Lenin and Modern Natural Science

PART I. GENERAL PROBLEMS OF THE PHILOSOPHY, METHODOLOGY AND HISTORY OF THE NATURAL SCIENCES

PART II. PHILOSOPHICAL AND METHODOLOGICAL PROBLEMS OF THE PHYSICAL SCIENCES

PART III. PHILOSOPHICAL AND METHODOLOGICAL PROBLEMS OF THE BIOLOGICAL SCIENCES

PART IV. THE PHILOSOPHICAL PROBLEMS OF THE EARTH SCIENCES

PART V. PHLOSOPHICAL AND METHODOLOGICAL PROBLEMS OF CYBERNETICS

LENIN AND MODERN NATURAL SCIENCE

This book elucidates the creative role of Lenin's philosophical ideas in the study of modern problems of natural science, in the solution of problems of the sciences of nature that are significant for methodology and world outlook. The articles included in the book are original investigations stimulated by Lenin's ideas. Most of the book deals with the philosophical aspects of modern physics, astronomy, the earth sciences and cybernetics. Of considerable interest is the study of philosophical problems in genetics and the essence of life.

Lenin's philosophical ideas are applied in the book to the development prospects of the natural sciences, to the analysis of the problems of modern scientific knowledge, and to the discussion of questions in the history of natural science.

Prominent Soviet philosophers and natural scientists, as well as outstanding foreign scholars, have made contributions to the book.

S. HARRISON

Lenin and Modern Natural Science

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M. E. OMELYANOVSKY

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PREFACE

This book, presenting modern problems of the natural sciences in the light of Lenin's ideas, is not only a tribute to the memory of an outstanding statesman and a scholar of genius; it also shows that Lenin's ideas and science today are inseparable.

Lenin's works are a great creative force. They are the spiritual weapons of mankind in the struggle against all oppression and slavery. Lenin linked seemingly abstract philosophical propositions with the revolutionary activities of the most revolutionary class in history, and revealed the great significance for all branches of science of the dialectical materialism created by Marx and Engels and further developed in his own works. This preface need not go into the details; the authors of this book have described, in their own ways and in detail, the influence of Lenin's ideas on the development, prospects and history of science, on the formation of the modern scientific world outlook, and on the methodology and the spirit of contemporary natural science.

Each of the authors is a prominent specialist in the particular field whose problems he made it his task to outline. There are outstanding originators of present-day natural sciences among them, too. It is therefore all the more significant and interesting that all of them regard dialectical materialism as the basis for understanding the philosophical problems posed by present-day developments in the natural sciences.

Marxism is not a dogma, but a guide to action. This was a favourite idea of Lenin's, and it determines the approach to the study of the problems treated in the book. Inevitably, the views of the authors do not entirely coincide on some problems relating to the philosophy and methodology of the present-day natural sciences. Certain problems and propositions handled in the book do, of course, require further constructive discussion. Marxist-Leninist philosophy is a living philosophy which develops and enriches its content with every great discovery in science, and we hope that the book brings out this point graphically and convincingly.

Part I

GENERAL PROBLEMS OF THE PHILOSOPHY, METHODOLOGY AND HISTORY OF THE NATURAL SCIENCES

P. N. Fedoseyev

LENIN'S IDEAS AND THE METHODOLOGY OF CONTEMPORARY SCIENCE

As the role of the natural sciences in the development of production in this age of scientific and technological revolution increases, as sciences become ever more ramified and interdependent, and as scientific information is accumulated at an extraordinary rate, so there is a growing need for a philosophical generalisation and interpretation of new scientific data, together with an interest in methodological problems. The fundamental principles for the solution of these problems are to be found, even today, in the ideological legacy of Lenin.

Lenin's basic methodological ideas are not becoming obsolete under the impact of the rapid progress of scientific cognition in recent times; on the contrary, they are becoming increasingly significant and relevant. This is primarily due to the shrewdness of Lenin's genius, the genius of a dialectical thinker, in determining the essence of the profound revolutionary changes and basic trends in the development of modern science. In his fundamental works *Materialism and Empirio-Criticism, Philosophical Notebooks* and others, we find a philosophical generalisation embracing a whole era in the development of science and, more important still, exceptionally significant methodological projections of the future advance of science. The fundamental nature and the growing significance of Lenin's idea of the inexhaustibility of the electron for the methodology of contemporary theoretical physics are becoming ever more apparent. The objective logic of the development of science demonstrates the relevance of Lenin's ideas.

The present-day revolution in the natural sciences is a continuation of the revolution that began early in the 20th century. The results of the initial stage of the revolution were generalised by Lenin; these fundamental generalisations have proved to have great significance as guidelines for the methodology of science at present as well. Indeed, Lenin's theses as to the necessity of dialectics for physics, the inexhaustibility of matter, the relationship between absolute and relative truth, and others remain topical for present-day science too. Moreover, what had been primarily applicable to physics spread to other fields of knowledge as well. The categories of philosophy must, of course, take into account the whole of the steadily growing spectrum of the content of contemporary science.

The new era in the history of social progress initiated by the victorious October Revolution has brought out in vivid relief the dialectics of social development. But, at the same time, this era in the history of science is marked by the strengthening of the creative links that Lenin perceived between dialectical materialism and the natural sciences.

The Progress of Natural Science and the Development of Dialectical Materialism

If one is to be guided by the creative spirit of Lenin's ideas on the methodology of science, upheld by all the genuine Marxist-Leninist parties, one must recognise that the essence of Lenin's behests concerning methodology is expressed in his appeal that materialist philosophy should be developed dialectically, in accordance with advances in the scientific cognition of the world and in practice.

Lenin invariably emphasised that dogmatism and ideological stagnation result inescapably in narrow-minded sectarianism and vulgarisers' attempts to substitute yesterday's slogans for scientific analysis of today's, reality, in losing touch with reality, and in adventurism in theory and practice.

Philosophy can influence science only if it is creatively perfected and adapted to the requirements of the rapidly

advancing natural sciences of our times. Of course, this task cannot be accomplished unless the philosophical problems are worked out, philosophical concepts analysed, and the history of knowledge and of philosophy profoundly studied. We are, however, dealing with the problem of ensuring the most fruitful co-operation between philosophy and the natural sciences under the conditions of the modern scientific and technological revolution. Attention is naturally focused on the age-old problem of elucidating the historical and logical relationship between philosophy and the natural sciences. The main problem here is the way in which dialectical materialism can facilitate further progress in the natural sciences, as well as the way in which the achievements of fundamental sciences can be used for the development and enrichment of materialist philosophy itself.

At the present stage an ever growing role in the solution of these problems is attributed to the analysis of the actual achievements of the natural sciences, the real processes of co-operation between philosophers and natural scientists, and the prospects of strengthening this co-operation. Essential for increasing the effectiveness of the alliance between the natural sciences and philosophy is the correct understanding of the process of the development of dialectical materialism, and of the fundamental fact, many times emphasised by Lenin, that the genuine perfection of Marxist philosophy proceeds on the basis of the primary principles of materialism and dialectics, in the struggle against all possible forms of bourgeois ideology.

In this connection, the question is sometimes posed: can one say that the creative approach to philosophy ultimately presupposes the substitution of some old or new "ism" for dialectical materialism? This formulation of the question is clearly untenable, as it contradicts experience. To develop 20th-century philosophy, one must develop dialectical materialism.

The attempts to negate the basic tenets of materialism, such as the proposition about the primacy of matter and the theory of reflection, are fundamentally alien to scientific cognition. Categories and concepts elaborated by the contemporary natural sciences cannot be opposed to the categories and principles of dialectical materialism. Reactionary philosophers, as of old, are attempting a revision of the concept of matter, negating its objective content. They are trying to set up an opposition between the theory of reflection and the method of modelling that is so widely and fruitfully used in science. They are attempting to bring into collision the concepts of information and feedback with the dialectical notions of interconnection and interaction, to replace the concept of the material object with that of structure, and so on. The relationship between the concepts of the natural sciences and the categories of dialectical materialism should be given comprehensive consideration. Taking into account the progress of concrete sciences, it is essential at the same time to develop the fundamental concepts of dialectical and historical materialism, bearing in mind the need to defend Marxist philosophy and intensify the struggle against bourgeois ideology.

The Marxist thesis concerning absolute and relative truth is fully applicable, of course, to philosophy itself. As Engels pointed out long ago, the more complicated the field of knowledge and the further we depart from immediately perceived material objects, the fewer absolute truths we encounter. It is beyond question, however, that materialist philosophy has, in the many centuries of its development, elaborated a number of principles that serve as the basis for the further development of knowledge. We would be inveterate dogmatists if we did not perceive the relative nature of many concrete propositions of philosophy or the need for their development or specification. But we would fall victim to relativism and, ultimately, idealism if we assumed that the development of philosophy presupposes a negation of its fundamental and unshakeable principles. Such principles do exist. We uphold these principles and uphold them we must, in the interests of scientific knowledge itself and in the interests of truth.

One is familiar with Engels's proposition, commented on and developed by Lenin, to the effect that, with every major discovery in the field of natural science, not to mention

social life, materialism must assume a new form or change its form. But neither Engels nor Lenin meant, of course, major discoveries in general, of the type that are made every year. What they meant were those discoveries that radically transform our concepts of reality. It is these epoch-making discoveries that enrich materialism.

Thus, the important work of genuinely scientific development of philosophy under the impact of new scientific data and practice, just like any other serious undertaking, does not admit of a flippantly sensational approach, going first to one extreme and then to the other, and liable to revise thoughtlessly even the fundamentals of our world outlook, leaving unanalysed the facts on which such a revision is based, being at times under the short-lived influence of transient episodes in the development of knowledge and reality itself. One must emphasise that the scientific development of materialism presupposes the conservation and, moreover, the consolidation of its content. As Lenin figuratively put it, Marxist philosophy is integral, "moulded out of one piece of steel."

It would be wrong to formulate the problem as follows: since Marx in his famous *Theses on Feuerbach* criticised the old materialism primarily for being contemplative and for underestimating the activity of the subject, and since the role of this activity in the transformation of being has grown enormously in the 20th century, one should entirely give up the view of the world as objective reality and treat it as activity. Would this be a development of scientific philosophy? The answer is definitely no.

Having built the "upper storeys" of materialism, i.e., having laid the foundation for the materialist understanding of social life, over and above the understanding of nature, Marx proved that social life is essentially practical and declared practice to be the basis of history and human cognition, and the criterion of truth. Early in this century, Lenin developed these theses in his remarkable books *Materialism and Empirio-Criticism* and *Philosophical Notebooks*. Continuing this Marxist-Leninist tradition, the materialists of the second half of the 20th century must declare: however powerful human activity may become in its world-transforming potential, being will never be reduced to that activity. After all, activity is the energetic attitude that man adopts towards the real situation around him. The effectiveness of activity depends on the subject's ability to profoundly reflect reality. Ignoring this fundamental requirement of materialism inevitably results in voluntarism and adventurism.

Science is effective only inasmuch as it correctly reflects both the present-day state of affairs and the trends of the further development of objective reality. Here, one must touch on a widespread misunderstanding. A well-known thesis from the *Philosophical Notebooks* is often quoted: "Man's consciousness not only reflects the objective world, but creates it." However, there is a tendency to ignore the fact that Lenin is here summarising Hegel's ideas on the transition of the concept or idea into practical action. The materialist interpretation of this thesis, according to Lenin, is "that the world does not satisfy man and man decides to change it by his activity".[1] We should be failing to carry out Lenin's behest about materialist re-evaluation of Hegel if we confused Hegel's idealistic statements with their materialist interpretation.

Is the argument valid that only the dialectics of "humanised nature" can exist, i.e., of nature that has been assimilated by man, and that it is unjustified to project the results of this dialectics on to the whole of nature? In his argument against this contention, Lenin showed that the thesis concerning the materiality of the world can, with every justification, be extended to the whole of the world, including those fields where practice and knowledge have not yet penetrated.

Mistakes also happen sometimes in the analysis of the present-day state of the problem of the relationship between materialism and humanism. One must not oppose them to each other or substitute the latter for the former. It would be a mistake to contend that modern natural science—which

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[1] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works*, Vol. 38, p. 212.

has broken through into outer space and the microworld, which is coming nearer to synthesising living protein and revealing the secrets of the cell, and which has created logical machines—can be based on naturalist humanism and not materialism.

True humanism can only be based on true materialism. Any other approach means a retreat from scientific dialectical materialism to pre-scientific anthropological materialism. In criticising Feuerbach and, to some extent, Chernyshevsky for their anthropologism and their abstract teaching on man, Lenin showed that the anthropological principle is nothing more than an inexact and weak description of materialism.[1] The truly scientific solution of the problem of strengthening connections between the subject and the object lies in the development of the teaching of man (the subject) in the light of 20th-century materialism rather than in a return to 19th-century materialism.

In dealing with the development of materialism, it is important to note that both Engels and Lenin had in mind a revision of propositions pertaining to philosophical generalisations of natural science induced by major discoveries, and not a revision of the principles of materialism themselves. That was what Lenin meant by "revision". Of course when one speaks of the development of Marxist philosophy, one also has in mind the development of its basic concepts, the development of laws and categories, as well as an understanding of their interconnection, in other words, one is dealing here with the development of method or general methodology as well as the development of the world-outlook basis of science. The main task of philosophers in this respect is the materialist interpretation, in collaboration with natural scientists, of the new concepts and data provided by the natural sciences.

To corroborate this thesis, it will be useful to cite some examples. Consider the concept of structure, which is accorded a most important status in the natural and other

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[1] V. I. Lenin, "Conspectus of Feuerbach's Book *Lectures on the Essence of Religion*", *Collected Works*, Vol. 38, p. 82.

sciences, and which reflects the character of the connections between the elements of some integral system. Of course, the simplest procedure would be to add this category to other philosophical categories and be content with this sort of development of dialectical materialism. Or one might view this category as exclusively scientific, having no bearing upon philosophy, and make up the list of philosophical categories without taking account of the appearance of such a category. The history of philosophy shows, however, that the development of materialism did not proceed in this manner, through the mechanical incorporation of natural scientific categories into philosophy or through their neglect.

Let us consider in this respect the evolution of the understanding of the material object from the point of view of the dialectical relationship between its form and content.

In ancient philosophy, e.g., in Aristotle, form was perceived as the active principle, creative and constructive, whereas matter was believed to be passive. When the mechanistic world outlook gained the upper hand, form came to be interpreted as the outer integument, a configuration of the material object having no connection with its inner essence, its structure.

Dialectical materialism formulated the problem of form and content in quite a different way, and the understanding of the material object became much more profound: form was interpreted as the inner structure of content and not as the outer shell. If we consider the classical works of Marxism, we can see the concept of structure aptly and effectively applied to the analysis of social phenomena. And that happened long before the concept of structure acquired an essential and universal significance in present-day science.

Thus, in Marx's *Capital* the concept of the economic structure of society is, one might say, the basis of theoretical analysis. On this basis, Marxism analysed and developed such concepts as the social and class structure of society. In general, it is nowadays impossible to analyse social phenomena without having recourse to the concepts of the social structure, class structure or economic structure of a society. Thus, when bourgeois sociologists claim to have discovered

the concept of structure in the form of the structural or systems-structural approach, etc., that has nothing to do with the real state of affairs.

Today dialectical materialist research into the concept of structure is continued by natural scientists and materialist philosophers working in close collaboration. One can refer, for instance, to the book, *Structure and Forms of Matter*, published in 1967 by the USSR Academy of Sciences as a volume in the series *Dialectical Materialism and the Present-day Natural Sciences.*

Numerous problems arise in the border area between cybernetic and philosophical studies. The philosophical interpretation of the new principles and concepts introduced into science by cybernetics is the main issue.

The results achieved in the quantitative description of such phenomena as information and control do not remove the problem of their qualitative analysis. Cybernetics extended the concepts of information and control, previously restricted to man's conscious activity, to all processes of information communication and control. A scientific study of functional systems permits of the similar application of such concepts as plan, goal, goal setting, decision and some others, reflecting the objective character of the goal-directed behaviour of all functional systems.

The significance of the philosophical investigation of these concepts is beyond doubt, and it should be encouraged in every way, as dialectical materialism itself will be enriched in the process and definitions of its categories made more precise.

The application of the basic principles and concepts of cybernetics and information theory to the development of the Marxist-Leninist theory of reflection seems to be of great significance. More than 60 years ago Lenin formulated the task of studying the ways in which matter that is supposedly insensitive is connected with matter that is made up of the same atoms (or electrons) and yet possesses a clearly expressed capability of sensation. An important role in the solution of this complex scientific problem is played by the cybernetic approach to the study of life and the psyche, the propositions of Lenin's theory of reflection serving as methodological guides.

The philosophical analysis of the basic principles and concepts of cybernetics creates one of the most important premises for the study of the genesis and mechanism of active reflection, for research into the essence of the qualitative leap in man's creative activity and the activity of social systems, and for the solution of the problem of the ideal, which is the main issue in the struggle between materialism and idealism.

Recently, philosophical studies of modelling have acquired great significance. It is important to bear in mind in this connection that there are no grounds for opposing modelling and the theory of reflection to each other. What we are facing here is something quite different, namely, the need for philosophy to take into account the rapid progress of modern science, the process of the birth of new notions and new concepts, and the need to cope with these concepts and theories, i.e., correctly interpret and generalise them. This is made possible by the objective flexibility of dialectical materialist philosophy, which does not, however, become relativistic. That is why it is impossible to analyse and present philosophical categories in the way it was done in the 19th and the early 20th century.

Materialist philosophers and natural scientists must enrich each other. Philosophers, in working out philosophical laws and categories, should base themselves on the results of modern knowledge. Natural scientists must not oppose the categories of some special science to philosophical categories, but should perceive their interconnections.

It would be dangerous to allow isolation and a gap in the application of the categories of the natural sciences and of philosophy. Indeed, philosophy would be divorced from science. It would be doomed to scholasticism and would stop playing any active role in the development of contemporary knowledge. On the other hand, the categories of the special natural sciences would have only a technical significance; all this is fraught with the danger of penetration by reactionary ideologies, when a meaningful philosophical world

outlook is replaced by purely formal categories. Apart from that, the natural sciences would then forfeit the methodological apparatus of scientific knowledge as a whole. Of course, every science has its own theoretical generalisations. There are also disciplines that serve as the instrument of generalisation for a group of different branches of natural science. But to ignore their connection and interaction with general philosophical categories would mean losing a great advantage provided by philosophy, namely, its methodological apparatus that is enriched in the process of elaborating methodological problems of the natural sciences.

Just as Lenin gave a profoundly scientific philosophical interpretation of the early 20th-century revolution in the natural sciences, proceeding from the creative spirit of dialectical materialism, so today the correct concept of the current scientific and technological revolution is being elaborated on the same thoroughly developed theoretical basis.

The Role of Methodology in the Development of Contemporary Natural Science

In considering the problem of interaction between dialectical materialist philosophy and the natural sciences, the unity of the world-outlook and theoretical aspect and the logico-methodological aspect of philosophical investigation come into the foreground. When examining the prospects for the development of such investigations, one frequently tends to set in opposition to each other the world outlook, on the one hand, and logic and methodology, on the other. Then again, when emphasising the methodological problems of science, one sometimes underestimates and even denies the significance of the world-outlook basis of science and the inferences drawn from its development pertaining to the world outlook.

Needless to say, the treatment of the concepts of matter and law in the light of contemporary scientific data, the classification of the kinds of matter in nature and the corresponding classification of sciences retain their significance in the theoretical and ideological respects. Moreover, the investigations themselves in the field of the methodological problems of natural science cannot be successful unless they are founded on a solid world-outlook basis, since the method summarises philosophical theory. Therefore the effectiveness of the method depends, to a great extent, on the world-outlook essence of the theory summarised by the method. The unity of the dialectical method and materialist theory is the unshakeable basis for the scientific nature of our philosophy. Proceeding from this principle, one can rationally interpret the fact that problems of the methodology of science are being pushed to the fore in the natural sciences. The essence of this trend is not determined by underestimating the role of the world outlook, it only characterises a more complex mediated introduction of the world outlook into the very fabric of science, first and foremost through methodology.

The increased role of methodology, the general philosophical teaching about the method of practical action and scientific cognition, is determined by two objective circumstances.

Firstly, the growth of knowledge presupposes not only increasing theoretical assimilation of the object of cognition, but also accumulation of information about the cognitive process itself. The "science of science" is acquiring ever growing importance, and it naturally focuses on problems of methodology for the most effective cognition of the world.

When dealing with these problems, it would be wrong to ignore the extensive experience of elaborating the methods contained in materialist philosophy and in the rational elements of idealist doctrines. Indeed, as Engels wrote, "even formal logic is primarily a method of arriving at new results, of advancing from the known to the unknown. . ."[1]. There are immeasurably greater grounds for applying this to dialectics and generally to modern procedures of logical analysis. Thus, the very growth of knowledge and the development within it of new trends towards formalisation, mathematisation, etc., require an analysis of the logic of science from the philosophical point of view.

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[1] F. Engels, *Anti-Dühring*, Moscow, 1969, p. 161.

Secondly, the increased role of methodology in modern science is also due to the collapse, in the 19th century, of the speculative approach of the old natural philosophy. Formerly, the influence of natural philosophy on natural science was historically justified, inevitable and, up to a certain point, fruitful. In the ancient world, there were no experimental data for constructing atomistic theory, and it was therefore formed within natural philosophy. Thus, in one way or another, natural philosophy filled the gaps that existed in natural science, sometimes well and sometimes badly.

But the 19th century marked the end of natural philosophy, since natural science formed a basis of its own, so that it did not need this philosophy in solving its special problems. When speaking of the end of natural philosophy, we do not mean to say that nature ceased to be the object of philosophical thinking. That is the view of positivists, but not of dialectical materialists. The most general laws of being and, consequently, of the development of nature are still the object of materialist dialectics. There can be no doubt, in our views, of the existence of the dialectics of nature, the philosophy of natural science or, as we tend to say these days, philosophical problems of natural science. But we reject natural philosophy in the specific sense, namely, as the method for the solution of natural scientific problems through philosophical speculation alone.

The natural-philosophical approach to methodological questions of natural science inevitably entails imposing a certain *a priori* concept upon natural science. In certain circumstances, this results in arbitrary decrees and distortion of the real meaning and significance of natural scientific discoveries. We know what such decrees in methodological problems of natural science lead to. Incompetent interference by some philosophers in the sciences of nature had disagreeable negative consequences for the relationship between philosophy and natural science. We all remember only too well the attacks of some of our philosophers on the theory of relativity, cybernetics, genetics, etc. This interference and, consequently, the natural-philosophical approach, which is now incompatible with really fruitful interaction between dialectical materialism and science, have been condemned. The natural-philosophical approach discredits philosophy, and so we cannot allow any revival of such an approach.

The influence exerted by philosophy on natural science is primarily realised through world outlook and scientific methodology. True, there are still philosophers who believe that the very concept of methodology is a bourgeois figment, Machist or even worse. This is, of course, a misunderstanding, one that can do much harm, for denying the methodological role of philosophy with respect to natural science would throw us back to a revival of the natural-philosophical approach.

The great significance attributed by Lenin to Marx's dialectical materialist method in the analysis of social phenomena is widely known. He wrote: "The elaboration of a new theory of methodology and political economy marked ... gigantic progress in social science, ... a tremendous advance for socialism. . . ."[1]

Just as great a role Lenin attributed to Marxist methodology in the natural sciences. Dialectical materialism as the methodology of the natural sciences facilitates the correct generalisation and interpretation of new scientific data. Methodological problems should be given particular attention in present conditions, when the natural sciences are working intensely towards a new generalising theory and new ideas. That is the road to the enrichment and development of dialectical materialism, and therein lies its main influence on the development of science. To fail to understand this now means to fail to understand both the active role of philosophy and the ways of its creative development.

We cannot ignore the fact that the main vehicle of attacks on materialism is logic and methodology. The general laws

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[1] V. I. Lenin, "What the 'Friends of the People' Are and How They Fight the Social-Democrats", *Collected Works*, Vol. 1, p. 267.

of the development of nature, the overall picture of the world are certainly the main object of philosophical analysis. However, in their struggle against idealism, materialists level their criticism against all sorts of logical and methodological contrivances through which idealism endeavours to penetrate the natural sciences.

Recent years have shown more fully and deeply the enormous significance of Lenin's philosophical legacy for present-day science; conclusions have been drawn from creative discussions of fundamental philosophical problems in quantum mechanics and the theory of relativity, some methodological problems in cosmology, cybernetics, the role of physics and chemistry in the study of biological processes, the relationship between the physiology of higher nervous activity and psychology, etc. This has made it possible to arrive at a better understanding of the greatest achievements of present-day science from the standpoint of the genuinely scientific philosophy, dialectical materialism.

Dialectical Materialism and the Unity of the Sciences

Of the many philosophical problems of contemporary science, the problem of the interconnections of scientific disciplines is acquiring ever greater significance. This is essentially the problem of the unity of the world and the specificity of its various domains and, accordingly, the unity of the tree of human knowledge and the qualitative specificity of the various branches of science. The amazing achievements of modern science have greatly deepened and extended human knowledge. Penetration into the sphere of microprocesses and mastery of atomic energy, on the one hand, and the breakthrough into outer space and the new stage in the study of the Universe, on the other, are the most striking indications of this process. At the same time, the intimate interlacing of various sciences and their interpenetration are taking place. The study of this process by philosophers and natural scientists is of great theoretical and practical significance.

The history of the natural sciences knows two directly opposing and apparently mutually exclusive tendencies: one is the tendency towards the breaking up and branching of sciences, their differentiation; the other, on the contrary, is the trend towards the unification of disconnected sciences within an integral system of scientific knowledge, that is, the trend towards integration. Originally the two tendencies operated independently, although they conditioned each other to a certain extent. One or the other of these tendencies prevailed at different stages of scientific progress. In the present-day natural sciences they form an organic unity: the greater the differentiation and branching of sciences, the more integral, whole, cemented, as it were, natural science as such becomes.

The reason for this is that the newly emerging scientific disciplines do not broaden the gaps between sciences, as was the case in former times, but, on the contrary, remove their previous isolation. Even in the middle of the last century, physics and chemistry were isolated from each other, but physical chemistry, a new science that appeared late in the last century, linked them, and the links are so close that the two sciences started penetrating each other: the formerly clear-cut boundary between them has disappeared. At present it is hardly possible to describe many processes as physical or chemical, since they simultaneously carry both kinds of properties. Chemical physics, which has emerged in this century, forms another important point of contact between physics and chemistry, in which their profound ties and mutual transition are revealed.

The same thing is happening on the border between chemistry and biology, on the one hand, and chemistry and geology, on the other, that is, at those points where chemistry comes into contact with the science of animate nature and the science of inanimate nature. Biochemistry, geochemistry and biogeochemistry are all sciences whose appearance in the course of scientific differentiation did not strengthen their isolation but, on the contrary, led to their interpenetration. The dialectics of the development of scientific cognition thus appears in the form of mutual conditionality of the two

opposing tendencies, differentiation and integration of knowledge. This is one of the most characteristic features of present-day natural science.

The growing interlacing of the sciences is due to the fact that natural science is penetrating more and more deeply into the dialectics of nature. Scientific knowledge is the reflection of an objectively existing thing, with all the properties and laws inherent in it. The interconnections between the various branches of modern science are a manifestation of the objective connections in nature. The interpenetration of the contemporary natural sciences is evidence of the fact that nature is basically indivisible, it is a unity in diversity: none of its domains is isolated from the others, but is linked with them directly or indirectly, through thousands of different threads, transitions and transformations.

