in astronomy. The theory of radiative transport in the gas nebulae, the theory of the internal structure of stars and the theory of stellar systems are examples of synthesis of this kind. It turns out that astronomy needs not only theoretical synthesis of systems consisting of atoms but also synthesis of, e.g., neutron and hyperon configurations of stellar masses, i.e., of configurations consisting of elementary particles.[13,14]

But while in astronomy synthesis is carried out on the theoretical plane and is intended to understand more deeply the investigated cosmic object, in laboratory physics, chemistry, and biology, along with theoretical synthesis a major role is played by the experimental realization of complex systems, both those previously examined in theory and those constructed by the trial and error method.

The higher the level of organization of a system is, the greater the extent to which the interrelationship and interaction of its components come to the foreground. As a result, the system displays increasingly complex qualities governed by laws which may prove so essential to the system that the elementary laws governing discrete parts of this system begin to play only a subordinate role. In this context, biological systems must be regarded as a result of natural synthesis leading to the rise of new properties compared with which the original physicochemical properties of the components of this system are trivial, and it is simply ridiculous to "reduce" living organisms to the simple sum of their component elements. (Of course, many less essential properties of living organisms can be obtained precisely by means of simple summation; e.g., the weight of the organism equals the total weight of its component elements, etc.)

The inductive (synthetic) tendencies in the development of the natural sciences have enormously influenced modern technology. Atomic boilers, semiconductors, fine chemical synthesis—such are the examples of the rise of entire new orientations of modern technology due to scientific discoveries. But there also exist instances where domains of science developed on the basis of the inductive method and already finding broad applications in technology continue to progress on the scientific plane. This may be exemplified by the development of lasers and masers. Probably the same situation will still long exist as regards protein synthesis.

Just as the analytic method, despite all its accomplishments, has not led and cannot lead to the establishment of some "final" and "most general" laws of elementary phenomena, so the accomplishments of the synthetic method, despite its enormous power and significance to the most varied domains of natural sciences, do not warrant the assumption that we are at the threshold of the synthesis of a "final," at least in its basic outline, unified natural-scientific picture of the world which would contain only minor "blank spots," particularly in the field of high-energy physics. Views of this kind, which now and then are expressed by a fairly large number of natural scientists, are just as naive as the proud confidence of physicists at the end of the 19th century that practically nothing important had remained to be discovered by the next generation in their science. Lord Kelvin was one of the very few who had perceived on the firmament of classical physics two "tiny" clouds: "the ultraviolet catastrophe" in the radiation theory and the negative result of Michelson's experimental attempt to discover the velocity of Earth with respect to the ether. But these two "tiny clouds" gave birth to such scientific colossi as quantum mechanics and the relativity theory! In our times a similar situation has arisen in astronomy.

Working on the theoretical synthesis of stellar systems consisting of a large number of stars, astronomers could apprehend many properties of stellar groups, clusters and galaxies. As late as at the end of the 1940s it seemed that the galactic nuclei also consist of stars alone. But observations showed that the phenomena occurring in these nuclei represent primarily gigantic explosions compared with which the bursts of the supernovae, which until then had been considered the most powerful processes of energy release in nature, seem child's play, and thus they could not be explained if the galactic nuclei were to be regarded as star clusters. It turned out that the composition of at least certain galactic nuclei contains hypermassive bodies capable of such explosions, bodies that differ from stars. At present there exist weighty reasons to believe that the processes conditioning these explosions can hardly be described within the framework of the known laws of physics. The same should be said concerning the processes of energy release in the quasars, discovered in 1963.

Those physicists who believe that the currently known fundamental theories of physics suffice to describe the entire diversity of phenomena in the Universe at first responded skeptically to facts pointing to the existence of an enormous energy potential in the nuclei of many galaxies and, whenever facts of this kind have been established completely reliably, they attempt to explain them from the standpoint of the known theories of physics, e.g., on the basis of the mechanism of gravitational collapse. But since new studies show that this approach is completely fruitless, their belief in the universality of the fundamental theories of modern physics literally hangs suspended in air. Here it is worth recalling Heisenberg's profound notion: "... The transition of the exact natural sciences from the already explored domains of experience to new domains will never signify the mechanical application of already known laws to these new domains. On the contrary, truly new domains of experience always will lead to the rise of new systems of scientific concepts and laws which are just as amenable to rational analysis as their predecessors but display a substantially different nature.''[15]

As we see it, the idea that the infinite number of the phenomena of nature can be apprehended on the basis of a limited number of fundamental laws and theories is inadequate. Nature is infinite in its diversity even as regards the level of its laws. That is, no matter how general and "final" may be the laws that we establish concerning the fundamental properties of matter, they always in principle have only a limited range of applicability. Therefore, any unified natural-scientific picture of the world represents only a relatively complete theoretical synthesis of knowledge and, as further advances are made in the study of nature, it will be superseded by new but always only relatively complete "unified pictures of the world" of an increasing generality and accuracy.