The overall connectedness of natural phenomena, reflected in the interconnections of various disciplines, exists and manifests itself in the individual natural sciences studying the specific objects of nature with their inherent specific properties and laws. One cannot establish the common link between sciences without taking into account the specificity of each of them, and vice versa, the specificity of any science, its subject matter and method cannot be understood if one ignores its interconnections with other sciences and also the common link between all sciences, including philosophy.

In order to understand the way in which the interpenetration of sciences reflects the unity of nature, one must bear in mind that the whole of nature appears to our intellect as a succession of stages in the development of matter and its forms of motion, beginning with the simplest and best-known ones and ending with man and the transition of the process of development, together with man, from the framework of nature proper into the domain of social history. All of the more complicated forms of motion and kinds of matter, including man, originally appeared and subsequenty developed from the simpler physical forms of motion and kinds of matter. Each time, profound qualitative changes occurred and dialectical leaps from one stage of development to a higher and more complicated one took place.

The progress of present-day scientific cognition is intimately connected with its differentiation. New scientific trends as well as scientific disciplines emerge continually. In an age of the rapid accumulation of scientific information, such specialisation both of sciences and scientists is inevitable and justified, as it helps to raise the productivity of research work. At the same time it would be a grave error to neglect the dark, and even sinister, trends of over-specialisation.

In accordance with the dialectical law of contradiction, increased differentiation of knowledge gives rise to the need for a synthesis of sciences capable of overcoming the isolation of the scientific disciplines. The problem today is naturally that of a more general synthesis of knowledge, covering not only natural, but social sciences as well. The introduction of exact methods into social disciplines is particularly significant for socialist countries, which improve their economies on a scientific basis.

In itself, the tendency for closer contacts between, and even, in a sense, coalescence of, natural and social sciences is extraordinarily important from the philosophical viewpoint, as old philosophy at different stages and in different forms implicitly admitted, or even explicitly declared, the inevitability of the gap between the natural and social sciences. According to Hegel, the principle of development is active in society, but does not work in nature. Feuerbach's materialist understanding of nature goes hand in hand with idealism in the treatment of society. This break was most acutely formulated by the neo-Kantians, who treat the natural sciences as sciences of laws, and social sciences as sciences describing unique and individual phenomena. Dialectical materialism broke down this philosophical barrier by placing the social sciences on a scientific basis and thus became an instrument for overcoming the contradiction between the development of the natural and social sciences.

Interaction of sciences is becoming a vital factor in their development. Modern natural sciences give a powerful impetus to the growth of the social sciences. The view of the objective character of laws became established in the natural sciences earlier than in the social sciences. The idea of the

mutability, development and transformation of phenomena gained a foothold in biology, geology and physiology before it penetrated sociology. Methods of precise quantitative analysis were also borrowed by the social sciences from natural science and technology. But philosophy and the social sciences, on the other hand, determine the most favourable conditions for scientific and technological progress, help to eliminate the obstacles in its way and, moreover, enrich the natural sciences with fruitful ideas and concepts.

The idea of law-governed development and change was expressed in philosophy long before it was accepted in the natural sciences. The atomistic theory was also formulated in philosophy thousands of years before it assumed the form of a natural scientific theory and was experimentally proved. The idea of statistical laws was firmly established in sociology before it gained recognition in microphysics.

An excellent example of the influence of philosophy upon the natural sciences is provided by the whole history of dialectical materialism. The concepts of "absolute space" and "absolute time" as outer forms divorced from matter and from each other still prevailed among physicists in the last century; dialectical materialism convincingly proved, however, that space and time are inseparably linked with matter and with each other. Early 20th-century science was only beginning to realise the complexity of the structure of the atom and the majority of scientists still referred to the electron as the ultimate, indivisible, "absolutely immutable entity of the world", whereas the great dialectician Lenin had already drawn the conclusion that there are no ultimate, immutable, indivisible entities, that matter is inexhaustible in its depth; the electron is just as inexhaustible as the atom.

The problem of the interconnections between sciences is the problem of the unity of the world and the qualitative specificity of its various domains. Hence the extremely important methodological question of the uniform basis of scientific cognition and the specific features of the subject matter and method of individual disciplines.

At the present stage in the development of the natural sciences, the analysis of the interconnections between them is an urgent theoretical and practical task. Unless there is a correct understanding of the role and place of the individual disciplines in the general system of contemporary knowledge, and a clear and precise formulation of the principles on which the various disciplines are linked with each other and related to the other fields of knowledge, one cannot avoid many serious difficulties, clashes and harmful negative consequences. Underestimation of the general laws of nature, and excessive isolation of sciences result in advances made in certain fields of scientific knowledge not being used to further progress in other fields.

Thus, when sciences are isolated from each other what could be comparatively easily and swiftly achieved through rational co-operation is arrived at only through long and hard work. On the other hand, disregard for the qualitative specificity of sciences, gross and often incompetent interference of representatives of some sciences in the affairs of others, without due respect for their specificity, is fraught with the danger of unnecessary clashes and often results in needless waste of effort, nervous energy and time.

Without the correct methodological approach to the relationships between sciences, rapid progress in one field may give rise to tendencies that hamper the development of other branches rather than facilitate it. The lesson of dialectics is that qualitative changes give rise to new regularities which should not be identified with the laws of the simpler forms of motion or reduced to them. Scientific cognition is impossible unless the qualitative specificity of phenomena and their specific laws are taken into account.

The elaboration of the category of law and regularity is of considerable importance, from the philosophical point of view. It is equally important to study the manifestations of the category of law both in the natural sciences and the social sciences. Many scientists in bourgeois countries oppose the social sciences to the natural sciences by rejecting, directly or indirectly, the laws of the development of society. Some Western historians insist on the impossibility of generalisation, laying heavy emphasis on the peculiarities of historical events, and ignoring the similarities and common features, and believe that the facts of the past have complete individuality. However, much stronger among bourgeois historians is the tendency towards generalisation of an outer form of historical events irrespective of their historically specific content.

Attempts of this kind have little to do with genuine science. Let us consider the rather popular cyclical trend. The adherents of cyclical concepts (the followers of Oswald Spengler and Arnold Toynbee) underline only the analogous aspects of phenomena occurring at completely different periods and entirely ignore their specific and peculiar features.

In actual fact, the similarities are due to the spiral-like development of society, in which the progressive movement forms a unity with cyclical elements. The cyclicalists deny the doctrine of social-economic formations and social progress, focusing their attention on recurrence only and attempting to prove the absence of the specific. In an indirect way, they reject the real laws of social development.

The cyclical concepts are viewed as an "effective weapon" against Marxism. Marxist scholars should therefore consistently denounce the new representatives of cyclicalism. The criticism of cyclical concepts is particularly important, as many of them are characterised by pessimistic and apocalyptic attitudes. In criticising them, it is important to remember that cyclicalists are sharply condemned by the extreme Right-wing elements in bourgeois historical science, who reject any laws in the historical process and insist on its complete unknowability.

The overcoming of anti-scientific theories in the natural sciences today is facilitated by the tendency of the social and natural sciences to fuse. As this tendency develops, a general philosophical synthesis of knowledge is carried out on the basis of dialectical materialism. Thus, dialectical materialism is a reliable method for linking the social and natural sciences. The tendency itself towards a synthesis of all natural and social knowledge presupposes a genuinely synthetic philosophical basis. This basis took shape in the course of a complicated and acute struggle.

The level of scientific development attained by the mid-19th century predetermined the downfall of speculative methods. The continued attempts of some philosophers to solve problems arising in the natural sciences by purely speculative methods completely discredited natural philosophy, and this undermined the former authority of any philosophical thinking in general in the eyes of many natural scientists. This situation in science gave rise to positivism. Auguste Comte, its originator, and all the trends of positivism in the past and present that have followed him rejected philosophy, by which they actually meant the world-outlook aspect of philosophy. The positivist treatment of many problems of formal logic, including those of experience, subject matter and classification of the sciences, mathematical logic, analysis of the language of science, etc., attracted natural scientists in many fields to positivism. At the same time, positivists limited philosophy to the problems just listed, and refused to consider world-outlook problems, which were declared to be "meaningless", that is, neither true nor false.

Some positivists (e.g. Ernst Mach) were atheists, but their attacks on materialism made their atheist arguments extremely weak and inconsistent, and even gave a helping hand to theology. Other positivists (John Stuart Mill, Herbert Spencer, Ludwig Wittgenstein and others) defended religious beliefs more or less openly, declared problems of world outlook to be beyond intellectual comprehension, and relegated them to the sphere of mysticism. In other words, positivists suggested that natural scientists should limit their investigations to facts only (the facts being given subjective idealist interpretation, it should be mentioned), leaving the problems of the nature of things and causality of the world outside the domain of the natural sciences and philosophy.

Directly or indirectly, this standpoint left world-outlook problems completely in the hands of the theologians and cleared the road for the Thomists, who have increased their influence within the last 50 years. The Thomists' position differs from that of the positivists. An important trend within Thomism at present is the attention given to problems of world outlook, the essence of being, the beginning and the end of the world, and the origin of life, whereas the solution of concrete natural scientific problems is left to scientists. Some theologians, the Thomists included, continue the tradition of the religious philosophers and attempt to give a theological interpretation to all the monumental discoveries of natural science.

In elaborating the world-outlook aspects of philosophical problems in the natural sciences, great attention must be given to arguments against modern Thomism as one of the most important and popular trends in bourgeois ideology. Thomism obviously claims to be a synthetic basis for the whole cognitive process. This synthesis, however, is effected from mystical premises that are essentially alien to science. Proceeding from the belief that scientific knowledge needs irrational additions, the prominent neo-Thomist Etienne Gilson writes: "We do not think that science is adequate to rational knowledge. . . ."[1]

The entire experience of the development of cognition proves that only the consistently materialist philosophy of Marxism-Leninism can serve as a genuinely scientific basis capable of synthesising natural and social knowledge. We see the truth of this not only when we oppose dialectical materialism to neo-positivism, Thomism and other trends of modern idealism, but also when we compare the philosophical level of the generalisation of knowledge with other forms and levels of synthesising scientific information.

The human mind has always felt the need for a synthesis of knowledge, and this is a reflection of the objective material unity of the world. One may say that, as far as its epistemological roots are concerned, philosophy was born of that need. There is no science without comparison and generalisation. Every law of science is a generalised reflection of phenomena. Historically, every field of knowledge has given rise to generalisations of its own. At one stage, formal logic and mathematics played a great role in these generalisations. By elaborating its own concepts and categories, formal logic facilitated the generalisation of scientific data. Mathematics

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[1] E. Gilson, *God and Philosophy*, New Haven, 1960, p. 113.

has long since served as an instrument for formally describing and generalising scientific truths. At the same time, a need for a wider generalisation of phenomena has always been felt. That is why philosophical generalisations developed side by side with formal logic and mathematics, and philosophy, particularly materialist philosophy, played just such a synthesising role. One ought to note that classical idealism has also made a considerable contribution to the elaboration of philosophical categories, thus promoting the generalisation of scientific achievements.

At present we are witnessing the continued rapid development of those scientific disciplines that are conducive to the generalisation of natural scientific data and, to some extent, the data of the social sciences. The diverse branches of mathematics play an important role not only as a means of expression, a means of describing phenomena, but also as a method of finding new truths. The development of logic, too, has been greatly stimulated. Cybernetics, a new and powerful instrument of knowledge, has now emerged. Quantum theory serves as an important means of generalisation for physics, chemistry and other natural sciences.

It would be wrong to ignore the enormous role played by the logical apparatus, mathematical means, cybernetics, and modelling in the development of present-day science. Philosophers who do not understand this or even reject the importance of these means of generalisation are simply backward people and can do nothing but harm to both philosophy and the natural sciences.

It should also be emphasised that precisely because of the vast development of logical and mathematical means of scientific generalisation it is important to develop the methodological apparatus, that is, work out the philosophical problems of the natural sciences and enrich Marxist philosophy. The heart of the matter is that, from the point of view of the level and method of generalisation, mathematics in its various branches, cybernetics and formal logic themselves require mutual links. Mathematics has broken up into a number of fields or, properly speaking, scientific disciplines. Logic also has several offshoots (many-valued

logic, in which the law of excluded middle does not apply; modal logic, the logic of norms, the logic of values, the theory of logical inference, etc.). Accordingly, there is a need for generalisation and synthesis of the generalising branches and disciplines themselves, and such generalisation can only be attained through elaboration of the philosophical problems of the natural and social sciences, the dialectics of natural and social processes, and dialectical materialism.

And, most importantly, mathematical, logical and cybernetic generalisations cannot provide solutions to such problems as the problem of the subject and the object, man and nature, nature and society, theory and practice, and a number of other general methodological problems that are the specific subject matter of philosophy, and dialectical and historical materialism. Unless these general philosophical problems are solved, the logical and mathematical apparatus will primarily have only technical significance.

Therefore, the elaboration of general philosophical categories and laws furthers a correct understanding and development of the entire generalising apparatus of present-day natural science, including every scientific discipline. That is why we believe that philosophy cannot pursue the goal of solving specific natural scientific problems. Nor can it develop in the absence of close links with the natural sciences; and the natural sciences themselves would be greatly impoverished, if their alliance with the philosophy of dialectical materialism were to be weakened.

Ever greater attention should be given to the trend towards synthesis of the natural and social sciences. The study of science as a large-scale synthetic system calls into being a number of special scientific disciplines in which the main emphasis is on problems involved in the structure of science, the means of obtaining and processing information, and the analysis of the specific features of man as the subject of scientific cognition. Man is no longer able to develop scientific knowledge "manually", by old-time methods. To an ever greater extent, he has recourse to "intelligent" machines, his assistants, and, with this aim in view, he has to study himself with increasing thoroughness. On the other hand, the natural sciences are ceasing to be disciplines studying the external world as something that merely confronts man and is only passively contemplated by him. The foundations of a new grandiose synthesis of knowledge are being laid, whose outlines were clearly drawn by Marx: "Natural science will in time incorporate into itself the science of man, just as the science of man will incorporate into itself natural science: there will be one science."[1]

As the natural and social sciences come into closer contact, the general theoretical level of all the branches and subdivisions of science rises considerably higher.

Scientific disciplines that only recently were primarily descriptive are becoming theoretically deeper, their need for philosophical substantiation growing accordingly.

A great synthesising role in the accumulation of integrative elements in various scientific disciplines is played by dialectical materialist philosophy, since it is the universal methodology of the cognitive process as a whole. In view of the great urgency of the problems involved in the synthesis of sciences, the mechanisms of interaction between philosophy and special sciences from the standpoint of the integrative role of philosophical knowledge are gaining new features that have to be studied more profoundly.

The integral philosophy of dialectical materialism, which has absorbed the historical experience of the development of cognition and is now geared to the future, ensures, together with the natural sciences, a methodological synthesis of contemporary scientific knowledge, that is, the unification of all spheres of science under the aegis of the universal creatively developing method of materialist dialectics.

The methodological function of philosophy lies, first and foremost, in the comparison and generalisation of data from different sciences, and in attaining a comprehensive or, one might say, maximally comprehensive synthesis of knowledge.

The laws and categories of dialectics represent this sort of maximal generalisation of the processes of the development of nature, society and thinking, are enriched by new data concerning existence and human cognition, and so serve, in their turn, as a reliable methodological instrument for penetrating into the essence of objects and phenomena.

Philosophical investigations reveal the logic of natural scientific cognition by generalising the data of special disciplines.

This standpoint, tested by the experience of philosophical work, retains its significance in present conditions, too. However, it includes further creative development of the methodology of scientific cognition, and generates the need to make more concrete and profound the analysis of changes taking place in the epistemological, methodological and world-outlook foundations of science, as well as the analysis of the role of materialist dialectics in the synthesis of a new scientific picture of the world. There must be further development of materialist dialectics as the method of scientific theoretical thinking. Therein lies the main task of studies into the philosophical interpretation of the rapid progress of the social and natural sciences.

The further successful development of scientific cognition is guaranteed by the fact that both philosophers and natural scientists in the socialist countries, as well as progressive scientists in bourgeois countries, are working to strengthen this creative alliance that Lenin bequeathed.

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[1] K. Marx and F. Engels, "Economic and Philosophic Manuscripts of 1844", *Collected Works*, Vol. 3, p. 304.

John D. Bernal

LENIN AND SCIENCE[1]

I will begin by quoting some paragraphs from an article I wrote for *Pravda* on the occasion of the 29th anniversary of the death of Lenin: "The economic analysis, the political message, the tactical advice in Lenin's work is still of day-to-day importance in the struggles of our times. Not less important is the lost perspective, the range of vision, that can lead us to understand the grand movements of nature and history.

"Lenin was a great scientist, among the first rank of his age in the sheer intellectual quality of his understanding, the greatest of all in the scope of his comprehension.

"Where other men saw this or that aspect of reality, he saw the whole. He saw it not as a static picture, but in movement, and he understood and learned to control the forces that determined that movement, and this shows itself most clearly in the way he absorbed, mastered, used and transformed the heritage of Marxism.

"When Lenin first encountered the works of Marx and Engels, they were already in danger, on the one hand, of being turned into a rigid and sacred doctrine expounded with more care for the letter than the spirit and, on the other, of being revised in terms of current philosophy and science so as to lose their real content and to become an acceptable apology for the very capitalist system Marx had fought against all his life."[2] Almost alone he saved Marxism as a living, fighting philosophy in the service of advancing humanity.

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[1] The article was prepared by the author for the Russian edition of this book. (Moscow, Mysl Publishers, 1969.)

[2] *Pravda*, January 21, 1953.

In doing so he exhibited to the full his grasp of scientific method. The first chapter of *What the "Friends of the People" Are*, written as far back as 1894, shows him penetrating to the centre of the dialectic method as used by Marx and Engels and showing it to be no formal scheme imposed on nature and society, but "nothing more or less than the scientific method in sociology, which consists in regarding society as a living organism in a constant state of development".

In this way, Lenin was able to avoid at the same time the extremes of dogmatism, a blind following of Marx's own text, and revisionism, taking liberties with that text by revising it to fit more closely the bourgeois tendencies of the official science of the time.

Throughout the 20th century, what may be called the phenomenon of Lenin has been the dominating factor, not only of world economics and politics, but also of world natural science. This has been for a number of reasons, different but related. In the first place, Lenin himself had a profound interest in the basic philosophical aspects of science, especially in the physical sciences, and took an active part in the great controversies of the early century, those on atomism and energetics. It was a time of acute and formative controversy which, in one form or another, is still with us. In the second place, Lenin insisted on the intimate relation between basic science and the practical achievements of technology. In the third place, this set of thoughts and theories had to be translated into real action in the new Soviet state, creating in the Soviet Union a new kind of science, closely related to the developments of the economy of the state.

All this was fundamentally Marxist in inspiration and was to have a great practical effect on the growth and nature of science, first of all in the old Russian Empire, but afterwards its influence was to transform science throughout the whole world, not least in the wealthiest capitalist country, the United States of America, and it was largely to characterise the development of world civilisation itself.

In all this, the personal influence of Vladimir Ilyich Lenin was to play a decisive part. In his early years, Lenin had no particular association with what we call science or, outside

Britain and America, what is called natural science, which is elsewhere known as simply one section of philosophy. His education, very much interrupted by the police, did not include it. Although he never took his degree, he did manage to qualify as a lawyer, so it is not surprising that by his reading he was able to gain a pretty wide knowledge of natural science. He was led to it, in any case, by his deep study of Marxism, especially the idea that all human knowledge is one. He seized the essential materialist content of Marxism. As he says, "A man in a dark room may discern objects dimly, but if he does not stumble over the furniture and does not walk into a looking glass instead of through a door, it means that he sees some things correctly. There is no need, therefore, either to renounce the claims to penetrate below the surface of nature, or to claim that we have already fully unveiled the mystery of the world around us."[1]

"The destructibility of the atom, its inexhaustibility, the mutability of all forms of matter and of its motion, have always been the stronghold of dialectical materialism. All boundaries in nature are conditional, relative, moveable, and express the gradual approximation of our mind towards the knowledge of matter."[2]

"Nature is infinite, just as its smallest particle (including the electron) is infinite, but reason just as infinitely transforms 'things-in-themselves' into 'things-for-us'."[3]

Science had a very important effect on the growth of civilisation and never more than at that time: this was only one link in the chain of interest that Lenin had in science. Another was the relation of science to economic development in the Russia of his time. He dealt with it in the most comprehensive way in his *Development of Capitalism in Russia*, and to a lesser extent but over a wider field in his *Imperialism, the Highest Stage of Capitalism*. In other words, he was fully aware, even before the 1905 Revolution, of the importance of science as a means of influencing economic and social events.

Perhaps the most important part of his life was his reaction to the failure of the 1905 Revolution. It did not lead him for a moment to despair or to turning to religion or to philosophical escape routes. Quite the contrary. The early 20th century was a great period of transition in the scientific and philosophical world. Old controversies which had affected the 19th century were reappearing in new guises. The disputes between materialism and idealism were reappearing in the form of disputes between atomism and energetics, particularly between evolutionism and vitalism.

Lenin was never taken in by these for a moment and entered vigorously into all the controversies. That was the time of the writing of *Materialism and Empirio-Criticism*, in which he characterised the common tendencies of the anti-materialists, Mach, Ostwald, Poincaré and Bogdanov. He was able to show that these tendencies marked a recurrence of long-overlaid religious tendencies, "Fideism". That in itself would not be enough to account for the heated nature of Lenin's polemic; these tendencies also had their political aspects. They came more and more to blur the definiteness of the class struggle and were part of the general trend of political compromise of the time of the defeat of the Revolution.

The controversies are, however, well worth following for their own sake and are admirably set out in the *Philosophical Notebooks*. In his *Empirio-Criticism*, he attacks particularly the tendency of the so-called modern philosophers to rely on other methods of arriving at truth than reason. It opened the way to all kinds of antiquated, not to say fallacious, methods such as mystical feeling and even pragmatism. The new contradictions in philosophy had been put down to a bankruptcy of science, but Lenin would have none of it.

It is for this reason that Lenin found himself turned against the denial of atomism and, by implication, of materialism, put forward by the positivist school of Mach and Ostwald. Lenin realised that the new discoveries in physics at the turn of the century, particularly that of the electron, seemed to indicate that matter was entirely electromagnetic,

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[1] V. I. Lenin, "Materialism and Empirio Criticism", *Collected Works*, Vol. 14, p. 276.

[2] Ibid., p. 281.

[3] Ibid., p. 312.

but this had been taken altogether too naively, as if matter had vanished into thin air. Lenin would have none of this and considered that the thermodynamics of Carnot and Gibbs could be used without any concessions to metaphysics. When one considers that the astonishing developments of relativistic and quantum physics have been subsequently absorbed into a general picture of the Universe without gross difficulty, the relatively minor explanation required by 19th-century physics did not demand much effort.

These remarks on the future of science were superseded in a few years by the outbreak of the First World War, which found him in Switzerland still occupying himself with questions of theory, including the philosophy of science and the theory of Marxism. He was all the time concerned with the task in front of him, of how science could be used in building up a new, socialist society. From then on, after the February Revolution in 1917 and his return to Russia, he moved into the full blaze of political and military events. But he did not forget for one moment the task in front of him in the scientific world. Despite the demands of the day-by-day struggles of the revolution and the intervention, he was busy formulating an organisation of a new kind of science. In this he built on the older institutions of the Imperial Academy of Russia, which maintained many of its original members, whom he found eager to co-operate in the service of the new, socialist state.

As a body, the old Academy was quite difficult to change, not from ill will but simply from inertia. I remember, on an early visit to Leningrad, an old scientist remarking to me: "We used to make museums for learned men, now we are making them for children." The tradition of science remained obstinately academic. Yet many of the figures in Russian science rose well above it. The force behind this rise was the enthusiasm inspired by Lenin in the younger workers. The essential new objective was the linking of science with production. The famous thesis of Lenin was: "Communism is Soviet power plus the electrification of the whole country."[1]

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[1] V. I. Lenin, "The 8th All-Russia Congress of Soviets", *Collected Works*, Vol. 31, p. 516.

With this production programme goes its analogue, to bring science itself to the people.

This implies another aspect as well, that of the planning of science. In itself the idea of planned science was considered a shocking innovation, destructive of the sacred liberty of science, and it was much abused in capitalist science. One of the ways in which it was made acceptable to the scientists themselves was by the reversal of the old trend of stinting science funds and replacing it by ample provision. Lenin ensured that any enterprising, ambitious worker in science found all the means necessary for his work. This trend, started in the Soviet Union, was at first denounced abroad but very soon afterwards copied there, and was to give rise to the "Big Science" of the second part of the century.

A characteristic feature of the Academy was that of its Institutes, a new kind of body, part research laboratory, part university department, part experimental factory. The Institute of Optics in Leningrad, for instance, concerned itself with the whole industry, beginning with raw materials and going on to field glasses and telescope objectives. It had the task, not only of the improvement of optics but of being a source of optical instruments for the whole Union. Between them these institutes furnished a series of bridges from science to practice. They gave scope for scientists of enterprise and sense to satisfy practical needs. Professor Joffe, for instance, claimed that he had, himself, founded 28 research institutes in the Union and virtually started Soviet solid state physics from which so much was to come, including the virtually universal transistor and a variety of thermal generators that were to find their place in space research.

At the same time the ideological aspects of science were not forgotten. True to its Marxist origin, the new science was taken as a weapon against reaction, particularly against the deeply ingrained religious sentiments which had been degraded to traditional superstitions. This superstition was more persistent than genuine religion. The numerous anti-god museums of the early days were really anti-superstition ones but I found an old peasant woman in one of them reverently kissing the exhibits.

The planning of science with a very special object was really part of the planning of industry and agriculture themselves. This marked the beginning of the great plans for creating the new industries and the transformation of nature, which were achieved in the main after Lenin's death but carried his imprint from the start. One of the first tasks of the Academy was a kind of stock-taking of the natural wealth of the Union, including the phosphate deposits of Karelia, the great Kursk iron deposits, the enormous extensions of the original Baku oilfields, the valuable deposits of diamonds in Yakutia in Eastern Siberia; many other such deposits have been found since.

With the expansion of resources came new improvements in methods of exploiting them. The opening up of technologies, electricity naturally coming high on the list, led ultimately to the original factory complex of Dnieprostroi. The field of aerodynamics and aeroplane construction was developed, almost from the beginning, by Zhukovsky and Ilyushin. Very soon Soviet aeroplanes were treated respectfully in world flying circles, both in peace and in war.

Lenin died too soon to see the great physical discoveries of the mid-century, but the preparation was not lacking. The importance of nuclear physics was very early recognised. Kapitsa came from Leningrad to study under Rutherford in Cambridge and devised a number of methods for the separation of isotopes which effectively helped to provide the basis for nuclear fission. One of the most curious facts was the way in which all this progress was treated outside the Soviet Union. The scientists of Britain and America were divided in their minds about it. They wanted, at the same time, to run down the Soviet Union and its achievements and also to frighten the West with them. It was pathetic to watch the ups and downs of their attitude. Each new Soviet advance was first denied in the West, then accepted but attributed to spying, and finally used as a need to stir up their own science. The sputnik was a decisive example of this process. It was confidently predicted that this was far beyond the scientific capacities of the Soviet Union; even the atom bomb could be doubted. But the rapid progress gradually forced its acceptance and then led to absurd exaggeration of the missile gap, which was used to urge forward the U.S. armaments race.

We seem to have come a long way from Lenin, but luckily his impulse has endured and has set for a whole new generation the tone of science, not only in the Soviet Union but all over the world. Thanks to that inspiration, it can no longer be maintained, even by its worst enemies, that scientific and technical progress are incompatible with socialism as built on the model of Lenin's work. On the contrary, socialism furthers science and it has helped enormously to enlarge its scale and make it a basic part, not only of the economy but of its ideas.

Those who claim to be Leninists, though they may be distant in space and time, cannot claim any closer links with Lenin than the actual successors of the works he created and watched over in their formative years.

Todor Pavlov

ON THE DIALECTICAL UNITY OF PHILOSOPHY AND THE NATURAL SCIENCES

Everyone who has read *Materialism and Empirio-Criticism* and other philosophical works by Lenin is aware that he recognised and creatively developed Engels's definition of philosophy as the science of the general laws of motion and the development of nature, human society and thought.[1] Lenin's starting point was the significance of Marxist philosophy as a world outlook and its definition by Engels as logic and dialectics. One should immediately point out, however, that Lenin, as well as Engels, never adhered to "epistemologism". For both Lenin and Engels, logic is the total, the summary, the conclusion to be drawn not just from the entire history of *human knowledge*, but also from the entire history of *the world itself, the objective reality itself.*

Thus, Lenin does not reject the ontological aspect, but the definition of scientific philosophy should not be limited to it. Then again, Lenin does not reject the epistemological aspect either, but it too does not exhaust dialectical materialist philosophy.

When writing about the philosophical concept of matter in *Materialism and Empirio-Criticism,* Lenin sometimes uses the word *epistemological,* between inverted commas, or speaks directly of the "epistemological concept of matter", having in mind that that does not mean pure epistemologism; the ontological aspect, that is, the existence of matter outside consciousness and independently of it, is far from being rejected in dialectical materialist philosophy; on the contrary, it

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[1] F. Engels, *Anti-Dühring*, Moscow, 1969, p. 168-69.

is especially stressed. This fact is sometimes neglected in present-day philosophical Marxist literature.

The scientific definition of philosophy as such is certainly not exhausted by what has been said above. Engels in his book on Feuerbach, and Lenin in *Materialism and Empirio-Criticism* stressed time and again that the main question of any philosophy is the relation between being and consciousness. In this connection, Lenin gives the classical definition of the philosophical concept of matter as objective reality existing independently of human consciousness and reflected by it. "Materialism in general recognises objectively real being (matter) as independent of the consciousness, sensation, experience, etc., of humanity. Historical materialism recognises social being as independent of the social consciousness of humanity. In both cases consciousness is only a reflection of being, at best an approximately true (adequate, perfectly exact) reflection of it."[1]

It follows from this that in defining the subject matter of Marxist-Leninist philosophy one should point out the *fundamental guestion* of philosophy. That does not mean, of course, that the subject matter of philosophy should be limited to its fundamental question; Lenin says that the relationship between consciousness and matter is the fundamental question of philosophy, but that does not mean that it is its only question. The point is that without the fundamental question of philosophy there can be no scientific philosophy, although it must study, as we have already noted, not only the fundamental question but also the most general laws of the development of natural, social and spiritual phenomena, problems of world outlook, formal and dialectical logic, their correlation, etc.

There are world outlooks (e.g. religion) that are not scientific.

There are also synthetic concepts of the world that are generalisations of special sciences of nature, but they are not necessarily philosophical in character. *Such concepts as-*

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works,* Vol. 14, p. 326.

sume philosophical significance only when they answer the fundamental question of philosophy, in addition to the study of the most general laws of nature, society and thought.

It is extremely important to note that Lenin's definition of matter concerns not only matter as such, but, in one way or other, extends to space, time, necessity, freedom, society, etc. Space and time, as objectively real forms of being, can and should be the subject matter of philosophical investigation. Lenin devotes special chapters in his *Materialism and Empirio-Criticism* to their analysis, as well as to the analysis of necessity, freedom and social being.

The atom is the smallest particle of an element in the infinite material world. In certain respects, the atom may be the subject matter of philosophical investigation, insofar as it exists independently of human consciousness and is reflected in it. When the atom is viewed in its relations with other atoms from the point of view of its specific structure and structural laws, it is the subject matter of natural scientific inquiry, of special scientific and not philosophical investigation.

Similarly, society is only a part of the reality of the Universe.

Society may be either the subject matter of philosophical study (when the relationship between social being and social consciousness is studied), or the subject matter of special scientific research (dealing, for example, with the structure of social formations).

To sum up, one may say that in all attempts to formulate and solve the genuinely scientific philosophical problems the authors must define their attitude to the fundamental question of philosophy. It is by no means accidental, therefore, that since *Materialism and Empirio-Criticism* appeared its most contested concept has been Lenin's theory of reflection; in other words, the opponents of Marxist philosophy rejected the philosophical standpoint expressed in the proposition that matter is objective reality reflected in our sensation, in our consciousness.

Let us consider some problems connected with the development of dialectical materialist philosophy (Lenin's theory

of reflection, Marxist-Leninist epistemology and dialectics) in recent years.

Let us first deal with the problem of the relationship between philosophy and mathematics.

Philosophy, the Natural Sciences and Mathematics

These days, no one can deny that mathematics is an instrument or method of enormous significance for the further development of scientific cognition itself as well as the cognition of nature, social life, socialist construction and social practice in general. Anyone who is concerned with economics knows that, without mathematics, it has become impossible to obtain answers to questions about optimal plans for technological and economic construction. It may be for this reason that the view has been expressed in mathematical and philosophical literature that mathematics is an omnipotent science dominating all the other sciences with their problems, hypotheses, etc.

This view undoubtedly contains a measure of truth, but one cannot say that it is the whole truth. Marx's dictum that the level of development of a science can be judged by the extent to which it uses mathematics is generally known. Kant insisted that scientific investigations need mathematics in order to be precise. All this is certainly true. Mathematical methods are applied in processing measurement data in the study of the quantitative relations of the structures of objects.

The question arises, however; by what mathematical means can we prove that the measured objects and the standards of measurement that we apply are objectively real? What is the real content of the notion of exactness itself?

All this is frequently ignored or underestimated. It comes about, therefore, that some exponents of mathematics and the precise natural sciences (and not they alone) raise the mathematical sciences to an absolute and actually forget that, for instance, Marx's *Capital* and Lenin's *The State and Revolution* or *Materialism and Empirio-Criticism* were not created with mathematical principles or methods of investigation.

In the course of its historical development, mathematics influenced philosophy and was in turn influenced by it. Suffice it to remember that mathematics played a most important role in the formation of rationalism (Descartes), which sees the ideal of human cognition in the strictly logical nature of mathematics. Philosophy itself is not reduced to rationalism, and its method, in the broad sense of the term, differs from the purely formal methods of mathematics (which appear as specific methods of a special discipline in relation to the method of philosophy).

In *Materialism and Empirio-Criticism* Lenin wrote that it was not his intention to deal with the special theories of physics.

Recently, there have been many works whose authors in the name of Marxism fill their philosophical papers with specific physical, mathematical and biological problems. This is offered to the reader as the standard of present-day Marxist-Leninist philosophical thinking, *the papers alluded to sometimes actually containing not a jot of Marxist-Leninist philosophy.*

It is certainly not our contention that the authors of contemporary Marxist philosophical studies should not concern themselves with generalisations of natural scientific, mathematical or other materials from special sciences. Dialectical materialism cannot develop without such generalisations and suitable conclusions, that is, it ceases to be a scientific philosophy without such generalisations. But philosophical generalisations or philosophical inferences from natural scientific propositions and discoveries are not to be reduced to the analysis of data from the standpoint of some particular scientific discipline. Propositions of special sciences should not be substituted for philosophical conclusions and statements, although the latter presuppose the discovery and application of the former.

Philosophy is concerned with the laws of cognition, of theoretical thinking reflecting the material world, and cannot therefore be reduced to any natural scientific, mathematical, technical, social or any other scientific discipline of a similar nature.

Since antiquity, mathematics has played an essential role in the development of logic. Its significance has grown considerably since the mid-19th century owing to the study of its logical instruments, the foundations of mathematics, and the creation of mathematical logic. At the same time, Marxist dialectical logic appeared. Mathematics throughout its history (and in this respect it is no different from all other sciences) has been the scene of struggle between materialist and idealist trends. Outstanding mathematicians, particularly those who kept close links with the natural sciences, usually defended, often spontaneously, the materialist view of their science. When dialectical materialism appeared, the problems of the essence of mathematics were interpreted in a new light.[1] The ideas of dialectical materialism applied to the mathematical sciences were further developed mainly in the works of Soviet mathematicians.[2] Lenin's theses on the role of abstraction in cognition, the unity and struggle of contradictions as the law of cognition, the epistemological roots of idealism, the complexity of the ways of cognition, etc., are extremely important if one is to comprehend the essence of mathematics.

Thus, the entire development of mathematics in the historical and logical aspects, in its present-day complexity and multiformity does not bypass philosophy; on the contrary, only philosophy (and we mean here dialectical materialism as the highest stage in the development of philosophical thought) leads to an adequate understanding of mathematical science.

We believe that the following thought of Lenin is of exceptional theoretical and methodological value for Marxist-Leninist philosophy and scientific knowledge as a whole: "The really important epistemological question that divides the philosophical trends is not the degree of precision attained by our descriptions of causal connections, or *whether these descriptions can be expressed in exact mathematical formulas*

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[1] See F. Engels, *Anti-Dühring*, Moscow, 1976.

[2] See A. N. Kolmogorov, "Mathematics". In: *The Great Soviet Encyclopedia*, Vol. 26, Moscow, 1954. There is an extensive bibliography appended to the article.

(Italics added.–*T.P.*), but whether the source of our knowledge of these connections is objective natural law or properties of our mind, its innate faculty of apprehending *a priori* truths, and so forth. This is what irrevocably divides the materialists Feuerbach, Marx and Engels from the agnostics (Humeans) Avenarius and Mach."[1]

These statements by Lenin show quite clearly that the problem of objective reality and its reflection in human consciousness is not a mathematical or natural scientific problem, but rather a philosophical (epistemological) one, and the solution of this problem as such cannot be arrived at by any formal or formalised theories and methods.

All of this does not depreciate, of course, the role of mathematics as a special science, but it compels a distinction between mathematics and philosophy, between form and formalism, between symbol and symbolism, etc. The fact that mathematical logic has proved to be an extremely fruitful science, widely applied in the whole of present-day science and technology, particularly in cybernetics and the theory of information, is generally recognised. But it does not provide a logical or practical basis for raising formal and formalised methods in logic and mathematics to an absolute, thereby playing into the hands of modern reactionary philosophy in one way or other.

Symbol, sign and signal have a certain cognitive significance only inasmuch as (a) their application proceeds ultimately from certain ideas viewed as subjective images of objective phenomena, and (b) human thought using symbols, signs and signals goes back, in some manner and to some extent, to the images and ideas and to their verification through human practice. In any other case, any symbolism and any semiotics prove to be just a modification of a single tradition of rejecting, overcoming, or underestimating the fundamental dialectical materialist epistemological standpoint, dialectical materialist methodology, the fundamental question of philosophy.

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 159.

These are the general conclusions to be drawn from the development of the Marxist-Leninist epistemology, in particular from the theory of reflection and its relation to mathematics. There can be no doubt that the further development of science, including materialist dialectics, will fully bear out these conclusions.

Lenin formulated the principle of the coincidence, or identity, of dialectics, logic and epistemology.[1] This does not mean that he made no distinction between them. He regarded dialectics, logic and epistemology as different aspects of an indivisible dialectical materialist philosophy. Dialectics, logic and epistemology, as distinct from the special natural, social and technical sciences, formulate and solve the fundamental question of philosophy on an abstract level and at the same time concretely, and particularise the philosophical concept of matter. Lenin did not reject the dialectical unity of philosophy and the special sciences, but he did not identify them with each other either.

In defining logic as the science of truth taken as a whole, Lenin never treated formal logic, dialectical logic and epistemology together with its basis, the theory of reflection, as special non-philosophical sciences. The relationship between philosophy and special sciences is that of unity, not identity. This idea permeates Lenin's entire philosophical work. At the same time his works (especially *Materialism and Empirio-Criticism* and *Philosophical Notebooks)* contain the idea that the fundamental question of philosophy does not exhaust its content, for it studies the universal laws of the development of nature, society and thought, the varied forms of social activity, as well as the significance of practice as the basis and objective, the criterion of human knowledge and as immediately given reality.

The various special sciences consider the objects of their analysis primarily from the point of view of their specific structures and laws, and that is what confers on them the status of special sciences, whereas scientific philos-

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[1] See V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works*, Vol. 38, p. 175.

ophy uses the structures and laws established by the special sciences in order to discover universal connections and relationships, and universal laws of objective reality and cognition; it studies the relationships between the various forms of consciousness and the various forms of social and natural being (matter).

The fundamental question of philosophy cannot be reduced either to the problem of the structural laws of being and consciousness or to the problem of the most general structural laws of the world. If the general laws of the structural composition of the world are to be interpreted in the spirit of structuralism and opposed to the fundamental question of philosophy, that leads inevitably to the old-time attempts to reject and "overcome" the difference between materialism and idealism, that is, to a repetition of the mistakes of Mach and his followers, a complete denial of the significance of scientific philosophy as such.

Lenin chose a different way, namely, the way of consolidating the status of the fundamental question of philosophy, the philosophical concept of matter precisely as a philosophical and not a natural scientific one; he chose the way of developing the theory of reflection as the theoretical basis of the dialectical materialist epistemology. Lenin's unremitting attention to the progress of natural, social and technical sciences enabled him to generalise their achievements and formulate fruitful scientific predictions (e.g. the one concerning the inexhaustibility of the electron). The subsequent development of the concrete sciences confirmed the indisputable correctness and methodological value of the investigations and conclusions contained in Lenin's philosophical works. Lenin's generalisations in the field of the natural sciences made a considerable impact on the development of physics, mathematics and other special sciences. As for his generalisations concerning the social sciences and the revolutionary practice of mankind, they had a decisive influence upon the subsequent development of human society and on the destinies of the peoples of the world.

How was it possible that Lenin, who did not consider himself a specialist in any of the natural sciences, arrived at

conclusions that were of fundamental significance for the development of science as a whole? Wherein lies the extraordinary power of Marxist philosophy, further developed by Lenin? These questions were answered by Lenin himself: "It goes without saying that in examining the connection between one of the schools of modern physicists and the rebirth of philosophical idealism, it is far from being our intention to deal with specific physical theories. What interests us exclusively is the epistemological conclusions that follow from certain definite propositions and generally known discoveries. These epistemological conclusions are of themselves so insistent that many physicists are already almost reaching them. What is more, there are already various trends among the physicists, and definite schools are beginning to be formed on this basis. Our object, therefore, will be confined to explaining clearly the essence of the difference between these various trends and the relation in which they stand to the fundamental lines of philosophy."[1]

Lenin's views on the relationship between philosophy and special sciences have long been given a simplistic interpretation both by some scholars in the special sciences and by certain philosophers. Exponents of special sciences expected philosophers to be erudite or at least specialists in one or several fields of science and technology, whereas philosophers for their part expected representatives of concrete sciences to be little short of professional philosophers. Lenin states clearly that in speaking of the philosophical idealism of some physicists he has no intention of dealing with physics as a special science, but that does not mean that specialised scientific research in physics and philosophy can develop in absolute isolation from each other.

As we pointed out earlier, a peculiar "philosophical" style recently became popular with some philosophers in various countries, who speak and write of philosophical problems, leaving them essentially unanalysed and unsolved, and dealing with purely special problems of some natural, social

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 252.

or technical disciplines. This sort of philosophising does not admit of the epistemological formulation and solution of problems, although the natural course of events directs not only philosophers, but natural scientists as well towards it.

The epistemological conclusions which Lenin has in view are linked with a series of generalisations as well as the investigation and formulation of the most general laws of development of being and consciousness. Firstly, this deals a stunning blow to the neo-positivist contention that no philosophy is needed and that special sciences are their own philosophy. Secondly, it shows that the most general conclusions of concrete sciences cannot, in the final analysis, fail to have some bearing on the philosophical definition of matter and the fundamental question of philosophy.

Thus, special sciences cannot exist and develop separately from scientific philosophy, just as, conversely, scientific philosophy presupposes concrete sciences, which in the process of continual differentiation and simultaneous integration arrive at propositions and discoveries requiring epistemological conclusions.

Physicists, chemists, cyberneticists, astrophysicists, biochemists, biologists and scholars working in other fields of scientific knowledge can use their own instruments and methods to solve their difficulties, e.g. the problems of the theory of elementary particles, quarks, etc. (to take an example from physics), which are relevant to the structure and specific laws of the development of matter. It is the specialists in the sciences who are investigating and should investigate the concrete problems of physics and other sciences. But these scientists, whether they like it or not, rely in their studies on certain philosophical, epistemological and logical principles. Similarly, philosophers investigating certain universal forms of being, the laws of the interconnection between matter and consciousness, and certain epistemological and logical problems, turn to the achievements of special sciences and draw the necessary inferences from them. If philosophers were content with the formulation and study of purely formal or purely logical and epistemological problems, they would be isolated from the special sciences and

would end in sterile abstruseness, scholasticism and, ultimately, mysticism.

Philosophy is not just a generalisation of the achievements of special sciences and man's practice, it unifies them into a single whole and serves as the methodological basis or premise for the further advancement of scientific knowledge.

Philosophy, Information Theory, and Other Trends in Modern Scientific Thought

The 1940s saw the emergence and rapid development of *cybernetics* and scientific disciplines related to it, including the special *information theory.*

The term "information" had been used long before the creation of cybernetics and information theory as special sciences. In this traditional "pre-cybernetic" sense, the concept of information is almost synonymous with the concept of reflection and does not present any new problems for epistemologists.

The problem of relationship between information and reflection arises only when the concept of information is given the content ascribed to it in mathematics, cybernetics, etc. In this case, the problem of the *objective or subjective character of information* is pushed into the foreground.

We have had occasion to point out that not only W. Ross Ashby, F. H. George, and Norbert Wiener, but also a number of other distinguished scholars in the field of cybernetics and information theory do not believe it necessary to deal with "consciousness" and "the subjective elements related to it". This standpoint was most clearly expressed by Ashby, who said that he had never felt the need to introduce the words "consciousness" and the "subjective element" into his cybernetic and information analysis.

Whatever interpretation might be ascribed to these statements by cyberneticists, the conclusion that information is an objective process is quite justified. This conclusion was most clearly formulated by Soviet scholars, as in this statement: "The concept of objective reality existing independently of man's consciousness includes, together with the processes of the transformation of matter and energy, information processes as well."[1] The development of cybernetics has confirmed this idea on more than one occasion, and we shall not dwell on it here at length. For our present purposes, another idea expressed by the two scholars is of greater significance: "The remarkable hypothesis formulated by Lenin concerning the property of reflection inherent in all matter and related to the property of sensation, but not identical with it, is comprehensively realised in the information processes studied by cybernetics."[2]

This idea elucidates the essence of reflection as the property of all matter, which is transformed through a long evolution into the highest form of reflection, human consciousness. Scholars have studied the dialectical transition from the above-mentioned property of all matter to the social and essentially logical thinking of man. But not all authors drew the necessary conclusions from this development of reflection in general. Some of them rejected the presence of reflection in all matter, others treated it as a hylosoistic and panpsychic property.

It may well be, as was pointed out by the outstanding Soviet physicist S. I. Vavilov, that future physics will include in its orbit "as the basic elementary phenomenon 'an ability related to sensation', and will explain many other things on the basis of it".[3]

We may also point out that not only cybernetics and cybernetic information, but also information pertaining to microgenetic processes confirms Lenin's *logical* hypothesis. These information processes demonstrate the correctness of Lenin's thesis on the propensity of any form of matter for *reflection,* and not *sensation* or *thought.* The latter property is only inherent in a highly developed and highly organised

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[1] A. Berg, I. Novik, "The Development of Cognition and Cybernetics", *Kommunist,* No. 2, 1965, p. 20.

[2] *Ibid.,* p. 21.

[3] S. I. Vavilov, *Collected Works,* Vol. 3, Moscow, 1956, p. 150 (in Russian).

form of matter. In other words, the development of cybernetics and information theory confirms once again Lenin's theory of reflection as the basis for dialectical materialist epistemology.

In our view, Professor Ashby and other exponents of cybernetics are right in saying that information is *objective* in character, but they err on another score, in sometimes confusing *subjectiveness* and *subjectivism.* The subjective aspect of consciousness is not only its weakness or fault, it simultaneously means its strength and advantage over purely objective but soulless, automatic information. Scientific and artistic creative work is impossible outside the psychic, internal, subjective nature of human consciousness, although the subjective aspect must naturally be based on the objective content of the human mind and thinking. *Cybernetic devices and methods are used for determining the optimal variants in the organisation and management of the economy, production, trade, transport, and other activities.* As for the scientific basis of control of social development, it is provided by the social sciences, including Marxist-Leninist philosophy, as it is a generalisation and at the same time the theoretical and methodological precondition for the successful development of the natural and technological sciences as well as the special social sciences.

The possibilities of cybernetics or any other science should not, of course, be restricted. Each of them has its own field, its problems, specific methods, organisation, etc. Cybernetics has unlimited prospects for further magnificent achievements. But, however immense they may be, cybernetics cannot replace the human brain and the human consciousness, which in their deepest essence are not only a biological, but also a socio-historical product, organ and function. *Cybernetic devices, mathematical computers and methods function as a powerful instrument in man's hands for the optimal formulation and solution of many extremely important questions. However, the scientific basis for the development of socialist society is provided by the social sciences and philosophy viewed as a scientific world outlook and as the method of the cognition and transformation of reality.*

The technology of "logical thinking" realised through cybernetic machines and considered by some theoreticians to be identical with logical thinking itself cannot fully replace man's creative thinking and dialectical logic, although it forms the basis for drawing the distinction between logic and logical technology, between creative thinking and the automatic modelling of some forms and processes of human thinking ("cybernetic thinking").

Thinking of human knowledge in its entirety and in its development, Lenin defines logic (leaving aside, for the time being, the differences between formal and dialectical logic, which were both treated as equally philosophical, and not special scientific disciplines) as "the science not of external forms of thought, but of the laws of development 'of all material, natural and spiritual things,' i.e. of the development of the entire concrete content of the world and of its cognition, i.e. the sum-total, the conclusion of the *history* of knowledge of the world".[1]

All attempts to refute or at least shake this classical definition of logic by Lenin proved to be unavailing. Much more important, however, is the fact that this definition of logic is basically in agreement with the interpretation of logic by Marx and Engels, and that it is actually built on the theoretical basis of dialectical materialist epistemology, i.e. on Lenin's theory of reflection.

Quite recently a new science began to take shape, "the science of science". Its emergence is a kind of positive reaction to the needs which arose out of the present-day enormous growth of science, the increase of its role in the life of society, an extraordinary growth in the complexity of its structure, the drawing of increasingly greater numbers of people into scholarly activity, etc. On the basis of comprehensive research into the problems of the development of science and technology as a whole, the science of science develops the scientific foundations of planning, organisation and direction of science.

As should be clear from the above, the science of science does not contain any "anti-philosophical" elements; it plays no role as a philosophical science and does not replace dialectical materialism, for example. However, one encounters just this sort of view in the literature, used for anti-scientific purposes.

We have considered only some of the fundamental aspects of Lenin's theory of reflection, but even that is evidence of its vitality, its great significance for the solution of the most complicated problems of revolutionary practice and theory now facing mankind. The progress of the present-day natural sciences and science as a whole is a veritable triumph of Marxist-Leninist philosophical thought.

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[1] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works*, Vol. 38, pp. 92-93.

P. V. Kopnin, P. S. Dyshlevy

LENIN'S IDEAS ON THE ALL-SIDED FLEXIBILITY OF CONCEPTS AND PRESENT-DAY PHYSICAL KNOWLEDGE

> All-sided, universal flexibility of concepts, a flexibility reaching to the identity of opposites–that is the essence of the matter. This flexibility, applied subjectively, = eclecticism and sophistry. Flexibility applied *objectively*, i.e. reflecting the all-sidedness of the material process and its unity, is dialectics, is the correct reflection of the eternal development of the world.
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> *V. I. Lenin*

What Philosophical Route Is Modern Physics Following?

From its very beginnings, physics has riveted philosophers' attention. Indeed, originally it was part of philosophy, and in Britain it was traditionally called "natural philosophy" almost up to the present day. But even when it became completely independent and fundamentally opposed to natural philosophy, its links with philosophy, although essentially changed, did not disappear, but became intrinsically even closer.

Physics studies phenomena, properties, and laws of a fairly general and even, for inanimate nature, universal character, and so philosophy solves the problems of matter, motion, space, time and causality largely on the basis of the experience of contemporary physical knowledge. True, some philosophers establish at times such rigid links between philosophy and the theoretical constructions of present-day physics that the concepts and laws of physics are treated in their works as philosophical categories. Hans Reichenbach, for instance, proclaims Einstein's relativity theory to be the modern philosophy, which undoubtedly leads to the elimination of philosophy as an independent realm of knowledge. Of course, radical changes in physics, such as the revolution at the turn of the century, exert considerable influence on philosophy, but neither philosophy nor physics loses in the process its own subject matter and conceptual apparatus.

Physics influences the development of philosophy not only through major advances in the study of nature, structure, and kinds of matter, and the laws of motion at different levels, in the micro-, macro- and megaworlds. Of no less significance is the study of the process of physical cognition itself, the structure of its theories, their successive changes, etc.[1] Philosophers are attracted in this respect not only by the fact that, owing to its fundamental discoveries, physics has nowadays become the leader of the natural sciences. In studying the process of physical cognition, one may follow the most typical features of present-day scientific cognition. Mathematics clearly expresses one of its aspects, the tendency towards a strictly proved deductive theory, but the entirety of knowledge even in the natural sciences can never be constructed after this pattern; science will always feel the need to construct theories involving the generalisation of empirical knowledge. On the other hand, even now there are scientific disciplines, whose method remains that of description and explanation, which essentially remain within the limits of what is provided by observation and experiment.

Mathematical apparatus in such fields is either lacking entirely or is used for the purely quantitative expression of results already obtained in an empirical way.

In contemporary physics, one deals with a combination of profound theory, in which new results are obtained with the help of a modern mathematical apparatus, and with the most

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[1] See P. S. Dyshlevy, "Epistemological Features of Present-Day Physics", *Dialectics and Modern Natural Sciences*, Moscow, Nauka Publishers, 1970 (in Russian).

sophisticated experiments. The peculiarities of physical knowledge are most clearly revealed in methods like the mathematical hypothesis, which is being used ever more extensively. Quantum mechanics and the general theory of relativity, which determine the shape of modern physics, are largely based on this method. Here, mathematics is not just a technical apparatus for the quantitative expression of relations established by experience, but a means of obtaining fundamentally new results, to be later tested by experiment. Mathematical extrapolation and experiment in their interconnection make it possible to construct a theory that is both meaningful and sufficiently stringent logically. Physics will never be satisfied with a theory that is nothing but formal apparatus, it always looks for physical meaning and sense behind the apparatus and tries to interpret the formulae and equations, including those obtained empirically.