4. THE PROBLEM OF EVOLUTION OF THE UNIVERSE IN MODERN NATURAL SCIENCES

It is well known that the path for the idea of evolution in natural sciences was blazed as early as at the end of the 18th century. We are referring to the famous cosmogonic hypothesis of Laplace, whose historic significance is difficult to overestimate. However, the concrete form of the idea of evolution in the natural sciences of that era—the form of mechanistic evolutionism—was still highly incomplete. Moreover, many investigators who perhaps unconsciously were strongly influenced by instances of cyclic (periodic) succession of phenomena well known from daily life (succession of days and nights, succession of seasons of the year, seasonal changes in nature, etc.), regarded evolution as a mechanistic cycle of integration of the systems of certain "simplest" elements followed by their disintegration into the same elements, with each evolutionary cycle culminating in the return to its point of departure. To be sure, the further penetration of the ideas of evolution into the natural sciences gradually undermined both mechanistic evolutionism (here the rise of Darwin's theory and subsequently of the mutation theory was of tremendous significance) and the theory of the mechanistic cyclicity (owing to the discovery of the principle of the growth of entropy and its application to an increasing number of increasingly varied systems).

Nevertheless, mechanistic evolutionism found refuge in certain domains of the natural sciences until as late as the end of the first third of the 20th century, e.g., in astronomy, where certain specific difficulties of the investigation of cosmogonic processes and the lack of a sufficient quantity of empirical data resulted in the rise of a myriad of unsubstantiated and often heuristically valueless "cosmogonic hypotheses." These hypotheses assumed that all the states of the heavenly bodies are nearly stationary, so that their evolution consists in a smooth, extremely slow transition from one stationary state to another.

Pursuant to tradition dating from the cosmogonic hypotheses of the 18th and 19th centuries it was assumed that all heavenly bodies originated from some formerly existing tenuous nebula. The fact that in our Galaxy we have not observed any very large masses of diffuse matter and that an overwhelming part of its matter is concentrated in the stars signified from this standpoint that the formative process of the stars of our Galaxy has in the main come to an end during some distant epoch in the past and that the Galaxy in its present-day state does not undergo any rapid evolution accessible to observation.

Clearly, however, when studying the evolution of some object or another it is particularly important to proceed not from a priori assumptions but from an analysis of the object's properties isolated on the basis of the generalization of observational data, since each level of the material world corresponds not only to its own particular structural laws but also to evolutionary patterns differing from the other levels.

It is also clear that the pattern of development of an object at any structural level of the organization of matter can be conditioned by factors that are hardly perceptible during the examination of stationary, equilibrium states of the object, so that special attention must be devoted to the search for and study of nonstationary, non-equilibrium states of various objects, the more so considering that astronomy has already comparatively long ago discovered many types of cosmic bodies in which relatively rapid changes, sometimes of a catastrophic nature, are occurring.

We first commenced research based on a consistent application of this approach in the 1930s at the Leningrad University and we are now continuing it at the Byurakan Observatory. This research has resulted in the formulation of new theories of the rates and paths of the evolution of many types of stars and stellar systems.

Analysis of observational data on the stationariness and nonstationariness of the stars and stellar groups existing within the Galaxy showed that our Galaxy, contrary to previous commonly accepted theories, is a system in which turbulent and sometimes extremely rapid changes are occurring.

The application of the principles of stellar dynamics to the discovered star clusters led to the conclusions that even if these clusters exist in a "stationary" state, owing to interaction between the stars they must "evaporate," as it were. As a result of this process, many clusters should disappear within as little as several hundred million years and some of them even within several tens of millions of years.

The totality of the visual binary stars in the Galaxy was subjected to a similar analysis and it turned out that the processes of the disintegration of the binaries, occurring owing to their encounters with stars in the surrounding field, predominate over the processes of the formation of new binaries during random rapprochements between stars.