Another distinctive feature of present-day physical cognition is the increased role of the subjective factor–the observer with his instruments and devices. The object under study interacts with the subject, and this interaction is, on the one hand, essential and, on the other, inevitable. This characteristic tendency of natural scientific knowledge at the present stage in its development poses a number of epistemological problems.

In the analysis of the peculiarities of physical knowledge the question is often asked: what route does it follow, what philosophy has foreseen it and expressed it in its categories? Reichenbach believes that modern physics has inflicted a fatal wound on Kant and Kantianism as it has refuted the concepts of *a priori* space, time, causality, etc. Indeed, modern science has proved the changeability of these concepts, and their connection with the experience of cognition in general and physical cognition in particular. All of this is correct. But there is also the fact that the study of the formal side of knowledge is of great significance for modern science, and that is exactly the aspect emphasised in Kant's epistemology.

One should also do justice to his idea of the synthesis of experience and thinking in cognition.

Modern thinkers also insist that physicists and exponents of other natural sciences have not yet fully realised the way in which the routes of their advancing knowledge were for a long time ahead correctly defined by Hegel's philosophy, and that the meeting of Hegel and Einstein has still to come. The paradoxicalness characteristic of the theories and concepts of modern physics was expressed in general philosophical form in Hegel's logic. Physicists had difficulty in accepting the dependence of spatio-temporal characteristics on the state of motion of physical systems, in accepting the quantum hypothesis, and they misinterpreted the role of the subject in cognition, and so on. This happened because they had been brought up in a different, metaphysical tradition and had not properly assimilated the lessons of Hegel's philosophy. This observation is quite reasonable, although Hegel too had missed many trends of modern natural scientific knowledge.

Lastly, some foreign philosophers are attempting to prove that modern physics is literally following the precepts of the empirical line in philosophy. Both Philipp Frank and Hans Reichenbach never tire of repeating that the method of modern physics is a replica of empirical philosophy, founded on sensational perception and analytical principles of logic as the sources of knowledge. It is, of course, only possible to reduce the method of relativistic theories or quantum mechanics to radical empiricism or logical positivism by previously distorting their logico-epistemological essence. But one cannot fail to recognise that empirical philosophy in some ways influenced physics and helped it to overcome mechanism and to accept the physical picture that was worked out by the new physics.

Thus, physics followed the roads indicated by Kant and Hegel and empirical philosophy, and yet at the same time it did not follow them. Can it be that the development of cognition in certain realms of natural science, in physics for instance, generally proceeds independently of any philosophy, is subordinate to its own laws and has no need of any philosophical epistemology? Experience shows that physics, like other domains of knowledge, has always had recourse to philosophical concepts, and essentially it cannot function without them, if only because the interpretation of scientific theories requires three types of language: (1) the language of its own concepts, (2) the language of modern formal logic, (3) the language of philosophical categories, through which the results of physical cognition are included in the general stream of knowledge and the history of world civilisation.

Neo-positivist philosophy at one time advanced the thesis that the language of philosophy and its conceptual apparatus can and should be reduced to the terms of formal logic and the concepts of the separate special sciences, thus giving philosophy the desired scientific stringency. Experience has shown, however, that, firstly, this is not practically realisable, and, secondly, it deprives us of one of the most important intellectual means of interpreting both reality itself and the results of scientific cognition. Elimination of philosophy in any form leads to the spiritual impoverishment of man. The problem is not whether we do or do not need philosophy, but what form philosophy must take so that its conceptual apparatus will improve our understanding both of reality itself and scientific knowledge of it.

The concepts created by contemporary philosophy should promote the understanding of objective reality, but they should reflect this reality, first, from the point of view of its universal properties and laws and, second, proceeding from the need for the transformation of the world in keeping with man's essence. These concepts make up the categorial apparatus of philosophy enabling the scholar to include the results of a theoretical system in the general stream of development of cognition and practice. Philosophical categories and the language expressing them form the intellectual background of the times, without which productive activity in general and interpretation of scientific theory in particular are impossible. These categories give the language system the character of socially significant knowledge. Their role in the interpretation of the theoretical system is extremely varied; in particular, they ensure, on the one hand, the freedom of theoretical thinking, and on the other, determine it,

and direct it towards comprehending objective reality in forms that are necessary for man's practice.[1]

The theoretical function of philosophical categories is due to the fact that they are created on a broader basis than the notions of any concrete field of knowledge; they generalise the experience of knowledge as a whole and not of some definite object. Categories serve as means of controlling creative thinking as they provide considerable leeway for imagination while keeping it at the same time within the limits of theoretical thinking. But that does not mean that any domain of knowledge, including physics, follows philosophy blindly. Like any practice that tests and corrects that theory (and cognition in any sphere acts as practice with respect to philosophical theory), physical knowledge introduces something new, something that was not foreseen by previous epistemology.

The interdependence of philosophy and the cognitive process in the special sciences is realised in the following form: following the logic of its own development and generalising the experiences of cognising the world, philosophy creates categories that do not just register after the fact the results obtained in the natural sciences and the humanities, but express the needs, the aspirations and the trends of their further advancement. That is precisely why science often arrives at notions that have already been considered, in one form or another, in epistemological concepts. On the other hand, the analysis of the results of cognition in the separate sciences reveals a certain inadequacy of philosophical knowledge and poses new epistemological questions.

Just this sort of interrelation has established itself between Marxist-Leninist philosophy and modern physics. Logic and epistemology elaborated by Marx and Engels and further developed by Lenin proved to have great ability to foresee the routes of the advancement of cognition in science, and in physics in particular. One may give a host of examples

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[1] See P. V. Kopnin, "The Logical Foundations of Modern Science", *Dialectics and Modern Natural Sciences*, Moscow, Nauka Publishers, 1970 (in Russian).

showing that the difficulties facing 20th-century physics and caused by the breakdown of mechanistic and contemplative materialism had already been solved on the epistemological plane by Marxist-Leninist philosophy. In the 20th century physicists realised that the absolute space and time postulated by Newton were non-existent. Marxist philosophy had already formulated this thesis in the 19th century. But at the same time, in assimilating the results of physical cognition, Marxist philosophy perfected its categorial apparatus.

Marxist-Leninist philosophy was capable of doing so because it had absorbed the entire positive experiences of philosophical development, brought to light the strong points of the epistemology of Kant, Hegel, and the empirical trend, synthesised them, trying to eliminate the limitations of each, and continually enriched the categories of theoretical thinking on the basis of the latest results obtained in various sciences, physics included. Lenin expressed this idea in his works, in particular in *Materialism and Empirio-Criticism* and *Philosophical Notebooks,* showing that Marxism, on the one hand, follows the best traditions in philosophy, the logic of the inner motion of its categories, and on the other, retains and consolidates its links with developing science and uses its experience to enrich its categories with new content and to develop them further. This explains the fact that materialist dialectics has preserved its significance as a philosophical method which conforms to the results and tendencies of the various fields of contemporary science.

The Dialectics of Concepts and the Development of Physical Knowledge

The interdependence of contemporary philosophical and physical knowledge can be demonstrated by considering the dialectics of the development of concepts and theories.

In his philosophical works, Lenin developed the idea of the interdependence and the all-sided universal flexibility of concepts as the continuously changing way (or form) of comprehending the essence of phenomena. Emphasising the objective nature of concepts, Lenin demonstrated the dialectics of their formation and functioning as instruments of man's thinking. The idea of flexibility of concepts was prompted according to Lenin, by the course of the development of philosophy, in particular the study of Hegel's *The Science of Logic.* Lenin wrote: "The *reflection* of nature in man's thought must be understood not 'lifelessly,' not 'abstractly', *not devoid of movement,* ***not without contradictions,*** but in the eternal *process* of movement, the arising of contradictions and their solution."[1] Correspondingly, the concepts formed by man "are not fixed but are eternally in movement, they pass into one another, they flow into one another, otherwise they do not reflect living life".[2] The mobility and flexibility of concepts reaches to the identity of opposites. In other words, just as there exists a universal bond between objects and processes in nature, just as any object and process may be transformed under certain circumstances into something else (its opposite), so concepts are interrelated and may be transformed into one another.

The dialectical approach, the genuinely scientific analysis of knowledge and its elements, including concepts, require, on the one hand, the discernment of differences, transitions to the opposites (from the positive statement to the negative), and, on the other, the unity of opposites, the connections between the negative and the positive. Lenin pointed out that it was Hegel (and not Kant) who showed the transition of certain categories of thinking into each other. Admittedly, Hegel's ideas were developed on an idealistic basis and therefore contained much that was mystical, fantastic and illusory. The dialectics of the cognitive processes on the materialist basis was developed by Marx and Engels, and, under changed historical circumstances, by Lenin.

Returning time and again to the characteristics of materialist dialectics as a philosophical doctrine, Lenin wrote that

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[1] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works,* Vol. 38, p. 195.

[2] *Ibid.,* p. 253.

it is the teaching which shows "how opposites can be and how they happen to be (how they become) identical—under what conditions they are identical, becoming transformed into one another—why the human mind should grasp these opposites not as dead, rigid, but as living, conditional, mobile, becoming transformed into one another."[1] But the universal interdependence and flexibility of concepts reaching to the identity of opposites is only one aspect of their dialectic relations. The mobility of scientific concepts is manipulated to its own ends by relativism, which treats it subjectively as the activity of thinking unconnected with the movement of events and processes of objective reality. But, as Lenin has shown, materialist dialectics, as opposed to relativism and sophistry, regards the transformation of concepts as the "ever deeper cognition of the *objective* connection of the world."[2]

Only materialist dialectics has shown how and why the flexibility of concepts is combined with their highest objectivity and concreteness. The development of the natural sciences, and physics in particular, in the 20th century has confirmed the inferences drawn by Lenin, and provided ample data for new epistemological generalisations. The recognition of transitions of concepts into one another, their connections and differences, the proposition concerning the objectivity of concepts, which does not rule out the relationship between the absolute and the relative in their content, should form the necessary basis for the methodology of contemporary natural sciences. One must constantly bear in mind that "man cannot comprehend=reflect=mirror nature *as a whole,* in its completeness, its 'immediate totality', he can only *eternally* come closer to this, creating abstractions, concepts, laws, a scientific picture of the world, etc., etc."[3]

Physics, like other natural sciences, manipulates concepts, and that is even more apparent in contemporary than in classical physics. Even a hundred or two hundred years ago scientists studying nature could pride themselves on dealing with facts, with the results of experiments. As Hegel remarked, according to the natural scientists "they only observe and say what they see; but this is not true, for unconsciously they transform what is immediately seen by means of the Notion. And the strife is not due to the opposition between observation and the Absolute Notion, but between the limited rigid notion and the Absolute Notion. They show that changes are non-existent.... As we find in all expression of perception and experience; as soon as men speak, there is a Notion present, it cannot be withheld, for in consciousness there is always a touch of universality and truth."[1] And further Lenin remarks: "Quite right and important—it is precisely this that Engels repeated in more popular form, when he wrote that natural scientists ought to know that the results of natural science are concepts, and that the art of operating with concepts is not inborn, but is the result of 2,000 years of the development of natural science and philosophy. The concept of transformation is taken narrowly by natural scientists and they lack understanding of dialectics."[2]

Modern physicists have no doubt that they are dealing with extremely abstract concepts which are a long way off from the mere registering of empirical observation results, and that these concepts are unstable. A different question is causing them intense discomfort: what lies behind the formulae, equations, and terms of physical theory? How can its signs and the relations between them be interpreted in order not to deprive physics of its prime objective, the cognition of objective reality? It is important to emphasise here that the major physicists of the 20th century do not treat the continuous evolution of the elements of physical knowledge as the basis for rejecting the objective existence of the physical world or its knowability. Contemporary physicists' style of thinking is essentially different from that current at the turn of the century. But this does not mean that 20th-century physics does not know the problem of the objective

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[1] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works,* Vol. 38, p. 109.

[2] *Ibid.,* p. 179.

[3] *Ibid.,* p. 182.

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[1] *Ibid.,* pp. 263-64.

[2] *Ibid.,* p. 264.

nature of physical knowledge. This problem arises in various concrete forms every time physical science advances to a new stage in its progressive development, and the existing picture of the world is replaced by another.

The problematic character of the objective nature of modern physical knowledge is clearly expressed in a book by the prominent American scientist G. C. McVittie.[1] He writes that any physicist, whether he is engaged in the field of classical, relativist or quantum physics, must answer the following questions: "What is the nature of scientific knowledge? Are its conclusions certain and absolute fragments of a final truth, or are they inevitably temporary and evanescent constructs?"[2] The premise for the philosophical standpoint of any physicist must be the thesis of the "existence of matter"[3], says McVittie; he also emphasises the point that what is immediately available to the physicist is sense-data, i.e. data obtained by observation and experiment, which are then ordered and systematised by the physicist through abstract operations. G. C. McVittie then considers two points of view on the methods of ordering and systematising the data.

He writes that, according to the first point of view, the final results of the study of sense-data expressed in the form of concepts, principles and theories show that these data "reveal the existence of an External World called Nature whose properties are *rational* and are also *independent* of the scientific observer. The observer is engaged in discovering these properties through the indications given to him by his sense-data."[4] From this point of view the laws of nature are the principles guiding the "work" of this external rational world. In this first view the notions of "cause and effect", "proof", "discovery", and "truth and falsehood" and the like are usually employed. Thus it would be said, for instance, that "Newton *discovered* the inverse square law of gravitation, that Einstein *proved* that he was *wrong* and *discovered* that the *cause* of gravitation was the curvature of space."[1] G. C. McVittie remarks that if, indeed, science is engaged in discovering the properties of an independently existing world, then "it must be admitted that the inquiry has been singularly unsuccessful. There are in fact many features of this World which the scientists have purported to discover during the past that have had to be modified or abandoned.... The particular set of properties of the External World, which, on this view, we believe ourselves to have discovered today, is in no better case, in spite of the fact that we attach to them the adjective 'modern'. We believe in these properties for precisely the same kind of reason that our predecessors believed in the features which they thought they had 'discovered', namely, because we need them in order to interpret the sense-data that are available to us at the present moment. They serve the purpose of ranging the sense-data into neat portmanteaux of theory, of rationalising the confusion with which we are presented."[2] If the first point of view (i.e. "the doctrine of a rational External World") is accepted, as G. C. McVittie stresses, the analysis of the history of physics "forces us to conclude that science is everlastingly in error, a Kepler, a Newton or an Einstein periodically proving that his predecessors were mistaken."[3]

According to the second point of view, which is an alternative of the first, G. C. McVittie goes on, science, its concepts and theories are regarded as "a method of correlating sense-data". In other words, although a collection of sense-data may or not form a rational whole, "the human mind by select-

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[1] See G. C. McVittie, *General Relativity and Cosmology*, London, 1956, p. 3.

[2] *Ibid.*, p. 3.

[3] The same idea was given its most definite expression by the French scholar M.-A. Tonnelat: "The objectivity of an external world independent of our consciousness is a postulate accepted by every physicist." [M.-A. Tonnelat, "The Renovation of the Concept of Relativity in Einsteinian Physics", *The Einstein Collection*, Moscow, 1966, p. 195 (in Russian)].

[4] G. C. McVittie, *General Relativity and Cosmology*, p. 4.

[1] *Ibid.*

[2] *Ibid.*, pp. 4, 5.

[3] *Ibid.*

ing classes of data succeeds in grouping them into rational systems". Concepts and their systems, in G. C. McVittie's view, differ only in that they differently unite into rational wholes the sense-data which physicists call physical events. Newton's mechanics and gravitation theory, for instance, group the phenomena of planet motion into one rational system, whereas quantum mechanics (another system of correlation) groups atomic phenomena into a different system. Such concepts as "electromagnetic" and "gravitational" fields, "light", "atoms", etc., are only concepts used in fabricating systems of correlation and not the characteristics of the external world. The content of these concepts may change depending on the interpretation of certain sense-data; for instance, in the interpretation of one group of data, "light" is regarded as a stream of particles, and, in another, as a wave. G. C. McVittie emphasises that, if one takes this position as the starting point, "the notions of truth and falsehood, of cause and effect, of discovery and explanation may now either be discarded or looked upon as arbitrary". In this approach, the physicist's task lies only in finding ways of constructing a rational scheme of thought in the shape of a conceptual system (theory) that includes within its framework the maximum number of apparently unconnected sense-data.

In this case, Einstein's general theory, for example, differs from Newton's theory of gravitation only in that the former as a method for correlating phenomena includes, apart from the usual movements of the planets, also the movements of Mercury's perihelion. It follows naturally that two or more physical theories can interpret one and the same physical phenomenon (e.g. the phenomenon of aberration is equally well interpreted in terms of Newton's theory and Einstein's theory), and that physical theory in general cannot be "correct" or "incorrect"–it can only be adequate or inadequate as a means of correlation within the terms of a definite group of data. Suppose a concept of the general theory of relativity as fundamental as the field of gravitation is regarded from this point of view (to which G. C. McVittie is inclined in the final analysis) as "nothing more than an aid in the calculations that have to be performed".

Accordingly, if one follows the second point of view, the laws of nature, as G. C. McVittie insists, are "simply the fundamental postulates lying at the base of a theory and are to be regarded as free creations of the human mind. These creations must be in agreements with observation, and the better they are the more observations they will serve to interpret and the more new kinds of observation they will suggest for investigation."[1] This is the essence of McVittie's reasoning.

Thus, although G. C. McVittie originally accepts (as something taken for granted) the assumption of the existence of matter (and makes no principled objections to its knowability) and regards the continuous evolution of physical knowledge as the normal state of physical science, in the final analysis he treats sympathetically the point of view that concepts and systems of concepts (theories)are merely different ways of systematising the observer's sense-data and nothing else. The result is that although the physical world exists objectively, physicists have no knowledge of it but merely systematisations of sense-data, and these data are not viewed as images of the physical world. Thus G. C. McVittie is inclined towards a subjectivist positivist conception of the nature of physical knowledge.

However, there exists another and the only correct way out of the epistemological difficulties arising in the process of constructing relativistic and later quantum physics. This way out was indicated by Lenin at the beginning of the 20th century, and it consists in accepting the standpoint of dialectical materialist epistemology, according to which the objective character of natural scientific knowledge is intrinsically linked with the dialectical nature of cognition as the process of comprehending the truth.

What aspects of the dialectics of concepts are particularly important for understanding the process of their development and successive change in modern physics or, for that matter, in science in general? (1) A scientific concept is not reducible to the registering of the immediately given, to the expression

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[1] G. C. McVittie, *General Relativity and Cosmology*, p. 6.

of sense-data. Lenin emphasises that "the approach of the (human) mind to a particular thing, the taking of a copy (=concept) of it *is not* a simple, immediate act, a dead mirroring, but one which is complex, split into two, zigzag-like, which *includes in it* the possibility of the flight of fantasy from life. . .".[1] (2) Science inevitably goes into abstraction, and that process is contradictory, since abstraction to a certain extent kills the living motion of reality. Hegel showed that "in abstract concepts (and in the system of them) the principle of motion *cannot* be expressed otherwise than as the principle of the identity of opposites."[2] Lenin develops this idea on the materialist basis as follows: "We cannot imagine, express, measure, depict movement, without interrupting continuity, without simplifying, coarsening, dismembering, strangling that which is living. The representation of movement by means of thought always makes coarse, kills–and not only by means of thought, but also by sense-perception, and not only of movement, but *every* concept. And in that lies the *essence* of dialectics. And precisely *this essence* is expressed by the formula: the unity, identity of opposites."[3] Therefore not a single abstraction, concept or law can under any circumstances be made into an absolute or fetish. Lenin makes a stand against natural scientists who made fetishes of some categories at the turn of the century, pointing out naively realistic tendencies in the interpretation of the nature of such categories. Here again he turns to Hegel. Lenin stresses that "the 'treatment' and 'twisting' of words and concepts to which Hegel devotes himself here is a struggle against making the concept of *law* absolute, against simplifying it, against making a fetish of it. *NB* for modern physics!!!"[4] And, further on: for Hegel "causality is only *one* of the determinations of universal connection, which he had already covered earlier, in his *entire* composition, much more deeply and all-sidedly; *always* and from the very outset emphasising this connection, the reciprocal transitions, etc., etc. It would be very instructive to compare the *'birth-pangs'* of neo-empiricism (respective 'physical idealism') with the solutions or rather with the dialectical method of Hegel."[1] (3) But abstractions are not the goal, but the means for comprehending the concrete, a way of approaching truth. "Thought proceeding from the concrete to the abstract–provided it is *correct* (NB). . .–does not get away *from* the truth but comes closer to it. The abstraction of *matter*, of a *law* of nature, the abstraction of *value*, etc., in short *all* scientific (correct, serious, not absurd) abstractions reflect nature more deeply, truly and *completely*."[2] To attain a deeper reflection of reality by abstractions (in concepts and theories of science), they are taken as a whole. Lenin emphasised that "human concepts are subjective in their abstractness, separateness, but objective as a whole, in the process, in the sum-total, in the tendency, in the source."[3]

(4) Finally, the movement of concepts, their successive change and development are linked not only with limitations on certain concepts in a definite (new) field of phenomena, but also with the strengthening of the absolute content of these concepts and their systems. As Lenin stressed, "not empty negation, not futile negation, *not sceptical* negation, vacillation and doubt is characteristic and essential in dialectics–which undoubtedly contains the element of negation and indeed as its most important element–no, but negation as a moment of connection, as a moment of development, retaining the positive, i.e. without any vacillations, without any eclecticism."[4]

The process of the movement of concepts presented in dialectical materialist epistemology expresses the tendencies of the development of contemporary physics, and many major physicists spontaneously arrive at this dialectic. One can distinguish four main concepts of the epistemological nature of

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[1] V. I. Lenin, "Conspectus of Aristotle's Book *Metaphysics*", *Collected Works*, Vol. 38, p. 372.

[2] V. I. Lenin, "Conspectus of Lassalle's Book *The Philosophy of Heraclitus the Obscure of Ephesus*", *Collected Works*, Vol. 38, p. 345.

[3] V. I. Lenin, "Conspectus of Hegel's Book *Lectures on the History of Philosophy*", *Collected Works*, Vol. 38, pp. 259-60.

[4] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works*, Vol. 38, p. 151.

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[1] *Ibid.*, p. 162.

[2] *Ibid.*, p. 171.

[3] *Ibid.*, p. 208.

[4] *Ibid.*, p. 226.

natural scientific notions in the methodological investigations of 20th-century natural scientists. The first concept is this: any notion is a direct, immediate reflection of some element of objective reality. According to the second concept, any notion is a means of correlating and systematising our sense-data, experiences, and ideas, i.e. experimental data (from this point of view, the value of concepts is determined by their ability to aid the construction of a maximally rational scheme which systematises apparently unconnected sense-data). The third concept: notions are a means of expression of some "absolute idea" or even abstract mathematical scheme standing above "common matter" or lying at its basis. Finally, according to the fourth point of view, concepts act as logical means of systematising the results of interaction between the object and the subject of cognition (of material-practical and theoretical interconnections), being in the final analysis a reflection and a representation of the essence of things and processes of the material world. The first point of view is naively realist, the second positivist, the third objective idealist, the fourth dialectical materialist. It must be noted that under the impact of facts the leading physicists of modern times, Albert Einstein, Niels Bohr, Louis de Broglie, Werner Heisenberg, Max Born, Paul Dirac and many others had to give up the first concept, which was most fully implemented in classical physics. They were also disappointed in the second concept (the third one, generally speaking, was not at all popular among physicists in the late 19th and the first half of the 20th century)—suffice it to recall Max Born's criticism of the positivist concepts of H. Dingle and Henry Margenau[1], which early in the 20th century appeared attractive to physicists because of their anti-metaphysical and anti-mechanist orientation, larded with scepticism, which is quite useful at a period in which concepts and notions are being radically transformed. Thus positivist epistemology cannot satisfy physicists because of the flimsiness of its foundations, contradicting the very essence of physical science: the former proceeds on the assumption that sense-data are the only and "ultimate" reality, whereas physics of necessity recognises the objective existence of the external world, which is the source of sensations and perceptions and, consequently, the content of physical knowledge. The second concept therefore leads to subjectivism and agnosticism (ample evidence for that is provided by the numerous statements by physicists directed against positivist epistemology).

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[1] See M. Born, *Physics in My Generation*, London and New York, 1956.

The ideas and principles of materialism and dialectics are becoming increasingly popular among major physicists in capitalist countries. Einstein and other relativist physicists as well as the majority of the Copenhagen school of physicists headed by Niels Bohr followed this, the only correct route in the problem of the nature of physical knowledge, but their position in the methodology of physics is not always consistent as they are trying to avoid the unambiguous materialist solution of the fundamental question of philosophy within the framework of epistemology; in other words, they do not always consistently follow the basic tenets of dialectical materialist epistemology. It should be remembered what an important role in the materialist orientation of the epistemological foundations of 20th-century physics was played by studies in the methodology of physics by Soviet physicists like S. I. Vavilov, A. F. Ioffe, Ya. I. Frenkel, M. A. Markov, V. A. Fok, I. Ye. Tamm, A. D. Alexandrov and many others who consciously accept the principles of dialectical materialist philosophy.

The creators of new fundamental physical theories of the 20th century themselves emphasised the objective character of concepts and conceptual schemes in physical science. Einstein wrote: "The concepts of physics stand in relation to a real external world, that is, ideas of things are posited which presuppose a real existence independent of the perceiving subjects (bodies, fields, etc.)."[1] On a different occasion he remarked that "without the belief that it is possible to grasp the reality with our theoretical constructions, without the

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[1] A. Einstein, "Quanten-Mechanik und Wirklichkeit", *Dialectica*, Vol. 2, No. 3/4, 1948, p. 321.

belief in the inner harmony of our world, there could be no science. This belief is and always will remain the fundamental motive for all scientific creation."[1]

The leading physicists of the Copenhagen school headed by Niels Bohr have frequently pointed out the continuity of classical and quantum physics, both of which recognised the objective character of concepts and conceptual schemes. Bohr wrote that the widening of the existing conceptual framework of physics expressed in the construction of quantum and relativistic physics does not "imply any appeal to the observing subject, which would hinder unambiguous communication of experience. In relativistic argumentation, such objectivity is secured by due regard to the dependence of the phenomena on the reference frame of the observer, while in complementary description all subjectivity is avoided by proper attention to the circumstances required for the well-defined use of elementary physical concepts."[2] Werner Heisenberg remarks: "Objectivity has become the first criterion for the value of any scientific result. Does the Copenhagen interpretation of quantum theory still comply with this ideal? One may perhaps say that quantum theory corresponds to this ideal as far as possible. Certainly quantum theory does not contain genuine subjective features, it does not introduce the mind of the physicist as a part of the atomic event."[3]

One may draw the conclusion that, as far as the recognition of the objective character of physical knowledge is concerned, the standpoint of the founders of modern physics does not differ fundamentally from that of the founders of classical physics (though in 20th-century physics, of course, the logical procedures for representing objective reality are changed).

Recognition of the objectivity of concepts and conceptual systems in 20th-century physics does not mean, however,

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[1] A. Einstein and L. Infeld, *The Evolution of Physics*, New York, 1961, p. 296.

[2] N. Bohr, *Essays 1958/62 on Atomic Physics and Human Knowledge*, New York, London, 1963, p. 7.

[3] W. Heisenberg, *Physics and Philosophy. The Revolution in Modern Science*, New York, 1962, p. 55.

that there are no significant differences between the exponents of classical and quantum physics in the interpretation of the epistemological nature of physical knowledge. The point is that, as Bohr has demonstrated, in order to ensure objectivity of description and integral coverage of experimental data, "it is necessary in almost every field of knowledge to pay attention to the circumstances under which evidence is obtained".[1] This point is made with the utmost clarity in Heisenberg's *Physics and Philosophy.* He admits that at the base of the natural sciences lie various forms of realism, whose essence can be expressed thus: we objectivate a proposition if we insist that its content does not depend on conditions under which it can be verified. Accordingly, the measure of the objectivity of propositions of a physical theory is determined by the independence of verification conditions. In this respect, Heisenberg singles out two forms of realism, practical and dogmatic (or metaphysical).

The first admits that "there are statements that can be objectivated and that in fact the largest part of our experience in daily life consists of such statements", whereas the second "claims that there are no statements concerning the material world that cannot be objectivated",[2] and that a natural scientist's statements do not depend on the conditions in which they are varified. Dogmatic realism in the past played a significant role in the development of the natural sciences; suffice it to mention here that the viewpoint of classical physics is the viewpoint of dogmatic realism. Only after the appearance of quantum physics did it become clear that natural sciences are possible without dogmatic realism as their basis, that practical realism has always been the essential basis of the natural sciences and will remain such in the future.

The course of Heisenberg's argument shows that he is not talking about objectivity of description in the sense of recognising the external world as the source of our knowledge,

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[1] N. Bohr, *Atomic Physics and Human Knowledge*, New York, 1958, p. 2.

[2] W. Heisenberg, *Physics and Philosophy*, p. 81/82.

but in the sense of the correlation between the subjective and the objective in the cognitive process. In more definite terms, Heisenberg's argument could be interpreted as follows: in the methodology of earlier physics it was assumed that all physical knowledge consisted exclusively of concepts and propositions that characterised only physical objects, whereas the new methodology explicitly recognises the presence also of concepts and propositions which characterise the conditions of obtaining information about the external world. The metaphysical and mechanistic epistemology, which regards the subjective only as something illusory, secondary, superficial and erroneous in the cognitive process and ignores the dialectics of the objective and the subjective, cannot serve as the epistemological method for 20th-century physics. That, essentially, is Heisenberg's conclusion. And it is, of course, the correct conclusion. The trouble is, however, that Heisenberg goes no further: he fails to see, or does not want to see, a new, dialectical materialist epistemology which serves as the necessary instrument of cognitive activity in the hands of contemporary scholars. From this point of view, all his attempts to find a "new epistemology" "are superfluous, as it exists already and, moreover, many physicists are successfully using it.

The Dialectics of the Subject and the Object as the Starting Point in the Interpretation of the Objectivity of Physical Concepts and Theories

The construction of relativistic and later quantum physics resulted in the posing of a question within the framework of physical methodology that had been the subject of philosophical discussion long before 20th-century physics came into being: does the researcher obtain objective knowledge, when no physical event can be described without reference either to the observer or to the experimental instruments which, as it appears, may essentially change the behaviour of physical objects? In relativistic physics, physical events cannot be described without an indication of the velocity of

motion of the inertial frame of reference in which the observer is situated; in quantum physics, atomic events cannot be described without reference to the measuring devices used by the researcher and to his procedures in carrying out observations of physical objects etc., the observation itself presumably changing the course of events.

Dialectical materialist epistemology answers this question, and the essence of the answer is that the interaction of the subject and the object on the practical level does not contradict the recognition of the objective existence of the external world, but actually presupposes that existence, and that, accordingly, the subjective element in the knowledge obtained expresses an aspect in the objective activity of the subject and is irreducible to something entirely illusory, erroneous and conditional. The objectivity of our knowledge is due to the fact that the source of that knowledge is the objective external world, and that in the course of cognitive activity man obtains objective truth, i.e. knowledge that does not depend on the subject. However, this objective truth in our knowledge is not expressed all at once in its entirety and absolutely, but only approximately relatively and partially at every given stage in the development of science. This dialectical contradiction of the objective and the subjective, the absolute and the relative, far from rejecting the modern form of materialism (as Heisenberg and some other Western physicists tend to think), was largely investigated by Marx, Engels, and Lenin long before the debate on the objectivity of the knowledge provided by relativistic and quantum physics.

Consequently, the development of modern physics has followed the road of materialism and dialectics in spite of the fact that the founders of modern physics themselves tried to reject the thesis of the undoubted dialectical materialist orientation of science in general and physics in particular. Einstein, Bohr and the majority of other modern physicists agree that the conceptual system and description methods in 20th-century physics are objective in their nature, i.e. they are conditioned by the existence of a material world cognisable through material practical interaction between the subject of cognition and physical objects as fragments of this world. The relativist and quantum methodology does not contradict the thesis of the possibility of absolutely objective description in physics, regarding this thesis as an ideal to be attained by the development of physical knowledge which is realised in each (new) concrete theory and each concrete description procedure only partially, incompletely, and relatively. But it is precisely this methodology that corresponds to Lenin's doctrine of the dialectics of the relationship between the objective and the subjective, the absolute and the relative.

Let us proceed now to a more concrete consideration of concepts and conceptual systems (their development and interdependence) in 20th-century physics. For this purpose, we shall require certain additional definitions. The basic cognitive relation in the methodology of 20th-century physics is, in our view, as follows: physical objects–conditions of cognition–the observer; in other words, man's activity as the subject of cognition is characterised through the two notions of "observer (researcher)" and "conditions of cognition".

The conditions of cognition at the experimental level are taken to mean the background of the physical processes studied by the observer who, in an indirect way, interacts with physical objects, as well as instruments for studying them, namely, frames (bodies) of reference and measuring devices designed by the researcher on the basis of certain theoretical premises. At the theoretical level, conditions of cognition are taken to mean the "language of observation" functioning in the given theoretical system, as well as the scientific background and the means of developing and interpreting new theoretical systems.

Bearing these definitions in mind, we may point out that the conceptual apparatus of modern physics may be classified in the following way: (a) concepts "immediately" characterising certain aspects of the physical world (e.g. motion, interaction, causality, space, time); (b) concepts characterising the physical object "in itself" (e.g. invariant quantities and correlations, matter, field, vacuum); (c) concepts characterising the relation of conditions of cognition to the physical object (e.g. the variant quantities, let us say, co-ordinates, the relativity of simultaneity); (d) concepts characterising the conditions of cognition in their relation to the object and the observer (e.g. the body of reference, the system of co-ordinates, measuring devices).

It may be assumed that the conceptual apparatus of physical science will develop in the following directions: (a) making the content of the concept more precise; (b) consideration of the limitations on the applicability of the concept; (c) limiting the sphere of applicability of the concept; (d) splitting the concept into two or several other concepts; (e) principled rejection of the justifiability of certain concepts; (f) the construction of fundamentally new concepts. It must be emphasised that both relativist and quantum physics simultaneously follow several ways of developing the conceptual apparatus.

Let us try to particularise these propositions, so to speak, tentatively. Let us note first of all that the content of physical concepts is continually made more precise through planned experiments; at every given stage the quite definite "extension" of the given concept (its sphere of application) is already known. Of course, the concept enters one or several logical systems characterised by equal spheres of application for all component concepts; it is just in the case of a concept's membership in such systems that the problem of the limits on its applicability arises.

Relativistic and quantum physics are characterised not only by the "splitting" and limitations of the applicability of old concepts, but also by the formulation of concepts that express most graphically the qualitative specificity of the physical phenomena under study. Thus, in relativistic physics, the "extension" of the concept of the velocity of the diffusion of physical interactions is limited (the velocity of light travelling in a vacuum is regarded as maximum velocity), the concept of velocity is "split" as it were into two concepts–the velocity of light travelling in a vacuum and all the other velocities; the concepts of space and time are made more precise in their content, too (the concepts of "absolute space", "absolute time", "absolute simultaneity" and others are eliminated as fictitious), and so on.

Relativistic physics rejects the concept of "mechanical ether" and introduces a fundamentally new concept, that of field. This concept is then "split", as it were, into the concepts of electromagnetic field and gravitational field (it is not charges and particles, but the field in the space between charges and particles that is essential for comprehending physical phenomena). After the emergence of relativistic physics, a process of classifying fundamental and non-fundamental physical concepts started in physical science (for a "non-fundamental" concept may prove to be "fundamental", as happened, for instance, with the concept of simultaneity in relativistic physics). Physicists perceived the relative nature of the division of concepts into "fundamental" and "non-fundamental" and, moreover, became more careful in their treatment of "fundamental" concepts and more critical in their attitude to existing definitions of concepts.

Quantum physics, too, begins by limiting the sphere of application of a number of concepts of classical physics. For example, quantum physics limits the "extension" of such concepts as "co-ordinate" and "impulse of a particle". These classical concepts can characterise atomic objects only in relation to measuring devices and are mutually exclusive. In this sense, the Copenhagen interpretation of quantum mechanics may be regarded as a kind of adaptation of "old" classical concepts to the new mathematical formalism for the description of new, i.e. atomic physical objects. But this does not mean that all characteristics of microparticles are related to a certain class of macroscopic measuring devices: such characteristics as charge, mass, spin, degrees of freedom, the form of the wave equation for the given field, the law of interaction with other particles and some others do *not* depend on the structure of the device (whereas the particle's co-ordinates and impulse are not unambiguous or certain macroscopically). This aspect of the problem was especially stressed by several prominent Soviet scholars, in particular M. A. Markov and V. A. Fok. Thus, V. A. Fok wrote: the subject matter of quantum mechanics is "the result of interaction between the atomic object and the device described in classical terms. The properties of the atomic object are inferred from the consideration of such interactions, and the predictions of the theory are formulated as the expected results of interactions. This formulation of the problem does not rule out the introduction of quantities characterising the object itself irrespective of the device (the charge, mass, spin of the particle, etc.), but at the same time permits the study of the object as regards those of its properties (e.g. corpuscular or wave) whose manifestation is conditioned by the structure of the device.

"The new formulation of the problem thus permits the consideration of cases where the different aspects and properties of the object are not manifested simultaneously, i.e. where it is impossible to particularise the process in which the object participates. This will be the case where the manifestation of the object's different properties (e.g. the electron's propensity for localisation and for interference) requires incompatible external conditions. Following Bohr, one may say that properties appearing in mutually exclusive conditions complement each other. Consideration of the simultaneous manifestation of complementary properties makes no sense. That is why there is no inner contradiction in the concept of 'corpuscular-wave dualism'."[1]

However, the construction of quantum (as well as relativistic) physics, apart from limiting the sphere of application of classical physical concepts, also involves the construction of fundamentally new ones. This was particularly stressed by the Soviet scholars V. A. Fok and M. E. Omelyanovsky. Bohr's main efforts, as V. A. Fok pointed out, were directed towards demonstrating the limitations of old classical concepts; little is said in Bohr's works about the features of the new basic concepts of quantum mechanics which in this sense take the place of classical concepts, and the unlimited possibilities for making descriptions of atomic objects more precise through new concepts are not emphasised. "Philosoph-

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[1] V. A. Fok, *Quantum Physics and the Structure of Matter*, Leningrad, 1965, pp. 11-12 (in Russian).

ically significant are not only limitations inherent in the description of phenomena *per se*, irrespective of instruments of observation ("complementarity"), but also the constructive part of quantum mechanics and new fundamental concepts linked with it.

"In our view, such fundamental concepts on which atomic physics may be built are as follows: relation to means of observation, the difference between the potentially possible and the accomplished (or between prediction and fact) and, lastly, the concept of probability as the measure of the potentially possible. The quantum physics apparatus whose immediate function is that of calculating this measure is at the same time an instrument for introducing new abstractions, new and finer physical concepts and a more precise description of atomic objects on that basis. Owing to the introduction of new fundamental concepts, the concept of causality is also given a new formulation."[1]

The construction and development of relativistic and quantum physics have also demonstrated the flexibility and interdependence of such fundamental concepts as "interaction", "forms of motion", "space and time", "law", "causality" and many others. The emergence of the so-called "unifying" physical theories (such as the special theory of relativity, and quantum mechanics), attempts to create a "unified field theory" and other trends towards unification in the development of 20th-century physics are a convincing proof of the inner interdependence of physical concepts.

Modern Physics as a Source of New Logical and Epistemological Ideas

Following Heisenberg,[2] one may insist that there are at present a number of closed theoretical systems (physical theories) in physical science: Newton's mechanics, thermodynamics (including the statistical approach), electrodynamics and the special theory of relativity, quantum mechanics and the general theory of relativity (the theory of elementary particles being constructed now will also be a new theory). Each of these systems has its own fundamental concepts and basic principles. The relationship between these closed systems of concepts is this: classical mechanics is contained in the special theory of relativity as its extreme case (where light velocity may be viewed as infinite) and in quantum physics as its extreme case, where the Planckian quantum of action is viewed as infinitely small. Classical mechanics and, partially, electrodynamics and the special theory of relativity are necessary for quantum mechanics as the basis for the description of experiments. Thermodynamics may be linked with any of these systems with the exception of the general theory of relativity. The independent existence of electrodynamics and the special theory of relativity as well as quantum mechanics may provide evidence for the possible appearance of a new closed system of concepts, namely, the theory of elementary particles, which will contain the two systems indicated above as extreme cases.

Physicists who are interested in the logical and epistemological analysis of their theories and the elucidation of their philosophical foundations, and Marxist philosophers studying the methodology of physical knowledge face the major problem of finding out what new questions arise in this analysis and what methods should be used in their solution, thus promoting, on the one hand, a more correct interpretation of the results of physics, and the establishment of the basic trends of its development, and, on the other, the replenishment of the stock of materialist dialectical concepts with new categories, in particular those expressing the relationship between experiment and speculation in cognising physical objects, the role of the categorial apparatus in the interpretation of physical theories, the significance of various principles in the establishment, choice, and verification of theoretical systems of knowledge, and so on.

It will not be out of place here to draw attention to some of Einstein's remarks concerning the assessment of the con-

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[1] V. A. Fok, "Notes on Bohr's Articles on His Argument with Einstein", *Uspekhi fizicheskikh nauk*, Vol. LXVI, No. 4, 1958, p. 600.

[2] See W. Heisenberg, *Physics and Philosophy*, New York, 1962, Chapter VI.

ceptual apparatus of modern physics in general. Earlier we quoted his statements about the objective character of physical concepts. This proposition, however, does not rule out the fact that the relation between experiment and theoretical constructs (certain ways of describing reality) is very complicated and many-valued. Einstein stressed that "there is no empirical method without speculative concepts and systems; and there is no speculative thinking whose concepts do not reveal, on closer investigation, the empirical material from which they stem."[1] At the same time Einstein admitted the "purely fictitious character" of the foundations of any physical theory. He wrote that most of the 18th and 19th-century natural philosophers were "possessed with the idea that the fundamental concepts and postulates of physics were not in the logical sense free inventions of the human mind but could be deduced from experience by "abstraction"—that is to say, by logical means. A clear recognition of the erroneousness of this notion really only came with the general theory of relativity, which showed that one could take account of a wider range of empirical facts, and that, too, in a more satisfactory and complete manner, on a foundation quite different from the Newtonian ... the fictitious character of fundamental principles is perfectly evident from the fact that we can point to two essentially different principles, both of which correspond with experience to a large extent; this proves at the same time that every attempt at a logical deduction of the basic concepts and postulates of mechanics from elementary experiences is doomed to failure."[2]

Recognition of the fictitious character of the basic principles of physics, as Einstein points out later, does not, of course, preclude the thesis that in science we can "hope to be guided safely by experience"[3] in determining the essence of things and the regular connections of phenomena.

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[1] A. Einstein, Foreword to Galileo Galilei's Book *Dialogue Concerning the Two Chief World Systems*, Berkeley and Los Angeles, 1962, p. XVII.

[2] A. Einstein, *Ideas and Opinions*, New York, 1954, pp. 273-74.

[3] *Ibid.*, p. 274.

A distinctive feature of the methodology of 20th-century physics is the recognition of an extremely complex and equivocal relation between the conceptual apparatus functioning in a given theoretical system and the experimental situation. In other words, the method of description in physics is not formed in a direct logical way from experimental situations: its content and structure are also greatly influenced by the conditions of cognition at the level of theoretical description, the "inner" laws of the development of theoretical knowledge. If one takes the view of metaphysical mechanistic epistemology, it is impossible to even imagine, let alone understand, how one can construct two different theories based on identical theoretical foundations; but that is exactly the situation that arose in physics after the appearance of the general theory of relativity. The fact that the development of conceptual systems in 20th-century physics was not always motivated by immediate needs and experimental results and concrete experimental situations, that there are "inner" laws of the development of theoretical knowledge, that there is no rigid unequivocal relation between the instruments of description and explanation and the given experimental situation—all this can be rationally interpreted only on the basis of dialectical materialist epistemology, which throws light on the dialectics of the relation between theory and experiment, viewing experiment as the basis and criterion of truth in theoretical description and explanation and at the same time pointing out the complicated nature of the content and structure of theoretical knowledge and of the laws of its development.

Einstein then emphasises that physical science before the 20th century knew only indivisible concepts. In 20th-century physics, the concepts "*split into two branches*, one of which belongs to *quantum theory*, the other, to the *(relativist) theory of the field*. Their unification is desirable, but not attained yet. The second branch might develop on the basis of the Faraday–Maxwell ideas concerning the substitution of the concept of field for that of mass. The idea that matter can be viewed as the points of special density of the field has so far eluded realisation. The tendency is preserved, however, to reduce the multiformity of phenomena to a purely theoretical scheme of the least possible number of elements."[1] Thus, in the opinion of Einstein himself, he failed to formulate the "pure physics of the field": relativistic physics was built on two fundamental concepts, those of matter and field. In the absence of a unified system of concepts in modern physics, Einstein is justified in drawing the conclusion about the problematical character of ways of expressing the real states of the physical systems under study. In Einstein's view, "it is at present unknown what adequate means of expression and what fundamental concepts are to be used for the complete description of the 'real state' of the investigated physical systems (the material point? the field? some other means of definition that is yet to be discovered?)".[2]

The construction of relativistic and quantum physics naturally involves an advance in the conceptual system and principles of physics as well as in the physicist's methods of thinking. Heisenberg says that in relativistic physics for the first time the need was shown for periodic changes in the fundamental principles of physics, and that "it would certainly have been still more difficult to understand quantum theory had not success of the theory of relativity warned the physicists against the uncritical use of concepts taken from daily life or from classical physics".[3]

It is now generally recognised that relativistic physics was the main force rejecting the traditional metaphysical axioms and asserting the right of the physicist to advance ideas according to his previous experience. The general theory of relativity introduced many new fruitful theoretical constructions into physics and produced a critical attitude to propositions that seemed to be self-evident. I. Ye. Tamm believes that "the works of Bohr and Einstein exerted a decisive

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[1] A. Einstein, *A Collection of Scientific Works*, Vol. 2, Moscow, 1966, p. 399 (in Russian).

[2] "Remarques prėliminaires sur les concepts fondamentaux par A. Einstein", Louis de Broglie, *Physicien et Penseur*, Paris, 1953, pp. 6, 7.

[3] W. Heisenberg, *Physics and Philosophy*, p. 127.

influence not only on physics in this century, but on the modern scientific view of the world as a whole. The theory of relativity and quantum theory demonstrated the general laws of the development of scientific cognition. Our knowledge is not *a priori*, it follows from the analysis and generalisation of the entire human experience. Therefore any breakthroughs into a new and hitherto unknown domain call for a radical revision and generalisation of the basic concepts and notions, even those of space, time and physical law. This does not mean, of course, that a new stage in the development of science neglects the results of the preceding one. With every new step, the limits of the applicability of concepts and laws that were regarded as universal are established and more general laws are discovered. Therefore, the demands on new theories are becoming more stringent: a theory must not only explain newly discovered facts, but also include all the previously discovered laws as extreme cases, indicating the precise limits of their applicability. Thus, the entire foundations of classical physics are contained in the more general laws of the theory of relativity and quantum theory, from which they follow, under conditions in which the velocities of bodies are small in comparison with the velocity of light and the spatio-temporal scale of phenomena and body masses are such that the so-called action is great in comparison with the quantum constant h."[1]

Thus, the construction, development and functioning of concepts as a way of understanding reality in 20th-century theoretical physics–one of the most advanced forms of theoretical knowledge in general–give convincing evidence of the dialectical nature of concepts, their flexibility and many-sidedness, and of the infinite variety of the forms of their interdependence in specific logically closed systems called physical theories. All this demonstrates, once again, the correctness of the Marxist thesis: "The significance of the *uni-*

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[1] I. Ye. Tamm, "In Memory of Niels Bohr", *Problems of the History of Natural Science and Technology*, No. 17, Moscow, 1964, p. 3 (in Russian).

versal is contradictory: it is dead, impure, incomplete, etc., etc. but it alone is a *stage* towards knowledge of the *concrete*, for we can never know the concrete completely. The *infinite* sum of general conceptions, laws, etc., gives the *concrete* in its completeness. The movement of cognition *to* the object can always only proceed dialectically: to retreat in order to hit more surely. . . ."[1]

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[1] V. I. Lenin, "Conspectus of Hegel's Book *Lectures on the History of Philosophy*", *Collected Works*, Vol. 38, p. 279.

B. M. Kedrov

LENIN ON THE DIALECTICAL TREATMENT OF THE HISTORY OF THE NATURAL SCIENCES

Although Lenin was not a professional historian of the natural sciences, the history of the sciences of nature was given considerable attention in his works. Lenin linked it up with broader philosophical problems–methodological and world-outlook ones, and with the general problem of the relationship between Marxist philosophy and modern natural science, which always attracted Lenin's attention. We shall attempt to outline, from this standpoint, the position taken by Lenin with respect to the history of the natural sciences, and the significance he attributed to the study of the development of the natural sciences from the point of view of the further elaboration of Marxist dialectics.

The History of the Natural Sciences as the Source of the Creative Elaboration of Marxist Dialectics

Lenin viewed the history of separate natural sciences and of science as a whole as a mighty life-giving source for the creative elaboration of materialist dialectics. In Lenin's opinion, materialist dialectics had to be enriched by philosophically interpreted and logically processed and enriched results of the entire preceding development of the sciences of nature. Apparently, Lenin conceived this idea as he was writing *Materialism and Empirio-Criticism*, where the idea is substantiated that, according to the dialectical point of view, one has to consider the evolution of human knowledge from lack of knowledge. This proposition contains the essence of the dialectical view of natural science history. According to Lenin, to think dialectically in this field means not to assume our knowledge as ready-made and immutable, but to look into the ways in which out of ignorance grows knowledge, and incomplete and imprecise knowledge becomes more complete and precise.

The first answer to these questions is Lenin's idea of the stages of cognition. In the book mentioned above these stages are primarily considered in their concrete expression (classical mechanics and new physics). Later, in the *Philosophical Notebooks,* we find broader generalisations.

In characterising the structure of Hegel's *The Science of Logic,* Lenin first of all determines the role and place of the history of science in relation to dialectics. Hegel's *The Science of Logic* has the following structure: the teaching of being, the teaching of essence, the teaching of concept. Proceeding from the history of science and its philosophical generalisation, Lenin reveals and gives a materialist interpretation of the rationale for this division: "The concept (cognition) reveals the essence (the law of causality, identity, difference, etc.) in Being (in immediate phenomena)–such is actually the *general course* of all human cognition (of all science) in general. Such is the course also of *natural science* and *political economy* [and history]. ***Insofar*** Hegel's dialectic is a generalisation of the history of thought. To trace this more concretely and in greater detail in the *history of the separate sciences* seems an extraordinarily rewarding task. In logic, the history of thought ***must*** by and large, coincide with the laws of thinking."[1]

Lenin then particularises that general statement and indicates the various concrete stages of the movement of human thought from appearance to essence. "First of all impressions *flash by,* then *Something* emerges–afterwards the concepts of *quality* # (the determination of the thing or the phenomenon) and *quantity* are developed. After that study and reflection

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[1] V. I. Lenin, "Plan of Hegel's Dialectics (Logic)", *Collected Works,* Vol. 38, p. 318.

direct thought to cognition of identity–of difference–of Ground–of the Essence versus the Phenomenon–of causality, etc. All these moments (steps, stages, processes) of cognition move in the direction from the subject to the object, being tested in practice and arriving through this test at truth (=the Absolute Idea)."[1]

The dialectically generalised and elaborated history of the natural sciences, including the history of their various branches, must, in Lenin's view, serve as the means of finding out and substantiating the successive stages through which human cognition and, consequently, every science goes–for the whole of human cognition and not just within the framework of one particular science.

From this general point of view, the stages in the process of scientific cognition are the categories of logic, the categories of dialectics. Lenin explains this idea in the following manner. Man faces the network of natural phenomena. The man of instincts, the savage, does not single himself out from nature, whereas the conscious man does, the categories being the stages of this separation, i.e. of the cognition of the world, the nodes in the network which permit him to cognise it and achieve power over it.

This formulation of the problem is a direct indication of the enormous role to be played by the history of science in working out the categories of dialectics and at the same time the proper system of the entire dialectics. In dealing with dialectical logic, Lenin emphasises this focal point: logic (dialectics) must be inferred from the history of the cognition of the world, hence, from the history of science. Logic is not the science of the external forms of thought, but of the laws of the development of the whole concrete content of the world and its cognition. In other words, logic is the result, the sum total, the conclusion from the history of cognising the world.

That is why on various occasions and in many places in the *Philosophical Notebooks* Lenin comes back to the idea that it is necessary to elaborate, generalise and summarise

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[1] *Ibid.,* p. 319.

the history of science, including natural science, from the position of dialectics. He poses this task as one of the most important and immediate tasks for Marxists, and, far from losing its enormous theoretical significance, it has acquired even greater importance through the attempts to elaborate a system of dialectical categories and, through that, a system of dialectics as a science. But that requires an all-sided and profound study of the correlation of the historical and the logical in the aspect pointed out by Lenin when he spoke of the dialectical elaboration of the history of science. Lenin insisted that it was necessary to study the history of thought from the point of view of the development and application of the general concepts and categories of logic.

The great importance attached to this problem by Lenin is clear from this statement: "Continuation of the work of Hegel and Marx must consist in the *dialectical* elaboration of the history of human thought, science and technique."[1]

Lenin treated the problem as a matter of principle. And this is quite understandable if one takes into account that Lenin viewed the dialectical generalisation of the history of science as a concrete way towards the development of a general theory of Marxist dialectics–the proletariat's revolutionary weapon on the eve of the proletarian revolution. While posing the problem before Marxists in its most general form, Lenin also tried to particularise it whenever possible. Thus, in analysing the category of substance and its place in deepening our knowledge of matter, he pointed out that two kinds of examples were necessary: first, from the history of the natural sciences and, second, from the history of philosophy. But he immediately remarks that it is not "examples" that are needed here, as comparison is not proof, but the quintessence of both of the above-mentioned histories and the history of technology.