The number of single stars in the overall star field of the Galaxy is steadily growing owing to the disintegration of the star clusters and visual binary stars, and this process occurs only in one direction. Thus, disintegration and dissipation (in perfect accord with the second law of thermodynamics) characterize the general orientation of processes in our Galaxy and, as it turned out subsequently, also in other galaxies.

Our studies also formulated the concept of the "short scale" of the age of the Galaxy and its component stars.[16] The "long scale," adopted in the early 1930s, presupposed that the age of stars in the Galaxy is 10^{12}-10^{13} years. But the discovery of the inevitable disintegration of star groups and clusters over comparatively short periods of time demonstrated that the Galaxy in its present state cannot be of an age exceeding (in order of magnitude) 10^{9}–10^{10} years.

During the 1930s-1940s new important data were obtained concerning the orientation of the processes in star systems and the age of the stars in the Galaxy.

Facts showed that the formation of nebulae from stars is a fairly widespread phenomenon. By contrast, so far we do not know of a single instance where a compact object would take form from diffuse matter although transitions of this kind, assumed in the old cosmogonic hypotheses, are also presupposed in many cosmogonic theories popular to this day.

As a result of the work of the Byurakan astronomers in the late 1940s the existence of a new type of star systems—stellar associations—recently arisen groups of stars disintegrating directly after their birth, was established.[17] Most of these systems proved to be nonstationary in the complete meaning of that term, since their component stars rapidly recede away from each other. Thereby also our Galaxy has proved to be nonstationary, since the process of the formation of new stars (in the form of stellar associations) continues in it during the present era.

At the same time, this discovery was a strong argument in favor of the theory of the dissipation of matter from primordial small volumes as a most important part of the process of cosmic evolution. Besides, observations still have not provided any indication of the possibility of transition from a diffuse state to a dense state.

Further studies, particularly in the field of extragalactic astronomy, led to the discovery of numerous new proofs that the processes of evolution in the Universe are associated with the dissipation of matter, i.e., with transition from a more dense to a less dense state, contrary to the obsolete theories of the condensation of cosmic bodies from rarefied matter.

The existence of a considerable proportion of clearly nonstationary groups and systems also in other galaxies and galactic groups and clusters was demonstrated in the 1950s. It was discovered that numerous galactic groups and clusters display a marked variance of velocities, which points to the instability of the corresponding groups. To account for this phenomenon the following theory was advanced: the galaxies of each cluster from the moment of its formation have been endowed with such great velocities that the forces of mutual attraction are insufficient to preserve the cluster as a system. Moreover, it turned out that among multiple galaxies the proportion of unstable systems of the Trapezium type is many times as high as among multiple stars. In other words, instead of isolated manifestations of nonstationariness we observe ubiquitous processes of the disintegration of galactic groups and clusters.[18]

New vistas for the study of nonstationary phenomena in galaxies were opened by the discovery of the radiogalaxies, which are distinctly nonstationary objects capable of radio emission only during short intervals of time. Although the duration of their radio emission is measured in millions of years, this span of time still is short compared with the age of the galaxies. In other words the radiogalaxies represent a brief, passing stage in the evolution of galaxies.

It was precisely the study of the radiogalaxies that resulted in substantiating the idea of giant explosive processes occuring in the galactic nuclei. If the stage in the life to a galaxy during which it is capable of intense radio emission is termed the radio burst of the galaxy then, as has been shown, this radio burst is a result of a gigantic explosion within the galaxy's nucleus. The theory of explosions in galactic nuclei had at first encountered tremendous resistance from those astronomers who persisted in the belief that cosmic evolution consists primarily in the condensation of diffuse matter. To counter this theory, the completely unsubstantiated hypothesis that galactic collisions are the cause of radio bursts was proposed and had gained wide popularity. It took almost ten years before this invalid and sterile hypothesis could be entirely discredited in the eyes of science. However, even the proponents of the theory of explosions in galactic nuclei had not expected the direct proofs of this theory, which were found already in the early 1960s with the discovery of an explosion that had occurred only 1.5 million years ago in the nucleus of the galaxy M82 as well as owing to the study of the motions in the perinuclear regions of the so-called Seifert galaxies. By the same token, the concept of the cosmogonic activity of galactic nuclei, which had been introduced somewhat earlier, was substantiated. A further proof of these ideas was the discovery of the quasistellar radio sources (quasars).