A similar statement is made on a different occasion, where Lenin is dealing with the history of cognition of the universal connection of the world's phenomena. "Thousands of years have passed since the time when the idea was born of 'the connection of all things', 'the chain of causes'. A comparison of how these causes have been understood in the history of human thought would give an indisputably conclusive theory of knowledge."[1] In arguing that the splitting of a single whole and the cognition of its contradictory parts is the essence of dialectics, Lenin insists: "The correctness of this aspect of the content of dialectics must be tested by the history of science."[2] To carry out these instructions at least partially, a group of philosophers and historians of natural science and technology made an attempt to show the correctness of the aspect (or essence) of dialectics, pointed out by Lenin, in a joint monograph, *Contradictions in the Development of the Natural Sciences.*[3]

On more than one occasion the question arose: who must carry out the task that Lenin set for Marxists concerning the dialectical elaboration of the history of the natural sciences–philosophers or natural science historians? Philosophers alone cannot fulfil this task as it requires extensive knowledge of the history of a certain branch of natural science and of the totality of the natural sciences, a knowledge which philosophers, with rare exceptions, lack. Natural science historians, in their turn, especially those who follow the empirical descriptive trend in the study of the history of science, lack competence in the field of philosophy. Thus, neither the former nor the latter can cope with this task alone. What one needs here is the same close contacts between philosophers and natural science historians and the same fruitful mutual assistance that Lenin bequeathed when he spoke of the alliance between philosophers and modern natural scientists. Only if such creative, businesslike contacts are established can there be any hope that the task set by Lenin will be fulfilled.

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[1] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works*, Vol. 38, pp. 146-47.

[1] V. I. Lenin, "Conspectus of Lassalle's Book *The Philosophy of Heraclitus the Obscure of Ephesus*", *Collected Works*, Vol. 38, p. 349.

[2] V. I. Lenin, "On the Questions of Dialectics", *Collected Works*, Vol. 38, p. 359.

[3] See *Contradictions in the Development of the Natural Sciences*, Moscow, 1965 (in Russian).

Thus, the idea that stands out in the *Philosophical Notebooks* is that the development of dialectics and its systematisation must be carried out through a philosophical elaboration of the history of science. It is thus easy to see why it was that, when Lenin started listing those fields of knowledge whose philosophical elaboration was to form the basis for epistemology and dialectics, he listed the history of separate sciences (including, of course, the natural sciences) among the first, right after the history of philosophy. That was the way in which Lenin conceived the elaboration of Marxist dialectics on the basis of the logical generalisation and analysis of the history of science, including the history of the natural sciences.

The History of the Natural Sciences and Modern Times

As we see, Lenin in his philosophical works constantly turned to the history of natural science and its various branches using the data of physics, chemistry, biology, geology and other sciences as irrefutable arguments against idealism and agnosticism. He viewed the contemporary natural sciences as inseparably connected with their history and, conversely, he regarded that history from the point of view of the present. Comparing the past with the present, Lenin revealed the trends of the development of thought in the natural sciences at all of its stages. As a result, Lenin not only brought out the fundamentally new features that were characteristic of the contemporary natural sciences–he also discovered in the scientific knowledge of the past the rudiments of modern ideas and answers to questions which only seemed to be arising for scientists of our own times. The history of the sciences of nature provides ample evidence that man struggled with these problems a long time ago and, most important of all, correct answers to these questions were more than once obtained in the past.

As natural scientific discoveries always introduce fresh scientific data, the problems arising from the consideration

of those data always seem unusual and in need of a new approach. In fact, though, the latest scientific discoveries quite often raise time-honoured philosophical problems, only slightly changed by modern scientific data.

In his book, *Materialism and Empirio-Criticism,* Lenin traced in detail how, against the background of imperialism and proletarian revolutions, "the latest revolution in natural sciences" could be used by reactionary philosophy for the benefit of idealism and agnosticism, which had caused the crisis in contemporary physics and the natural sciences. Lenin wrote: "The new physics, having found new kinds of matter and new forms of its motion, raised the old philosophical questions because of the collapse of the old physical concepts."[1]

Such situations had arisen in various natural sciences earlier too, as is shown by the history of science, and they always ended in the same way, in a defeat for idealism and a victory for materialism. To confirm this idea, Lenin cites some facts. Introducing the term "physical" idealism, he recollects an episode from the history of philosophy and the natural sciences: in 1866, Ludwig Feuerbach counted the physiologist Johannes Müller among the physiological idealists. In studying the "mechanism" of our sense organs in connection with sensations (e.g. pointing out that the sensation of light derives from various stimuli upon the eye), Müller was inclined to believe that our sensations are not images of objective reality. "That a number of eminent physiologists at that time *gravitated* towards idealism and Kantianism is as indisputable as that today a number of eminent physicists *gravitate* towards philosophical idealism. 'Physical' idealism, i.e. the idealism of a certain school of physicists at the end of the nineteenth century and the beginning of the 20th century, no more 'refutes' materialism, no more establishes the connection between idealism (or empirio-criticism) and natural science, than did the similar efforts of ... the 'physiological' idealists. The deviation towards

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 279.

reactionary philosophy manifested in both cases by one school of natural scientists in one branch of natural science is a temporary deflection, a transitory period of sickness in the history of science, an ailment of growth, mainly caused by the *abrupt break-down* of old established concepts."[1]

This comparison of the present with the recent past in the development of science, as Lenin presents it, is not in the nature of an external analogy but is based on revealing a basic law: the natural sciences are not a nutrient medium for idealism; it is by its very nature alien and hostile to the natural sciences, whose foundations and sources are profoundly materialistic. Reactionary philosophy can therefore influence only an insignificant number of natural scientists and only for a short time. Further advances of scientific cognition show quite convincingly the complete groundlessness of the idealist interpretation of new discoveries in the natural sciences and confirm the materialist view of them, since only such a view accords with their nature, their essence and their character. Lenin turns to the history of the natural sciences in order to make this regular trend apparent.

When, at the turn of the century, Wilhelm Ostwald created his "energetics", Lenin showed that in effect this was an attempt to conceive of motion without matter. The idea of the material carrier of motion had been rejected on some occasions before that, too. Lenin refers to J. Dietzgen, who criticised the idealist natural scientists, who believed in the immaterial being of forces, and called them spiritualists. The end of those beliefs is well known: the spiritualists were routed and materialism emerged victorious.

Lenin showed that there were two ways open to the further philosophical evolution of Ostwald and his "energetics": one was towards materialism, where natural scientists were inexorably driven by the logic and the entire course of the scientific discoveries themselves, the other towards idealism, where scientists were driven by reactionary philosophy, which was fundamentally hostile to science. One could not, under such conditions, stay somewhere in between. And that was exactly what Ostwald tried to do in his attempt to reconcile the two main philosophical trends and rise above them.

Lenin's profoundly correct interpretation of the historical tendency in the development of natural science in general and Ostwald's "energetics" in particular was confirmed by this significant fact: in the same year as Lenin wrote his *Materialism and Empirio-Criticism,* Ostwald publicly recognised his defeat in the struggle against scientific materialism and atomistics as its concrete manifestation and openly admitted the reality of atoms, molecules and other material particles. And that was the inglorious end of yet another attempt at "refuting" materialism through references to natural sciences, in this case energy physics. Such situations arose later too, and Lenin's approach to their analysis invariably made it possible to find the right way out of the situation.

That is how the history of science and its philosophical analysis promote a deeper understanding of the present, helping to reveal the hidden inner tendencies of the development of scientific knowledge.

The Idea of Milestones in the Development of the Natural Sciences

The problem of relationship between the history of science and its present state assumes in Lenin's work the concrete form of the idea of milestones in the history of the natural sciences. This idea is based on the general view of the correlation between objective, absolute and relative truth, according to which absolute truth is the sum-total of the grains of relative truths. Each of the more profound or more complete relative truths attained by humanity is a new landmark in the development of science, in the development of cognition leading to the revelation of absolute truth.

From this point of view, Lenin compares the stage in the development of scientific knowledge (already passed by that time) at which science discovered atoms, and another stage (just setting in at the time) associated with the discovery of

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works,* Vol. 14, pp. 304-05.

electrons as parts of atoms. But these stages in the penetration into the essence of things are relative and transient, being only milestones on the infinite road of science towards absolute truth. Lenin emphasised this idea: "The 'essence' of things, or 'substance', is *also* relative; it expresses only the degree of profundity of man's knowledge of objects; and while yesterday the profundity of this knowledge did not go beyond the atom, and today does not go beyond the electron and ether, dialectical materialism insists on the temporary, relative, approximate character of all these *milestones* in the knowledge of nature gained by the progressing science of man. The electron is as *inexhaustible* as the atom, nature is infinite. . . ."[1] This means that dialectical materialism insists on the approximate, relative character of any scientific proposition concerning the structure and properties of matter.

In the *Philosophical Notebooks,* Lenin further developed this idea, citing as an example the comparative study of atoms and electrons; these objects represented successive milestones in the development of science and expressed at the time the past and present limitations respectively on the knowledge of the structure of matter. In expounding and critically elaborating, from the materialist point of view, the Hegelian dialectics, in particular the proposition concerning the correlation of the finite and infinite, and proceeding upon natural scientific data, Lenin insists that atoms and electrons are separate (finite) points, or milestones, on the infinite path of man's cognition of matter, infinite because matter itself is infinite in depth. One must not treat any bit of knowledge of the structure of matter attained by man as complete, final and exhaustive, metaphysically raising it to the rank of absolute truth or "ultimate truth". Neither atoms nor electrons nor any other kinds of matter exhaust all matter; they are not the primary bricks of the Universe. If, in spite of all this, we accept the view that, let us say, atoms *are* such primary particles, serious errors will inevitably follow which

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works,* Vol. 14, p. 262.

may become the epistemological source of idealistic inferences from scientific breakthroughs. That was what actually happened. Until the end of the 19th century, atoms had been considered the ultimate particles of matter, and matter itself was therefore regarded as an aggregate of atoms. When it turned out that atoms were complex entities consisting of electrons (negatively charged particles), the absurd conclusion was drawn that matter was exhaustible and could be "reduced" to electricity. That is why the idea of milestones on the infinite path of man's cognising nature is at the same time an antidote against idealistic notions. "Electricity is proclaimed a collaborator of idealism because it has destroyed the old theory of the structure of matter, shattered the atom and discovered new forms of material motion, so unlike the old, so totally uninvestigated and unstudied, so unusual and 'miraculous', that it makes it possible to smuggle in an interpretation of nature as *non-material* (spiritual, mental, psychical) motion. Yesterday's limit to our knowledge of the infinitesimal particles of matter has disappeared, hence—concludes the idealist philosopher—matter has disappeared (but thought remains)."[1]

Lenin compared the various milestones, or stages, in the development of science and the pictures of the world emerging at these stages not just in relation to atoms and electrons, but on a more general plane too. Referring to the interpretation of the nature of the motion of physical bodies in old and new physics, he wrote: "mechanics was a copy of real motions of moderate velocity, while the new physics is a copy of real motions of enormous velocity. The recognition of theory as a copy, as an approximate copy of objective reality, is materialism."[2] How precise is this comparative description of two milestones in the development of physics, old physics (classical mechanics) and new physics, particularly when one compares Einstein's theory of relativity and Newton's mechanics! Both are profoundly materialistic, both are indeed only milestones on the road of developing science

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[1] *Ibid.*, p. 283.

[2] *Ibid.*, p. 265.

representing relative truths, the difference between them lying in the fact that the relative truth contained in Einstein's theory is much more complete and profound and therefore closer to absolute truth than the relative truth contained in Newton's mechanics.

Lenin categorically denied the idealist imputation that materialists hold the vulgar view that only the mechanistic picture of the world is correct: "It is, of course, sheer nonsense to say that materialism ever maintained that consciousness is 'less' real, or necessarily professed a 'mechanical', and not an electromagnetic, or some other, immeasurably more complex, picture of the world of *moving matter.*"[1] This "immeasurably more complex picture of the world" was later elaborated by modern physics, where it is called the quantum mechanic picture of microprocesses. Nowadays an even more complex picture is being worked out, based on the penetration into the atomic nucleus and then deeper, into the elementary particles.

Milestones in the history of science mark the pivotal points in its progressive development. This permits the formulation and solution of the problem of periods in the history of science on the basis of its own movement. Every new period in its development means a radical change of the entire concept of the given science and basic notions corresponding to it, a radical break with old principles, laws (that is to say, the formulation of these laws), concepts, theories and ideas. This drastic and radical break with concepts is, according to Lenin, what makes a revolution in the natural sciences.

In this connection, Lenin cites an interesting statement by the positivist A. Rey (Lenin calls him a "conciliator", as Rey attempts to reconcile materialism and idealism): "In the history of physics, as in history generally, one can distinguish great periods which differ by the form and general aspect of theories.... But as soon as a discovery is made that affects all fields of physics because it establishes some cardinal fact

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 280.

hitherto badly or very partially perceived, the entire aspect of physics is modified; a new period begins. This is what occurred after Newton's discoveries, and after the discoveries of Joule-Mayer and Carnot-Clausius. The same thing, apparently, is taking place since the discovery of radioactivity...."[1] Approximately the same idea was recently expressed by the American historian of science Th. Kuhn in a book on the structure of revolutions in science. He put forth the idea that the development of science proceeds through drastic changes (i.e. revolutionary upheavals) punctuated by what he calls a "paradigm": within a single paradigm, development proceeds within the framework of established ideas, until they are exhausted and, through their drastic breakdown, the development of science arrives, in a revolutionary way, at the establishment of the next "paradigm".

Kuhn actually puts forward the thesis, long established in materialist dialectics, that cognition progresses through continual successive changes of the revolutionary and the evolutionary stages of development, through continuous transition from one stage or milestone of knowledge to another making up in their entirety the infinite path of the advance of science towards absolute truth. Only Kuhn's terminology is new.

Thus we see that the problem of milestones along the road of cognising matter and their comparative description is closely connected in Lenin's work with an analysis of the history of science and the comparison of the science of the past and present.

The Method for the Dialectical Elaboration of the History of the Natural Sciences

So far we have been speaking of the content of the task of the dialectical elaboration and logical generalisation of the history of the natural sciences. The problem arises, however, of the method for the formulation and accomplishment of

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[1] *Ibid.*, p. 305.

such a task. How should one begin the investigation? Some scholars answer: by assembling the facts and then analysing them; others insist on working out some initial logical scheme before turning to the facts.

The problem of the starting point of research is essential for contemporary historians of the natural sciences not only in the matter of working out a definite method for historical scientific investigation, but also in the matter of the correct assessment of the initial stage of any science, including any branch of the natural sciences. We find impressive ideas on the subject in Lenin's work *What the "Friends of the People" Are and How They Fight the Social-Democrats.*

In formulating problems of enormous general methodological significance, Lenin wrote this in connection with the critique of Marx's works by the Narodist ideologist Mikhailovsky: "But the funniest of all is that Mr. Mikhailovsky accuses Marx of not having 'reviewed (sic!) all the known theories of the historical process'. This is amusing indeed. Of what did nine-tenths of these theories consist? Of purely *a priori,* dogmatic, abstract discourses on: what is society, what is progress? and the like. . . . But, then, such theories are useless . . . because of their basic methods, because of their solid unrelieved metaphysics.[1] For, to begin by asking what is society and what is progress, is to begin at the end. Where will you get a conception of society and progress in general if you have not studied a single social formation in particular, if you have not been able to establish this conception, if you have not been able to approach a serious factual investigation, an objective analysis of social relations of any kind?"[2] This is how Lenin approached the problem.

As if foreseeing the possibility of methodological differences of opinion between contemporary investigators of the history of science, Lenin pointed out, as a common feature of the initial stages in any science, an inclination towards

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[1] Here and further in the work quoted here Lenin interprets metaphysics as pure speculation.–*B.K.*

[2] V. I. Lenin, "What the 'Friends of the People' Are and How They Fight the Social-Democrats", *Collected Works,* Vol. 1, p. 143.

speculative constructions that were viewed as the premise or even a substitute for concrete factual investigation. "This is a most obvious symptom of metaphysics, with which every science began: as long as people did not know how to set about studying the facts, they always invented *a priori* general theories, which were always sterile. The metaphysician-chemist, still unable to make a factual investigation of chemical processes, concocts a theory about chemical affinity as a force. The metaphysician-biologist talks about the nature of life and the vital force. The metaphysician-psychologist argues about the nature of the soul. Here it is the method itself that is absurd. You cannot argue about the soul without having explained psychical processes in particular: here progress must consist precisely in abandoning general theories and philosophical discourses about the nature of the soul, and in being able to put the study of the facts about particular psychical processes on a scientific footing."[1]

The injunction to begin scientific investigation with an analysis of the facts and not with philosophical speculation is complemented in Lenin's theory with an appeal for a concrete approach to the phenomena investigated. Abstract truth does not exist, truth is always concrete–that is a Marxist dialectical proposition to which Lenin adheres at all times, applying it to historical investigation as well. The soul of Marxism, in his view, lies in the concrete analysis of a concrete situation. That is why he valued Marx's *Capital* so highly from the methodological point of view. He wrote: "The gigantic step forward taken by Marx in this respect consisted precisely in that he discarded all these arguments about society and progress in general and produced a *scientific* analysis of *one* society and of *one* progress–capitalist."[2]

The above gives a clear answer to the question as to what any investigation, including an investigation into the history of science, should begin with and what is the essence of the scientific method applicable to any domain of scientific cognition. Lenin rejects outright as unscientific the procedure of

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[1] *Ibid.,* p. 144.

[2] *Ibid.,* p. 145.

starting out with a certain *a priori* logical scheme that is viewed as the premise or even as a substitute for concrete factual investigation. In such cases, facts are simply fitted into a preconceived logical scheme. That is a completely fruitless occupation on which no serious scholar should waste his time and energy.

The method of the dialectical treatment of the history of the natural sciences based on Leninist principles assumes that general statements do not precede concrete investigation as ready-made schemes, but are deduced from data on the real history of the natural sciences through logical generalisation of these data and their theoretical interpretation. This approach is concrete because, as Lenin points out, it is the history of separate sciences that is dialectically elaborated and generalised; the coincidence of the logical and the historical should not be proclaimed, it should be traced in concrete detail throughout the history of individual sciences.

Lenin's statements quoted above are also important in that they characterise, from the methodological point of view, the initial, pre-scientific stage of any branch of science. The role of this stage in natural studies was played by natural philosophy. But the latter has long since outlived itself, and a return to it in any shape or form would now mean regress, a reversion to a pre-scientific stage.

The Movement of Cognition from Phenomena to Essence and the Actual History of the Natural Sciences

Lenin's ideas about the milestones in the cognition of nature and the categories of dialectics as logically generalised stages in the development of science, including natural science, help one to understand the general course of the historical development of the natural sciences. Revealing the dialectical relationship between the historical and the logical is therefore equally important for elaborating both dialectics and the history of the natural sciences. At the same time, as we pointed out above, conducting historical scientific research by constructing a logical scheme to be mechanically applied to any particular case is out of the question. On the contrary, one must speak here only of deducing certain logical inferences from a concrete analysis of the history of the natural sciences.

In comparing the procedure for arranging dialectical categories as logically generalised stages of cognition that we find in Lenin's *Philosophical Notebooks* with the actual course of development of the natural sciences, one has to take into account certain circumstances. One should first of all bear in mind that one or several of Lenin's propositions must not be considered in isolation but in their entirety. This is necessary because Lenin's statements concerning the relationship between the logical and the historical taken in isolation may seem mutually contradictory, if they are not viewed against the background of Lenin's statements on the given question in their entirety and inner connection.

It would be just as wrong, we believe, to attribute a strict logical order to the history of each of the natural sciences, in which each of the stages of its development witnesses the formation of only one given category completely supplanting all the categories that emerged earlier and precluding any possibility of the emergence of later categories expressing a higher stage in the development of that science. In actual fact, the various categories are interlaced and interact with each other so that it is virtually impossible to find any separate category at any stage in the development of science in pure form. But in logic, that is not only possible, but also necessary, as only logic, by eliminating all the attendant circumstances in the actual course of the development of scientific cognition, reveals in pure form the inner order of stages through which the natural sciences pass, and presents it as the logical necessity of the development of scientific thought.

Let us now turn to some individual questions. Lenin formulated the proposition that one of the elements of dialectics is the movement of human cognition from the phenomenon to the essence and from a less profound essence to a more and more profound essence. Or, as Lenin says on a different occasion, "human thought goes endlessly deeper from appearance to essence, from essence of the first order, as it were, to essence of the second order, and so on *without end*".[1] This thesis, when applied to the real history of science, raises several questions.

The first question is: does this mean that the development of any science begins with empirical observation of phenomena without any attempt to penetrate into their essence until these phenomena have been studied enough for cognition to proceed to the description of the lowest (first) order essence? The answer is no. Moreover, scientific cognition of a natural object, as Lenin pointed out, is always preceded by the natural philosophical ("metaphysical", or speculative) approach; although unscientific, this approach often contains conjectures concerning the essence of the given phenomenon which are actually fully developed only in the distant future at a higher stage of the advancement of science. This means that the factual study of phenomena is actually preceded by speculative attempts to surmise their essence.

This was the case with primitive atomism and the ancient Greek philosophers' teaching of the elements and elementary components. All these were brilliant natural philosophical (i.e. purely speculative) conjectures about the essence of physical and chemical phenomena, put forward at a time when the natural phenomena themselves had not been systematically studied through experiment. True, natural philosophical conjectures, too, were based on observations of some natural phenomena, but that could not be regarded as their scientific cognition.

On several occasions Lenin makes references to the fact that such conjectures were later confirmed, in particular by modern natural science. For instance, Hegel believed Epicurus' idea of the "curvilinear" movement of atoms to be arbitrary and boring, but Lenin levels this question at Hegel: "and electrons?"[2] What Lenin had in mind here was the fact that modern natural science has discovered particles of matter smaller than the atom, i.e. electrons, which move along curvilinear trajectories within the atom around the atomic nucleus. Therefore Epicurus' conjecture, which Hegel treats as arbitrary and boring, was actually confirmed in the 20th century.

However, in Epicurus' times there were no known natural phenomena which, in order to be explained, would require the elaboration of the concept of curvilinear motion of electrons within atoms. Thus, in this case the real way of cognition had as its starting point an attempt at direct penetration into the essence of natural phenomena that had not been cognised or even discovered, and not the study of concrete natural phenomena. From the logical point of view, the real (and not speculative or seeming) penetration into the essence of phenomena can be accomplished only after, and on the basis of, the study and cognition of the phenomena whose essence man set out to discover and cognise. This occurs not only in logic, but in the actual history of scientific cognition.

The second question is: does the successive movement of cognition from the phenomenon to the essence and deeper into the essence mean that, from the moment the essence of phenomena is reached, the study of phenomena themselves is over, so that cognition then moves only in the sphere of abstract ideas of the essence? The answer is no. The study of phenomena, far from being completed with the beginning of penetration into their essence, brings about with every step either a more complete knowledge of already known phenomena or the discovery of new phenomena whose explanation requires the transition from the essence of the given order to the essence of the next higher order. Thus, the discovery of radioactive phenomena brought in its wake the transition from the idea of immutable chemical elements covered by the periodic law as formulated by Mendeleyev (a lower-order essence, so to speak) to the idea of chemical transmutable elements covered by the periodic law in its new, physical interpretation as expressed, for example, in the "displacement law" (a higher-order essence). This penetration into the essence, however, proceeded through the discovery and study of new natural phenomena so that the progress of cognition took place, as it were, on two planes: (a) from the essence of a certain order to the essence of the next higher order, and

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[1] V. I. Lenin, "Conspectus of Hegel's Book *Lectures on the History of Philosophy*", *Collected Works*, Vol. 38, p. 253.

[2] *Ibid.*, p. 294.

(b) from new phenomena (radioactivity) to the discovery of their essence coinciding with the essence of that higher order with respect to the earlier ideas about the essence (law) of chemical elements.

Thus, in this case the two cognitive processes–the movement of cognition from the phenomenon to the essence and its movement deeper into the essence–are actually combined; they coincide and proceed as parallel and interconnected processes. But here again logic clears these processes of all extraneous elements and brings out their primary logical order: first, phenomena are studied and then cognition proceeds to the discovery of their essence, that essence consisting of many stages and cognition moving into the depth of the essence stage by stage.

The third question: does the movement of cognition from the phenomenon to the essence mean that it is not at the same time involved in other transitions, e.g. from coexistence to causality and from the less deep causality to the deeper one? Again the answer is no. The real movement of cognition to truth is a complex, many-sided and inherently contradictory process. It cannot be fitted into a simple scheme like the one with which a book begins: first comes the title page, then the first page of the text, then the second, etc. But the logically elaborated and generalised history of thought, the history of scientific cognition must be represented in just such a simple successive arrangement, so that, although the logical coincides with the historical, it is at the same time essentially different from it with respect to the harmony and the successive arrangement of the various stages which, in the course of actual cognition, are often mixed up and entangled.

Thus, in the study of living nature, cognition registers the coexistence, as it were, of a multitude of living beings whose relations do not reveal any causal connections. But, as cognition proceeds from the phenomenon to the essence, the first superficial idea of the coexistence of various living beings is supplanted by a deeper understanding of the causal dependences between them and their dependence upon external conditions (the environment). It is this transition to the understanding of causal relationships in animate nature that enabled Darwin to destroy the old teleological view of living creatures. And it was at the same time a transition from the phenomenon to the essence in this particular field of natural science.

It was not by chance that Lenin originally pointed out, as one of the elements of dialectics, "the endless process of the deepening of man's knowledge of the thing, of phenomena, processes, etc., from appearance to essence and from less profound to more profound essence . . . from coexistence to causality and from one form of connection and reciprocal dependence to another, deeper, more general form".[1] Only later did he divide this originally integral element of dialectics into two independent ones. What we observe here is the multiplane nature of the movement of scientific cognition in the actual historical development of natural science. This plurality of planes, however, does not exclude the possibility of a logical elaboration of that movement which will enable it to be summarised in the form of a logically ordered arrangement of the various stages of cognition distinguished in that movement.

The Logical Sequence of Thought and the Actual Course of Natural Science

Let us continue the consideration of cases arising from the fact that the logical, far from fully coinciding with the historical, is the historical freed from the accidental and from its form in which the various planes and aspects interlace and overlap.

The fourth question: does the qualitative definiteness of a thing and then its quantitative definiteness mean that the qualitative study should always precede the quantitative study and that the transition to the latter marks the complete discontinuance of the former? No, it does not. Determining certain qualitative aspects of an object must naturally precede

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[1] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works*, Vol. 38, p. 222.

its measurement, aimed at cognising the quantitative aspect of the object. But the study of the quantitative parameters may begin before the qualitative definiteness is worked out in sufficient detail, so that the subsequent investigation of both aspects or definiteness of the given object may proceed simultaneously.

Moreover, there have been familiar instances in the history of science where the qualitative definiteness of unknown natural objects and, hence, the objects themselves, were established only on the basis of quantitative research. That was the way in which the invisible parts of the optical spectrum (ultra-violet and infra-red) were discovered: through quantitative (thermal) measurements.

This means that the qualitative and the quantitative aspect of objects and phenomena are in close interaction with each other, and that only in abstraction can we separate the one from the other and say that cognition moves from the establishment of the qualitative ("identical with being", according to Hegel) definiteness of the object to the establishment of its quantitative ("indifferent to being", according to Hegel again) definiteness. But that is precisely the way in which logic must work as it attempts to present the logical sequence of the movement of scientific thought in pure form.

The fifth question: can it be that practice may not and must not be viewed as a special stage in cognition–since it permeates cognition from beginning to end? The answer is no again. Of course, practice is and has always been, in the last analysis, the source and stimulus of scientific cognition, its "ultimate goal" (as far as spheres of application of its results are concerned) and the criterion of its truth. From the logical point of view, however, just as in the previous cases, the movement of scientific cognition towards truth can be presented in the way it was done by Lenin: "From living perception to abstract thought, *and from this to practice*–such is the dialectical path of the cognition of *truth*, of the cognition of objective reality."[1]

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[1] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works*, Vol. 38, p. 171.

But that does not mean, of course, that practice is simply relegated to the "third stage" in the actual movement of cognition and that it plays no role in the first two stages, the sensational and the abstract theoretical. What is meant here is the purely logical sequence in the establishment of the cognitive-practical functions of science, natural science in this case: first, its empirical function is established (the registering of facts, their initial systematisation, description, etc.); then, the theoretical function (determining the inner connections between facts, their generalisation and explanation, the possibility of prognostication, etc.); and finally, its practical, technological and production function, through which the way to new branches of industrial production is paved and the natural sciences increasingly become an immediate production force.

Some time ago philosophers argued about whether practice is "the third basic stage of cognition" (following the sensational and the rational stage) or not. The debate was annoyingly one-sided. One side only took into account the logical aspect of the cognitive process (logically generalised and cleared of concrete details), but it could not link this abstracted aspect with the entire actual process of cognition, the real history of science. The other side, on the contrary, proceeded from the entire actual process of cognition (the history of science as an indivisible whole) and did not see the possibility and the necessity of abstracting from it the logical aspect expressing the intrinsic logical connection and sequence of the various aspects of human knowledge.

The fact that in Lenin's proposition on the movement of cognition towards truth practice is the last link of the process and its highest stage does not mean that it cannot be considered as the initial point and the motive force of all knowledge and as a continually active criterion of its correctness. Just the opposite is true: practical application of scientific achievements, in particular natural scientific ones, reveals that practice is the source and the stimulus of the entire cognitive process and the verification criterion of its results.

In this peculiar way the relationship between the historical (concrete whole) and the logical (abstract) is disclosed in Marxist dialectics, and this is of exceptionally great importance for the dialectical elaboration of the history of the natural sciences.

The History of Chemistry Before the 19th Century in the Light of Lenin's Ideas

Let us now attempt to apply, in a schematic outline, of course, Lenin's ideas as presented above to the concrete science of chemistry with the object of its dialectical elaboration. This will be an attempt to realise Lenin's thesis that Hegel's dialectics in its rational, materialist interpretation is a generalisation of the history of thought.

The use of the history of chemistry for the purpose of its dialectical elaboration is chiefly explained by the fact that chemistry occupies the middle position, as it were, in the general system of the natural sciences, so that all the features of the historical development of these sciences are manifested in chemistry in their most typical ("mean") form.

In ancient times, chemistry as a science did not exist. There were, on the one hand, some purely empirical data accumulated in handicrafts, in rudimentary chemical production and primitive recipes, and, on the other hand, purely abstract, natural philosophical constructions of scholars engaged in abstruse speculations and not practical activity in chemical handicrafts. These two fields were totally unconnected. Natural philosophy was therefore unable to aid production and, conversely, practice was of little help to philosophical doctrines. Rudimentary chemical and physical notions were not yet differentiated, but merged together in the natural philosophical concept of the elements. This stage in the perception of real matter and its real properties and transformations was aptly summed up by Lenin's phrase "first of all impressions *flash by*".

Somewhat later, in ancient Alexandria, chemistry began to develop as alchemy. It existed in this form through the Middle Ages up to the Renaissance, and even until the mid-17th century. Alchemists and later iatrochemists, or medico-

chemists (Paracelsus and his followers), distinguished several common properties in various bodies and substances and attributed to these properties the nature of specific substances: first, the substance of volatility (the physical mutability of bodies) was postulated and named "mercury". This was not ordinary mercury, but a "philosophical mercury"–the mentally objectified property of volatility. Later, Arab alchemists added the substance of combustibility (the chemical mutability of bodies), called "sulphur". This again was not the real, but "philosophical" sulphur, the abstract principle of combustibility in its mentally objectified form.

During the Renaissance, iatrochemists added a third principle of the same kind–the substance of solubility (the "philosophical salt"). The result was the well-known doctrine of the three primes (*tria prima*), which were supposed to make up all bodies.

As we see, a stage in the cognition of matter was reached here when some properties were distinguished that had to be subjected to special study, so that the place of the original completely indistinct impressions "flashing by" was taken by something more definite, although not yet absolutely definite. This stage is described in Lenin's words: "then *Something* emerges."

In 1661, the English physicist and chemist Robert Boyle published the book *The Sceptical Chemist*, which marks the beginning of chemistry as a science. This process was completed more than a hundred years later, at the end of the 18th century, in the works of Lavoisier. Throughout these hundred-odd years, chemistry was a purely empirical analytical science. Its prime objective was the study of the chemical composition of substances up to and including components that cannot be further decomposed. These were named chemical elements. The notion of the chemical element as a scientific (chemical analytical and empirical) concept was opposed to the natural philosophical idea of the element and the alchemist's (pre-scientific) notion of the body primes as a "philosophical" principle.

There was a time when the qualitative study of the chemical composition of matter had not been carried out to any considerable extent; even in those times, however, some metals that were easy to free from admixtures were studied by quantitative and not only qualitative methods (e.g. the art of assaying). Thus it appears that in the actual history of the study of natural substances quantitative methods were used long before qualitative methods developed.

But, although quantitative methods (especially weight and volumetric analysis) had long been familiar aspects of man's practical life (trade, assaying, pharmacy, etc.), they could not, with rare exceptions, be used for the purposes of chemical analysis. The task was to discover and isolate the chemical substances themselves in their more or less pure form and, most importantly, to learn to decompose them into the actual (and not mythical or invented) component parts, ending with the chemical elements. Only this could serve as the basis for further systematic application of quantitative methods in chemistry. The 19th-century German chemist Justus Liebig used to say in this connection: before weighing, one must know what to weigh.

It is particularly important for chemistry to establish what a component part of a body is. Alchemists gave a very simple answer to that question: anything that a body educes in burning is a component. When a body is burning, we observe smoke and steam (that is the "mercury"), flames ("sulphur"), and what is left is ashes ("salt"). The body thus consists of these three elements. Boyle refuted this simplistic and naive view. To call substances educed by the body its component elements, one must be able to reconstruct the initial body out of them (e.g. the burnt firewood). But that is something no one had been able to do. The teaching of the three primes was therefore false.

We see that Boyle was the first to formulate the problem of chemical analysis on a scientific basis: its correctness had to be verified through reverse synthesis. That was the first hint at "the union of analysis and synthesis"[1] which Lenin later described as one of the elements of dialectics.

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[1] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works*, Vol. 38, p. 221.

For almost a century (from the 1660s to the 1750s), chemistry went through a period of the formation and development of methods for performing a qualitative analysis of substances, with chemists measuring weights only occasionally and in a limited way. On the whole, they were chiefly concerned with the problem of the qualitative definition of substances and their components. Chemistry was therefore going through a process that Lenin characterised in these words: "concepts of *quality* # (the determination of the thing or the phenomenon) ... are developed." The sign # refers to Lenin's additional comment: "Quality and sensation *(Empfindung)* are one and the same, says Feuerbach. The very first and most familiar to us is sensation, and *in it* there is inevitably also *quality*...."[1]

But qualitative research alone, even on the level reached by 17th-century chemistry, was incapable of correctly solving the problem of the components of the analysed bodies. Thus, chemists considered metal to be more complex than its cinders because the latter was educed from the former, they said. This idea lay at the base of the phlogiston theory, the first of all chemical theories. Even Boyle believed it impossible to determine whether sulphur is educed from sulphuric acid or vice versa. The burning of sulphur yielded acid, the treatment of acid with turpentine yielded sulphur sediment.

Things were even more complicated in the case of gases, which for a long time were regarded as simply "air", sometimes with added attributes "pure", "bad", etc. Even qualitative definitions were impossible here; it was impossible to isolate and identify them (within the framework of the dominant qualitative approach to matter).

The middle of the 18th century witnessed the introduction of quantitative methods of chemical analysis–weighing and volumetric measurements, which became the dominant systematic measurements in chemical research. Using these methods, Lomonosov and Lavoisier discovered the first

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[1] V. I. Lenin, "Plan of Hegel's Dialectics (Logic)", *Collected Works*, Vol. 38, p. 319.

(quantitative) law of chemistry–the law of the conservation of matter (the total weight of chemically interacting substances). In 1748, Lomonosov equipped the first chemical laboratory in Russia with scales placed in a special room. In 1755, the English chemist Black applied weighing technique to the study of calcination and discovered carbonic acid ("combined air"). The spread of quantitative methods of research (weighing and volumetric techniques) resulted in the discovery of various gases and the development of pneumatic chemistry, undermining the very foundations of the phlogiston theory. In 1772, Priestley and Scheele simultaneously and purely empirically discovered oxygen, and several years later Lavoisier gave a correct interpretation of some chemical processes that were most important at the time (combustion, oxidation, metal reduction, etc.). The phlogiston theory fell apart and Lavoisier constructed the new, oxygen theory. For the first time chemists were able to determine which substances were real chemical elements and which were just combinations of them. A "chemical revolution" took place as a result. Its starting point was, as we have said, the introduction of quantitative methods into chemistry.

All of this goes to prove once again that the development of the concept of quality is followed by the development of the concept of quantity, as was indicated by Lenin.

The chemical revolution of the 18th century completed the formation of chemistry as a science. But, on the whole, chemistry in the second half of the 18th century was still at the level of the empirical cognition of matter (although there were flashes of theoretical thinking in the work of such chemists as Lomonosov and Lavoisier, not to mention their predecessor Boyle). Late in the 18th century and early in the 19th, the first stoichiometric laws of the chemical composition of matter were discovered (the law of equivalent or reciprocal proportions and the law of constant proportions or definite composition). But these laws were originally simple empirical rules without theoretical substantiation or explanation. Their discovery still left chemistry at an empirical and, at the same time, analytical stage. The transition to a higher stage of the cognition of matter, corresponding to the development of abstract theoretical thinking by chemists, came about only in the 19th century. In this respect too, Lenin's thesis that the path of the cognition of truth leads from living contemplation to abstract thought is accurate. This part of the thesis covers the entire path of the origin, formation and further development of chemistry from antiquity up to and including the 19th century.

The History of the Chemical Atomism of the 19th Century in the Light of Lenin's Ideas

Before the 19th century, atomistic views were widespread among chemists but, as in ancient times, they were not based on concrete chemical empirical data about the composition of matter. But, whereas the ancient atomism was natural philosophical in character, 17th-century atomism became mechanistic since at that time mechanics developed in an extraordinarily rapid manner, leaving an imprint on all natural scientific concepts of the period.

In the late 18th and the early 19th century, empirical (chemical analytical) data were at last obtained which required for their explanation atomistic theoretical concepts. Stoichiometric laws played a particularly important role in this respect. In 1803, John Dalton came to the conclusion that, if one applied atomistic concepts, one had to assume that the measurable components of bodies, like indivisible atoms, should combine as whole portions. In this way Dalton predicted theoretically, and later discovered experimentally, the most important of stoichiometric laws–the law of multiple proportions. Theoretical thinking played the most decisive role in its prediction and discovery, and from that point onwards, chemistry proceeded from living perception and pure empiricism to the stage of abstract theoretical thinking. Abstract atomistic concepts, for the first time in the history of natural science, merged into an integral whole with the empirical data of chemical analysis.

The most important result of the integral introduction of atomistic ideas into chemistry was the establishment by Dalton of the atomic weight concept as the most essential characteristic of chemical elements. Dalton adopted the atomic weight of the lightest element (hydrogen) as the basic unit. Using this concept, chemists proceeded from the study of chemical phenomena to the discovery of their essence of the first order, so to speak. This essence was later expressed by Lenin in this way: the unity of opposites is particularised in chemistry as "the combination and dissociation of atoms".[1] Indeed, through the concept of atoms possessing their specific (atomic) weights, the familiar chemical reactions were presented in the abstract thinking of chemists as atomic interactions.

This mode of thinking on the part of chemists who embarked on the path of chemical atomistics is thus summed up by Lenin: "After that study and reflection direct thought to cognition... of the Essence versus the Phenomenon–of causality, etc."[2]

Thus, the *cause* of chemical elements being combined in multiple proportions was found to be this: elements consist of atoms, which are incapable of division and can only be combined as whole units. But immediately the next question arises: why and how do atoms combine? What force makes them tie up with each other in chemical combinations?

In an attempt to find answers to these questions, chemistry went through the same basic stages through which the concepts of quality and quantity develop. First, the concept arose that explained the reason for the combination of atoms (the cause of "chemical affinity") as the opposition between negative and positive electric charges. The first electrochemical processes were already being carried out in the early 19th century (Davy was the first to separate alkaline and alkaline-earth metals through electrolysis in 1807-1808). Soon after that, the Swedish chemist Berzelius constructed the electrochemical ("dualistic") theory, contending that each atom has unequal electrical poles. Depending on the magnitude of the pole, the total charge of the atom may be either negative (e.g. chlorine and oxygen) or positive (e.g. potassium and other metals). The opposite poles of the different atoms are attracted to each other, and this results in a chemical combination. For almost the whole of the second quarter of the 19th century, Berzelius' ideas dominated the minds of chemists.

There was a parallel development of organic chemistry, which faced a problem that was becoming ever more acute: how are the atoms of the four main elements, C, H, O, N, combined with each other? A new concept about chemical bonds between these atoms emerged. In the 1830s, Berzelius' theory suffered the first heavy blows inflicted by new chemical and physical discoveries. First, Jean Dumas found that the properties of a substance (e.g. acetic acid) are not changed when the positively charged hydrogen is replaced by the clearly negatively charged chlorine, which did not accord with the basic premises of Berzelius' "dualism". Second, Faraday discovered the laws of electrolysis which yielded the conclusion that, if atoms really possessed electrically opposite poles, they could not be different in their magnitude, as Berzelius had assumed.

In the 1840s, further development of organic chemistry and, in particular, the discovery of the law of the conservation and transformation of energy brought about the complete breakdown of Berzelius' theory. Its place was taken by the unitary theory, which viewed a component of a chemical combination as an intrinsically integral unit and not as consisting of two polar parts, as Berzelius believed. At the same time, chemistry saw the development of molecular concepts put forward early in the 19th century by Avogadro (1811) and Ampère (1814). The result was a new chemical revolution which opened the way to the transition to the essence of chemical phenomena of a higher (second) order.

In the 1850s, the concept of valency (or atomicity) as a quantitatively definite bond between atoms was worked out

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[1] V. I. Lenin, "On the Question of Dialectics", *Collected Works*, Vol. 38, p. 359.

[2] V. I. Lenin, "Plan of Hegel's Dialectics (Logic)", *Collected Works*, Vol. 38, p. 319.

in organic chemistry. Hydrogen again served as a unit, so that in other elements valency was either equal to that of hydrogen (as in potassium and chlorine) or to a multiple of it (2 for O, 3 for N, 4 for C, etc.). Combinations of atoms irrespective of their positive or negative electric charge were treated in a similar manner, as saturation of a certain number of valency units. From this point of view, there was no essential difference between the C–H bond in methane (CH_4) and the C–Cl bond in methyl chloride (CH_3Cl). This was a purely quantitative approach abstracted from the qualitative definition of the thing or phenomenon. Such quantitative concepts of valency gave rise to ideas about the inner constitution of organic molecules. In 1861, Butlerov constructed a theory of the chemical structure of organic compounds, taking into account not only the quantitative aspect of atomic interaction within the molecule (including their spatial arrangement with respect to each other in it), but the qualitative aspect as well, in the form of the effect of the combined atoms on each other.

This marked the transition to the discovery of the second-order essence of chemical phenomena. Immediately afterwards, chemists' thinking was directed towards the establishment of interconnections between the two essences discovered earlier–the atomic weights of elements (first-order essence) and their chemical individuality, their "chemism", which included their valency (second-order essence). The law establishing the connection between the two aspects of chemical elements referred to above was first discovered by Mendeleyev in 1869. His periodic law marked the transition to the essence of chemical phenomena of the third order. The first place in the natural system of elements built on this law was taken by hydrogen, thus symbolising the result, as it were, of the preceding history of chemistry, in which it was the primary unit both for atomic weights and valency values.

Thus, cognition takes place as the simultaneous movement from phenomenon to essence and from coexistence to causality, and this point is borne out by the history of progressive trends in natural science

Still, despite this correspondence, there are two different planes here, two sections of one and the same cognitive process. To show the numerous planes of the real movement of scientific cognition, one may refer to the discovery of the periodic law of chemical elements by Mendeleyev. This event in the history of natural science may be viewed simultaneously from various logical angles–as the transition from the description of chemical elements and their properties and, accordingly, the chemical phenomena involved to the discovery of their essence, and, in addition, as the transition (a) from the knowledge of the measure of a single chemical element (measure being interpreted as the unity of qualitative and quantitative definiteness of the element, its "chemism" and its "mass" as expressed in the atomic weight) to the knowledge of the main line of the relations of measure (as expressed in the arrangement of all elements in a sequence according to their atomic weights); (b) from the simple coexistence of chemical elements to the discovery of causal relationship between them (the regular dependence of their physical and chemical properties upon their atomic weight); (c) from the cognition of peculiarity in chemical elements (their division into "natural groups" according to the feature of similarity) to cognition of universality (their membership within a universal periodic system based on the periodic law common to all of them), etc.

Later, the way to the cognition of the fourth-order essence of chemical phenomena was opened with the emergence of the theory of electrolytic dissociation, which revived some of the aspects of Berzelius' theory. The interpretation of the nature of chemical affinity as the interaction of polar electric charges was confirmed. Valency of ionogens was explained by the presence of one, two or more positive or negative charges in corresponding ions–positive in cations, negative in anions.

Early in the 20th century, Lenin pointed out: "Each day it becomes more probable that chemical affinity may be reduced to electrical processes."[1]

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works,*

The discovery of the electron and radioactivity late in the 19th century permitted chemists and physicists to arrive at the essences of chemical phenomena of still higher orders, just like the subsequent development of the electronic theory of the atom (Bohr, 1913-1921) and, in particular, the construction of the quantum mechanical theory of chemical affinity (quantum chemistry) towards the middle of the 20th century.

All this provides evidence that Lenin's propositions concerning the paths of cognising truth and the stages traversed by cognition are completely borne out by the history of chemistry, in which they are concretely implemented.

The Need for Careful Study of the Science of the Past

So far we have been considering Lenin's attitude to the history of science mainly from the philosophical viewpoint. But he also approached the problem from a different, purely practical angle.

The high regard that Lenin had for collecting and studying material on the history of science and the work of individual scholars of the past is closely linked to his general stand on the attitude of Marxism towards the culture and science of earlier historical periods. Vulgarisers of Marxism and its enemies in particular have been at great pains to prove that Marxism means a rejection of the spiritual values accumulated by humanity during the last two thousand years. It is useful to remember in this respect how Lenin fought theoretically and practically against this pernicious concept.

In 1913, referring to the history of science in his article "The Three Sources and Three Component Parts of Marxism" he wrote: "The history of philosophy and the history of social science show with perfect clarity that there is nothing resembling 'sectarianism' in Marxism, in the sense of its being a hidebound, petrified doctrine, a doctrine which arose *away from* the high road of the development of world civilisation. On the contrary, the genius of Marx consists precisely in his having furnished answers to questions already raised by the foremost minds of mankind."[1]

Time and again Lenin emphasised that Marxism, far from rejecting the most valuable achievements of the bourgeois era, assimilated and developed them. It is only further work on this basis and in this direction, inspired by the practical experience of proletarian dictatorship, that can be viewed as the development of a really proletarian culture.

These ideas were also stated by Lenin in his speech "The Tasks of the Youth Leagues" at the Third Congress of the Young Communist League. Addressing the delegates of the Congress, Lenin warned that they would be making an enormous blunder if they assumed that one might become a Communist by assimilating communist slogans and the conclusions of communist science, without mastering the totality of knowledge out of which communism itself had grown. Lenin said that Karl Marx based himself on the firm foundation of the human knowledge acquired under capitalism and proved the correctness of his teaching, having completely mastered the achievements of earlier science. Everything that had been created by human thought he subjected to elaboration and criticism.

The study of the history of culture and science is a necessary element of communist education, instruction and training of young people. To carry out Lenin's behests, we must keep youth from being conceited, helping young people to understand how communism was born of the totality of human knowledge and how Marxist-Leninist teaching emerged, illuminating the path of mankind into the future.

In conclusion, let us cite an eye-witness' account of how Lenin treated the history of science, how he valued the scholars of the past. In 1947, the book *Mendeleyev and His Family* by O. D. Trigorova-Mendeleyeva was published.

Vol. 14, p. 251. Here "may be reduced to" is used in the sense of "is caused by electrical processes".

[1] V. I. Lenin, *Collected Works*, Vol. 19, p. 23.

Trigorova wrote: "In 1918, the executive of the Council of People's Commissars V. Bonch-Bruyevich informed me that Vladimir Ilyich Lenin had entrusted him with the message that I, as the daughter of Dmitry Ivanovich Mendeleyev, should write down my memoirs of my father, as not one single trait of the life of Dmitry Ivanovich could be forgotten, since they were all of great interest to the public."[1]

I asked V. Bonch-Bruyevich to give a more detailed account of the episode cited by Trigorova-Mendeleyeva and, in general, of everything that he heard about Mendeleyev from Lenin. Bonch-Bruyevich responded as follows: "I regret that I cannot comply with your request as I have not heard Vladimir Ilyich express any particular views about Mendeleyev. He held him in high esteem as a scholar; as a tribute to his memory, he took care of his family; he asked everyone who had associated with him to write down their reminiscences and said that all of this had to be published immediately. Vladimir Ilyich was extremely attentive to memoirs, reminiscences, diaries, letters and epistolary matters in general. He frequently said that it was all a very important source for the study of the period and of the life of various persons, groups, parties.

"He always insisted that these works should immediately be published, and he liked to read them carefully and even to write reviews of them, as he did in the case of the notes of Sukhanov, a man who was not 'one of us', as he put it, but who wrote most interesting memoirs on the first days of the February Revolution.

"That is why he urged Mendeleyev's daughter to write her memoirs, which she did, owing to his insistence.

"Vladimir Ilyich repeated on several occasions that it was necessary to publish a most complete collection of Mendeleyev's works, including absolutely everything that he had written.

"These are the few things that I can tell you on the question of interest to you."

The letter quoted here tells us a great deal. Lenin ascribed great value to documentary data on historical events, including the history of science; Lenin displayed a personal interest in these documents and recommended that they should be carefully collected, preserved and studied, as they formed part of the historical material whose elaboration (critical elaboration, of course) provided a deeper insight into the course of events in the past. These documents, in Lenin's view, should not gather dust in archives but should be brought, through publication, to the attention of readers; this would make these documents available for research aimed at their elaboration and generalisation.

This evidence assumes special interest when viewed in connection with all the statements by Lenin concerning the history of science and the history of natural science.

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[1] O. D. Trigorova-Mendeleyeva, *Mendeleyev and His Family*, Moscow, 1947, p. 3 (in Russian).

Part II

PHILOSOPHICAL AND METHODOLOGICAL PROBLEMS OF THE PHYSICAL SCIENCES

M. E. Omelyanovsky

LENIN AND DIALECTICS IN MODERN PHYSICS

On Dialectics in Natural Science

In the history of science and, primarily, in the history of philosophy and natural science, Marx and Engels were the first thinkers to unite conscious dialectics and the materialist understanding of nature. It could not be otherwise: Marxism, the great revolutionary doctrine of the working class and the working people of the whole world, developed in the latter half of the 19th century, a period which saw outstanding achievements in natural science; Marx and Engels made a profound study of the essential problems of the sciences of nature from the standpoint of their theory and answered the philosophical questions posed by the natural sciences of their times.

The traditions of Marx and Engels were continued by Lenin. In his famous book *Materialism and Empirio-Criticism* (1909) he generalised the epoch-making discoveries of physics at the turn of the century from the standpoint of dialectical materialism and revealed the philosophical essence of the latest revolution in the natural sciences. Now we have every right to state the inner unity of dialectical materialism and 20th-century natural science; this unity is a significant feature of 20th-century culture, and it was brought about largely through the Soviet Union's 60 years of development and the victory of socialism in other countries.

Lenin's genius had an immense number of brilliant facets. In developing Marxism and its philosophy at a time that was different from the historical period in which Marx and Engels had created their theory, Lenin also enriched the philosophical foundations of the natural sciences by contributing new and important propositions and conclusions, whose significance for the development of science cannot be compared with that of any other philosophical system.

It was not only in his book *Materialism and Empirio-Criticism* that Lenin expressed his views of the 20th-century revolution in natural science. Philosophical generalisations of this revolution and the philosophical problems raised by the new physics attracted Lenin's unwavering attention.[1] Of particular significance in this respect are his *Philosophical Notebooks* (1914-1916). The main theme of this remarkable work, the theory of materialist dialectics, is closely interwoven with philosophical generalisations and inferences from the data of the modern natural sciences.

Lenin wrote his last lines on the philosophical problems of the natural science of our century in his article "On the Significance of Militant Materialism" (1922) where, of all the tasks facing Marxist philosophers, the task of creating a unified front with the representatives of modern natural sciences on the basis of dialectical materialism is given pride of place. Many years have passed since that time, abounding in tremendous social, technological and scientific upheavals; natural science as a whole and physics in particular have changed enormously and made great advances. However, Lenin's thoughts about dialectical materialism as the only correct philosophy and true method of the modern natural sciences, about the philosophical conclusions to be drawn from the new physics, about its philosophical foundations and the prospects for its development, and about the essence and meaning of "physical idealism" have still retained their immense philosophical significance. They underpin all the work that has been done in the field of Marxist studies in the philosophical problems of physics and natural science as a whole, and stimulate these studies.

What is the real essence of modern or, as it is also termed, non-classical physics? It lies in relativistic and quantum physics and the physics of elementary particles which grows out of them. The discoveries and theories of non-classical physics broke down the basic concepts and principles of classical physics, which had seemed unshakeable since their origin. They were subjected to revolutionary transformation and became extreme cases of new, deeper and more general concepts and propositions of the theory of relativity and quantum theory which were not as obvious as the usual classical notions. Thus, non-classical theories in physics resulted in new methodological approaches and a new style of thinking among natural scientists.

Characteristic of modern physics is the fact, intrinsically linked with the methodological approaches inherent in it, that it has raised once again, in an unusual manner and, from the established viewpoint, quite unexpectedly, problems of reality and matter, time and space, the absolute and the relative, causal connection and law that had seemed completely solved in traditional philosophy. Logical formal systems could not (and cannot) cope with problems that were (and are) raised by the development of non-classical physics.

Marxists know full well now (and it was proved by the development of non-classical physics) that questions of this kind can be and actually are solved by dialectical materialism. But the deepest foundation for this truth was discovered by Lenin. It was he who expressed and proved the by now generally known proposition: "Modern physics is in travail, it is giving birth to dialectical materialism."