When studying nonstationary processes in galactic nuclei and quasars we are dealing with the study of a concentration of huge masses within relatively small volumes. This concerns masses of the order of 10^{10} (and sometimes even more) solar masses, condensed to volumes only a fraction as large as the volume of any star cluster. This concerns transformations of matter during which density changes by a factor of billions and the intensity of the gravitational field may reach incredible magnitudes. As was pointed out above, there is not and cannot be any guarantee that the laws of physics known to us are observed under these conditions either. Thus it would not be surprising if it turned out that the currently existing great difficulties of the theoretical interpretation of a number of nonstationary processes may in time reach an extent at which they will directly contradict the known laws of theoretical physics. Attempts to mathematically formulate part of these processes were first made by Jordan.[19] He assumed that his constructs pertain to the origin of the stars. Actually, however, they probably are more applicable to the question of the origin of galaxies.

Thus, although the duration of cosmogonic processes in most cases is large compared with the period of astronomic observations, in the life of cosmic bodies and their systems there also exist stages during which, in the course of the process itself of evolution, new forces radically altering their state arise in them. The rapidity of the attendant changes makes it possible either to observe these changes directly (bursts of novae, supernovae, etc.) or to infer pertinent conclusions on the basis of highly explicit indirect data (disintegration of open star clusters and stellar associations, explosions in galactic nuclei).

A curiosity intriguing from the standpoint of the history of science is worth noting: those astronomers who failed to understand the role of nonstationary objects in cosmic evolution usually have been prone to shut their eyes to the difficulties associated with their interpretation, regarding them as some "monstrosities" outside the pale of the general laws of evolution.

Yet the view that proved to be correct was the contrasting premise that nonstationary processes represent legitimate stages of cosmic evolution, although at any given moment the percentage of cosmic objects undergoing an unsteady-state stage of evolution is usually low and at any rate much smaller than the percentage of objects existing in stationary state (e.g., the number of stars in associations is small compared with the number of stars in the overall field of the Galaxy).

Nonstationary states usually represent a turning point in the evolution of an object, associated with the birth of new bodies (e.g., stellar associations) or with the transition of the object from one class to another (e.g., bursts of supernovae leading to the transformation of the star into a nebula).

Hence a detailed analysis of the nonstationary or transient phenomena has unlocked the prospects for a broader understanding of the evolution of cosmic objects. In fact, until the mid-1930s when the first important data on nonstationary objects had been obtained, evolutionary ideas had not played an essential role in astrophysics, although most astrophysicists were perfectly aware that they were dealing with changing, evolving objects. And if today the entire astrophysics has found itself to be literally permeated by the concept of the evolution of stars, star clusters and galaxies, this has undoubtedly been a result of the devotion of greater attention to the study of nonstationary objects in the Universe.

Present-day cosmogony demonstrates that a most important feature of the processes of the evolution of cosmic objects is their irreversible nature. If any cyclic changes occur in them at all, it is only as elements of the overall irreversible change in their structure. Essentially, when the evolution of some system or other is considered in the natural sciences, it is precisely an irreversible change in its structure, which in a number of important but particular cases takes the form of progress or retrogression, that is meant.[20]

Thus, the revolution in the natural sciences of the 20th century has made topical, among others, such philosophic problems as the problem of the subject and object of cognition, the problem of constructing a unified natural-scientific picture of the world (inclusive of the question of the degree of universality and limits of applicability of the fundamental laws and theories of modern physics) and the problem of cosmic evolution. The conclusions inferred from analysis of these problems tally with the basic postulates of dialectical materialsim. The fact remains a fact: the philosophy of dialectical materialism has been assisting and continues to assist many natural scientists, among whom I count myself, in conceptualizing a number of different problems. Of course, this philosophy does not represent a dogma or a universal prescription for all the instances in life. It is a particular mode of thinking which can lead to interesting and fruitful results. That is why I am at one with those authors who regard as necessary a close collaboration between philosophers and natural scientists in the solution of the fundamental problems of the sciences of nature.

In conclusion, I wish to express my profound gratitude to Cand. Phil. Sci. V. V. Kazyutinskiĭ who took a most active part in drafting this paper. The only reason why this paper is presented in my name alone is that, in the final analysis, it is I who am responsible for the views expressed therein.

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Translated by E. Bergman