Phenomena and facts like the electron and radioactivity (whose discovery marks the beginning of non-classical physics) that are inexplicable within the schemes and theories of classical physics, paradoxical situations like the one that emerged after the Michelson experiment or after the appearance of Planck's quantum hypothesis, and the situations rapidly succeeding one another in the course of the swift

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[1] See Lenin's notes on the natural science books that he read (V. I. Lenin, *Collected Works*, Vol. 38, pp. 52-59, 239-43, 327-38, 361-75, 394, 399-401, 409-76); his article "In Memory of Herzen", Vol. 18; his remark on the significance of the discovery of radium and the electron in his letter to Maxim Gorky (1913), Vol. 35, p. 84; and the article "The Three Sources and Three Component Parts of Marxism", Vol. 19.

development of modern natural science, inevitably led to non-classical ideas and theories in physics and at the same time to beliefs and approaches of a philosophical and methodological nature that were unthinkable in classical natural science.

Is it not meaningless to combine discontinuous particles and continuous waves, as is done in quantum mechanics? How is one to understand the transformation of particles of matter into light, and of light into matter, what is postulated in quantum electrodynamics? What does the merging of space and time into something integral mean in the theory of relativity? How is one to understand the transmutability of the elementary particles (which form the basis of all known matter) envisaged in the theory of elementary particles?

The content of these propositions is just as vast as the propositions themselves are short. Nature has proved to be quite different from the world pictured by classical physics, which was rooted in ordinary experience concerned with macroscopic phenomena. Modern physics overcomes the one-sidedness and limitations of cognition that arise from the level of everyday experience. Non-classical physics generalises experience involving the finest electromagnetic phenomena, the atomic and subatomic worlds, and immense phenomena on the scale of stellar systems and galaxies that differ profoundly from the macroscopic world, although they are linked to it through many transitions. That is why non-classical physics engendered "bizarre" theories (Lenin) and "crazy" ideas (Bohr), which reflect the objective nature more deeply, completely and correctly than the theories of classical physics. The problem arose of reflecting the comprehensive universal regularity of nature in concepts which, according to Lenin, must be "flexible, mobile, relative, mutually connected, united in opposites, in order to embrace the world".[1] Only dialectical materialism can cope with this problem.

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[1] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works*, Vol. 38, p. 146.

In the modern period of the development of physics, scientific ideas of a dialectical nature are emerging and taking hold within physics itself, stimulating its progress. Significant for present-day physics is the idea of the mutability and transmutability of all material realities, including elementary particles. The indivisible unity of opposite corpuscular and wave conceptions of matter is the necessary element of quantum physics. The theory of relativity would be impossible without the idea of the inherent connection between the concepts of space and time. Non-classical physics is itself developing in such a way that its different and opposing concepts, propositions and theories are united within new synthetical formations whose content includes the scientific results of the theoretical structures thus united. These features of modern physics mean in effect that it is developing in the direction of dialectical materialism and that a conscious application of dialectics in physics, is an immediate necessity.

It is significant that the very scientists who laid the foundations of non-classical physics speak of dialectics (and its principles) without using the term (there are, of course, exceptions). It is a well-known fact that, in his argument with Einstein about the epistemological problems of atomic physics, Bohr referred to "deep truths" that are "statements in which the opposite also contains deep truth".[1] It is often pointed out in the literature that Einstein rejected Bohr's views of quantum mechanics, but there are fewer references to the fact that Einstein emphasised the fundamental significance for physics of uniting the corpuscular and wave ideas, and that is what is important for quantum theory.

Turning, for instance, to the prominent German physicist Max Born, we see that he considered as correct that interpretation of quantum mechanics which, as he insisted, tried "to reconcile both aspects of the phenomena, waves and particles". In Born's view, the wider use of the concept of the particle in quantum mechanics had to satisfy two conditions:

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[1] N. Bohr, *Atomic Physics and Human Knowledge*, New York, 1958, p. 66.

first, the concept of the particle accepted in classical theory must be a limiting case of the new concept and, second, the latter must share some essential (but not all) properties of the classical concept.[1]

But dialectics that does not perceive itself as such philosophically (just like spontaneous materialism in the natural sciences in general, as Lenin pointed out on more than one occasion[2]) cannot be regarded as a sufficient basis for solving the philosophical problems of science. Their weak spots, such as their inability to reveal a dialectical opposition or explain the relationship between relative and absolute truth, are exploited by reactionary philosophers in their fight against materialism. Only a conscious application of materialist dialectics makes a scientist really free from one-sidedness and preconceived viewpoints in studying the philosophical problems of natural science, and opens up the correct prospects for their solution.

The truth of this will be more clearly seen later. The understanding of the phenomenon proceeding from the phenomenon itself; the determining role of the experiment in the study of phenomena; the need for unity of theory and experiment as a prerequisite for the harmonious development of science; a negative attitude to any dogmas in science and the need for new ideas in it based on experiment; recognition of the inexhaustibility of matter–these are the propositions which, in the view of the Soviet scholar P. L. Kapitsa, a physicist must take into account in his methods of studying nature.[3] These propositions express clearly and graphically the materialist and dialectic spirit of modern physics.

As we pointed out above, the new physics has raised, in an extremely unusual manner and, from the traditional viewpoint, quite unexpectedly, problems relating to the philosophy and logic of the natural sciences that seemed

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[1] M. Born, *Physics in My Generation*, London and New York, 1956, pp. 145-46.

[2] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 280.

[3] See P. L. Kapitsa, *A Life in the Service of Science*, Moscow, 1965 (in Russian).

to have been solved already. We shall restrict ourselves to the problem of objective reality in modern physics and the closely associated idea of dialectical contradiction that have given rise to a particularly acute struggle between dialectical materialism and other philosophical trends.

The Problem of Objective Reality

This problem attracted the constant attention of Planck, Einstein, Bohr and other great transformers of natural sciences, as Lenin called them. It is treated, for example, in a paper by Born entitled *Symbol and Reality*.[1] The various aspects of the problem of objective reality have also been studied by physicists who consciously adhere to the guidelines of dialectical materialism.[2]

Let us recall some of the definitions and attempt to define the problem itself. The "objectively real", or "the objective", or the "objectively existing" is that "which exists independently of human consciousness and (under certain conditions) is reflected by it". The "subjective", as opposed to the objective, is that "which exists in consciousness". From the standpoint of materialist philosophy, the concept of the objective is epistemologically equivalent to the concept of matter. Lenin wrote that "the concept matter ... epistemologically implies *nothing but* objective reality existing independently of the

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[1] M. Born, "Symbol und Wirklichkeit", *Physikalische Blätter*, 1964, Heft 12; 1965, Hefte 2, 3.

[2] See A. D. Alexandrov, "On the Meaning of the Wave Function", *Doklady AN SSSR*, Vol. LXXXV, No. 2, 1952; D. I. Blokhintsev, *Foundations of Quantum Mechanics*, Moscow-Leningrad, 1949; by the same author: "Critique of the Idealist Interpretation of Quantum Mechanics", *Uspekhi fizicheskikh nauk*, Vol. XLV, No. 2, 1951; S. I. Vavilov, "The Development of the Idea of Matter", *Collected Works*, Vol. 3; see also his other works on the philosophical problems of natural science; V. A. Fok, "On the Interpretation of Quantum Mechanics", *Philosophical Problems of Modern Physics*, Moscow, 1959; by the same author: "Quantum Physics and the Structure of Matter", *The Structure and Forms of Matter*, Moscow, 1967; *Philosophical Problems of Modern Natural Science. Papers of the USSR Conference on Philosophical Problems of Natural Science"*. Moscow, 1959.

human mind and reflected by it".[1] In accordance with this (materialist) interpretation of the objective and the subjective, cognition is the process whereby the objective, real world is reflected in man's consciousness. By creating concepts, theories and a world picture, man reaches an approximate and relative comprehension of the universal regularity of matter, which is in a state of perpetual motion and development.

Even during the classical period of its development, physics had already raised the philosophical questions: do its propositions expressed in mathematical formulae have any objective value? What is there to show that physical propositions are not subjective constructs? How is objective knowledge arrived at? This is the problem of objective reality in physics in its most general form.

In classical natural science, the solution of this problem appeared to be rather simple, although it did encounter some difficulties too. Most 18th- and 19th-century scholars, just like their counterparts of the present day, did not bother too much about "philosophical niceties". They believed the objective reality of the external world as reflected in human consciousness to be self-evident. Observed phenomena were explained on the basis of the mechanical macroscopic model. The motions of macroscopic bodies, including those of the celestial bodies known at the time, were relatively simple, and the observation of them did not require complicated specialised apparatus. The concepts expressing the measurable properties of such motion (velocity, acceleration, force, etc.) do not differ much in their level of abstraction from notions worked out by everyday experience.

But classical theory could not bypass the problem of objective reality altogether. How do I know that the "green" that I see is the same "green" that you see or he sees or any other observer sees? This is an example from ordinary experience, but classical physics has grown directly out of ordinary experience, and we shall begin by analysing this example.

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 261.

The question posed here is, in effect, the question of whether the sensation of "green" corresponds to something objective. In man's practical activity the problem is solved positively: one only has to imagine a colour-blind car-driver and the answer suggests itself. Moreover, the fact that we are familiar with daltonism and can to some extent avoid its undesirable effects confirms that the sensation of "green" corresponds to an objective reality.

From the point of view of the problem of reality, the analysis of such cases is no different from the analysis of the process of measuring and experimenting in general, where the immediate task is to register macroscopic parameters. Measurement and experiment, as well as study and reflection, in which the cognitive power of abstraction grows more and more, are the basis for all physical theories, both classical and non-classical. Having generalised what has been said here and taken into account the data from diverse fields of theory and practice, we arrive at the well-known premises of materialism, which Lenin formulated with classical clarity: the only source of our knowledge is sensations; objective reality is the source of human sensations or, phrased in a slightly different way, the external world cognised by man exists independently of his consciousness.[1]

This fundamental proposition of materialist epistemology is contested by Born in the paper mentioned above. He makes no objection to the essence of that proposition; on the contrary, he criticises idealism and apriorism, especially the views of Kant, the Machists and the logical positivists. But he does not consider Lenin's thesis to have been proved and wishes to substantiate his own position, basing it, as he believes, on modern physics (Born's work has a characteristic subtitle: *An Attempt to Philosophise in a Natural-Scientific Way, but Not the Philosophy of Natural Science*). Now, is Born right?

In Born's view, the impossibility of solving the question of whether the "green" that I see is the same "green" that

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[1] See V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, pp. 126-27.

someone else sees stems from the fact that "attempts are made to explain something concerning a single impression". Actually such "explanations" are impossible, and the way out that Born suggests is as follows. "Already in the case of two impressions from the same organ of perception, e.g. two colours, there is a communicable ... objectively verifiable utterance that is founded on comparison, first and foremost, judgements of similarity and dissimilarity. (It would be better to say, non-distinguishableness and distinguishableness. . . .) I cannot really say to the other person what my sensations are when I call something green, but I can–and he can, too –state that when the green of two leaves seems the same to me, it seems the same to him too."[1]

Actually Born is expounding here the idea that objective knowledge is not so much something that has a counterpart in objective reality as something that has a commonly accepted meaning. In view of the criticism to which Lenin subjected the views of Bogdanov who defined the objective as the generally accepted, there is no need to analyse Born's erroneous ideas. On the other hand, Born uses the example involving "green" to draw attention to the idea of invariance, the application of which, in his view, permits one to solve the problem of the transition from subjective to objective knowledge (Born worked out his proposals in this connection in greater detail in his other works).[2] This aspect of the idea of invariance is of considerable interest, but, before we proceed to analyse it, let us see if Lenin's proposition concerning the main premise of materialist epistemology is really without proof, as Born believes.

In trying to solve the problem of the transition from subjective to objective knowledge, Born failed to see the problem beyond it–the question of the source of the subjective. He failed to see that objective reality is the source of human sensations (and, consequently, of the subjective). One reads

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[1] M. Born, "Symbol und Wirklichkeit", *Physikalische Blätter*, Baden, 1965, Heft 2, S. 59.

[2] See his paper "Physical Reality". In: M. Born, *Physics in My Generation*, London-New York, 1956, pp. 151-63.

in Born's paper: "From our viewpoint, which considers the subjective as primary and the possibility of objective statements as problematic. . . ."[1] This idea does not depart from the natural scientific standpoint only if it is linked to the view that "subjectiveness" itself has its source in objective reality, but we do not find this view explicitly expressed in Born's paper. In short, Born's reasoning side-steps the fundamental question of philosophy (or rather, its first aspect) –that of the relationship between consciousness and matter– and its solution in materialism. Paragraph 1 of Chapter III in Lenin's work *Materialism and Empirio-Criticism* bears the title "What Is Matter? What Is Experience?" and contains logical and epistemological proofs of the need to accept the basic tenets of materialism.

The problem of objective reality in physical science became more and more involved as physics moved on from the macroscopic objects perceived in everyday experience into the domain of phenomena whose cognition required, apart from the finest specialised experimental equipment, non-classical theories with the kind of abstractions that were totally unknown in classical physics.

At a time when no one even suspected the possibility of a new physics, Engels remarked that "atoms and molecules, etc., cannot be observed under the microscope, but only by the process of thought".[2] Engels' profound insight became fully apparent only when physics began to look into the foundations of matter. Physical theories cannot do without mathematical abstractions and principles. The Boltzmann–Gibbs physical statistics and Einstein's studies into the molecular structure of matter gave definite evidence of the heuristic role of mathematics: the work of these scientists culminated in the Perrin experiments, which proved the molecular-atomic structure of the bodies under observation. What was the situation here, as far as the problem of objective reality was concerned?

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[1] M. Born, "Symbol und Wirklichkeit", *Physikalische Blätter*, 1965, Heft 2, S. 59.

[2] F. Engels, *Dialectics of Nature*, Moscow, 1954, p. 272.

In classical physics—and that includes the Boltzmann and Einstein studies mentioned above—in order to explain what was observed in the apparatus, it was sufficient to link up the observed data through a logical chain of reasoning (certain assumptions being added when required) with the system of basic concepts and axioms of classical mechanics. As regards the problem of objective reality, this meant that the transition from observation data to the knowledge of the objects under study was being reduced to the construction of a mechanical macroscopic model. As we know, classical physical statistics is indeed based on the fundamental concepts of classical corpuscular mechanics.

In the new physics, the problem of objective reality assumed a form that was different from that of classical physics. As has been mentioned earlier, the end of the 19th century witnessed the emergence of paradoxical situations in physics, in which observation data could not be explained within the theoretical schemes and concepts existing at the time. Only then did the problem of objective reality assume the form in which it appears in the new physics.

Of course, one may try to cover paradoxical situations by modifying in certain ways the schemes of classical explanations. These attempts are illustrated by L. Janossy's interpretation of the theory of relativity or, let us say, interpretations of quantum mechanics by Schrödinger and Bohm. Generally speaking, there is nothing logically reprehensible about these attempts. But the proof of the truth of various interpretations is in the fruitfulness of the results obtained through them, and here the progress of physical science has indicated unequivocally that the theory of relativity and quantum mechanics have developed as non-classical theories, that is, theories including a mathematical apparatus unknown in classical physics and entirely different (as compared to classical physics) basic principles and concepts.

The problem of objective reality in physics was, as many believed at one time, eliminated by positivism, whose exponents, be it Mach or the logical positivists, insisted that only the world of sensations existed, without the objective reality. From this viewpoint, as is expressed, for example, in

the work of the modern American philosopher Henry Margenau, nature ceases to exist independently of experience and appears to consist of sense-data and conceptual "constructs" (everyday objects, atoms, electrons, etc.), since the latter are formed in experience. Reality, according to Margenau, is that which affects either other objects or man's psyche, and is not reality beyond that effect. "...God, according to this version, is real to the person who believes in Him,"[1] asserts Margenau. No doubt, Born was right when he made his objections to positivism on this score: "Anyone who believes that the only important reality is the domain of ideas, the spiritual realm, should not have gone into the study of nature."[2]

Modern physics develops through transitions of theories into other theories, more general (and profound), and qualitatively different from the original theories. This kind of generalisation of theories necessarily involves the disappearance of certain concepts (those present in the original theory) and the formation of new ones (without which a new theory is not a theory at all). The disappearance of old concepts and the appearance of new ones is an integral process, in which old concepts (they are like absolute notions, or invariants, in the original theory) are subjected to a kind of relativisation, becoming aspects of new absolute concepts, or invariants, in the more general theory. Thus, in the theory of relativity the concepts of absolute length and absolute duration accepted in classical mechanics disappear, and the relativistic concepts of length and duration take hold, which are aspects of one of the most important invariants of the theory of relativity—that of interval, a type of "combination" of length and duration. Corpuscular and wave concepts, which are absolutes in classical theory, cease to be so in quantum mechanics; these concepts become relative, presenting aspects of a broader, post-classical concept of the particle endowed with certain invariant characteristics.

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[1] H. Margenau, "The Nature of Physical Reality", *A Philosophy of Modern Physics*, New York, 1950, p. 9.

[2] M. Born, "Physik und Metaphysik", *Naturwissenschaftliche Rundschau*, 1955, Heft 8, S. 301.

These two examples permit the formulation of some epistemological propositions about the idea of invariance. Firstly, one cannot agree with Born, who holds only invariants to be real and rejects the reality of the aspects of invariants. It is not on the idea of invariance that the objective meaning of physical concepts, statements, etc. is based. Suffice it to recall that the relativistic concepts of length and duration correspond to objective reality (this has been confirmed by direct experiment)–and these, as is well known, are certainly not invariants of the theory of relativity. In other words, not only invariants, but also their aspects are images of objective reality.

At the same time, one cannot reject the significance of the idea of invariance for the transition from subjectiveness to objective knowledge. It has to be admitted that the concepts of classical mechanics, and classical mechanics in its entirety, are essentially an approximation (although, within the limits of their application, these concepts are absolute). That this is so has been concretely proved from different approaches by the theory of relativity and quantum mechanics, which determined the limits of application of the concepts of classical mechanics and classical mechanics as such. Thus, the uncertainty relation in quantum mechanics has established the limits of application of the classical (absolute, in a sense) concept of the particle. In establishing the limits of application of the classical concept of the particle, it was borne in mind, for instance, that electrons, apart from the corpuscular properties, have wave properties as well. In more definite terms, determining the limitations of application of the classical concept of the particle signified a deeper cognition of material particles than was possible through classical mechanics. Naturally, the classical concept of the particle does not "work" beyond these limits, that is, it has no objective meaning and is a subjective construction.

On the whole, in view of the existence of a number of modern physical theories of an increasing degree of generality (classical mechanics-quantum mechanics-quantum electrodynamics-quantum field theory, or the theory of elementary particles), one can state that the relativisation of old absolute

(invariant) concepts and the introduction of new absolute (invariant) concepts in the course of the generalisation of a theory means the progressive movement from subjectiveness to objective knowledge, a deeper cognition of objective reality, dissolving the one-sidedness and the attendant subjective constructions of individual physical theories, while the theories themselves preserve the part of their content that corresponds to reality and become more integral.

Such is the philosophical role, we believe, of the idea of invariance in attempts to handle the problem of objective reality in non-classical physical theories. Modern physics provides convincing evidence for the dialectical nature of the relationship between matter and consciousness revealed by Lenin, and for his ideas on the relationship between the subjective and the objective. Matter and consciousness, the subjective and the objective are opposed to each other only within the limits of the fundamental question of philosophy, i.e. the relationship between consciousness and matter, since consciousness does not and cannot exist outside matter and independently of it. Lenin says: "To operate beyond these limits with the antithesis of matter and mind, physical and mental, as though they were absolute opposites, would be a great mistake."[1] That this is indeed so for modern physics is confirmed by the application of the idea of invariance in it.

The Idea of Dialectical Contradiction in Quantum Theory

Experimental data on the corpuscular as well as the wave properties of microobjects (particle tracks in the Wilson cloud chamber and the diffraction of particles, e.g. electrons or molecules) are incontrovertible and are not denied by any physicist. But how are these data–the corpuscular-wave dualism–to be interpreted in theory? This task is all the more important since in classical physics corpuscular and wave theoretical constructions are regarded as mutually exclusive.

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 246.

On the philosophical plane, the question first of all arises about the ontological status of "waves" and "particles": do the experimental data on microobjects which we designate by the words "pertaining to waves" and "particles" have any counterparts in objective reality? Is Ph. Frank, for example, right in stating that the electron is only a set of physical quantities which we introduce to state a system of principles from which we can logically derive the pointer readings on measuring instruments?[1]

A degree of similarity can be seen between Zeno's aporias pertaining to motion, and corpuscular-wave dualism. In the first case, it is a question not so much of the sensory authenticity of motion as of ways to express motion in the logic of concepts. In the second instance we also have the need to express, in the logic of concepts, the empirical authenticity of the corpuscular and wave properties of microobjects because we cannot be satisfied with the authenticity of these properties alone. The respective problems are in both cases solved by dialectics, but the cases themselves differ as regards the nature of the dialectical unities arising in them. In the case of motion (mechanical movement), the latter does not directly give rise to the idea of contradiction, and to this day we admire the virtuosity of Zeno's dialectical mind (this virtuosity is not always grasped by many contemporary scientists),[2] with which he advances the idea that "the real is one and many". In the case of corpuscular-wave dualism, on the contrary, the idea of the "duality of the one" is ordinary, while amazement is caused by the empirical fact of diffraction of electrons or visual experiments with light of low intensities, which signifies that the corpuscular and wave aspects *merge together.* How are we to unite the mutually contradictory corpuscular and wave aspects? Different approaches to the solution of this problem are possible.

At one time attempts were made to describe the wave phenomenon as one in a medium formed by particles. A case in

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[1] Ph. Frank, "Foundations of Physics", *International Encyclopedia of Unified Science,* Vol. 1, No. 7, Chicago, 1946, p. 54.

[2] See S. A. Yanovskaya, "Has Modern Science Overcome the Difficulties Known as 'Zeno's Aporias'?", *Problemy logiki,* Moscow, 1963.

point is Thomson's theory, according to which an electron behaves as though it were passing through an atmosphere saturated with electrical charges.[1] Theory in which fundamental significance is ascribed only to the particle, while the waves are regarded as something derivative, is being revived in modern physics in one form or another.

When quantum mechanics was created, Schrödinger tried to interpret the corpuscles as "wave packets". This interpretation did not tally with the facts (the "wave packets", as can be demonstrated, have to "spread out" in the course of time, which is not the case with microparticles), and, moreover, faced an insurmountable difficulty in explaining the interaction between two "wave packets" in physical three-dimensional space.

Theories have been suggested (by D. Bohm and others) in which corpuscles and waves are regarded as equally fundamental aspects of matter. They lay particular emphasis on the idea of the joint existence of corpuscular and wave properties of moving objects in a model of the classical type. The classical notion of the trajectory of motion is preserved in this model and the symmetry between particles and waves inherent in quantum theory is in effect eliminated.

Characteristic of these and similar interpretations is the application of some classical concepts and schemes to phenomena on an atomic scale. Classical notions and schemes are thereby interpreted as immutable and absolute in the respective conceptions. Methodologically, this feature of these conceptions is the main source of their weakness: at best they "explain" *post factum* the results already obtained on the basis of Bohr's conception, which rests on non-classical principles. Let us now turn to another viewpoint of the problem of uniting the corpuscular and wave aspects, one which differs in principle from those mentioned earlier.

Bohr described as "irrational" the method of uniting the corpuscular and wave aspects which is based on the idea of carrying over the concept of the wave from classical optics to corpuscular mechanics. Despite the fact that attacks on Bohr's

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[1] See J. J. Thomson, *Beyond the Electron,* Cambridge, 1929.

concept of uniting the corpuscular and wave viewpoints continue to this day, and despite Bohr's use of the term "irrationality",[1] one cannot but agree with Bohr in substance. The unification of the corpuscular and wave aspects in quantum mechanics greatly resembles the introduction of irrational and imaginary numbers in mathematics or the notion of the interval in the theory of relativity. From the standpoint of any formal logical system, one cannot proceed very far in analysing questions relating to such a unification. Here dialectical logic enters the scene, which may seem and does seem irrational to the rational mind, although in actual fact it is logically faultless.

Each of the earlier-mentioned ("rational") approaches to the problem of uniting the corpuscular and wave aspects highlights one-sidedly some element of the line of cognition which reflects the state of things as it really is. Materialist dialectics, on the contrary, precludes one-sided cognition. It provides everything necessary and sufficient for ascertaining the question: do the mutually exclusive–corpuscular and wave–pictures of the behaviour of microobjects have objective significance?

Matter, i.e. substance and field, is on the whole neither particles nor waves in terms of the classical theories, nor is it a combination of these latter in some macroscopic (classical) model. The corpuscular and wave properties are united in their opposition. In other words, matter has the properties of both particles and waves. The motion of microobjects can only approximately be regarded as the movement of particles and the propagation of waves. If we consider extreme cases, in some experimental conditions microobjects behave like waves and in others like particles. The so-called relativity with regard to the instruments of observation (the latter realise the conditions in which the mutually exclusive properties of microobjects are manifested) is a characteristic feature of description in quantum theory, which follows from recognition of the biunial corpuscular-wave nature of microobjects.

These ideas have been elaborated most distinctly and systematically by scientists who are conscious proponents of dialectical materialism.[1] The influence of idealist and metaphysical views on quantum theory is most strongly felt in a definite interpretation of the problem of uniting the corpuscular and wave pictures of the behaviour of microobjects: in the denial of the objectively real nature of the unity of the corpuscular and wave properties of matter at its atomic level and in the subjectivist interpretation of relativity with regard to the instruments of observation. This interpretation is most cogently expressed in the idea of the fundamentally uncontrollable interaction of the microobject and the instruments of observation.

"Fundamental uncontrollability" in the strict sense does not express any truth whatsoever, because processes and phenomena in nature are knowable in principle and hence are fundamentally controllable. But physicists often used the term with no definite meaning; it was a way of indicating the fact that quantum laws differed qualitatively from the laws of classical mechanics. But the opponents of materialism utilised this philosophically erroneous term, interpreting it in a subjectivist spirit.

Of late, the notion of "fundamental uncontrollability" has been disappearing from scientific works, especially those produced by physicists who object to the principles of positivism in natural science (we refer here not only to scientists who are conscious proponents of dialectical materialism). Thus, in his later works on philosophical problems in atomic physics, Bohr did not use the concept of "fundamental uncontrollability", stressing that the description of atomic phenomena reflects their objective nature. The term "complementarity", which Bohr retains in use, denotes a specific relationship between experimental data on microobjects obtained with the help of mutually exclusive means of observation. Although, as Bohr points out, these data seem to contradict each other, they actually furnish exhaustive information about the object.[2]

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[1] See M. Bunge, *Causality*, Moscow, 1962, p. 427 (in Russian).

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[1] See footnote 2 on page 143.

[2] N. Bohr, *Essays 1958/1962 on Atomic Physics and Human Knowledge*, New York, London, 1963, pp. 4-5.

We now have to examine more closely some aspects of the conception which proceeds from the recognition of the biunial corpuscular-wave nature of microobjects.

The *particle*–a basic concept of classical mechanics (just like its other basic concepts)–can be defined indirectly through Newtonian axioms. Such a definition means that the particle is characterised jointly by an impulse and a co-ordinate. But the classical concept of the particle cannot be applied on an atomic scale, since it does not correspond to the experimentally established quantum regularities expressed by quantum formalism. The uncertainty relation plays a major part here. It not only establishes the bounds of applicability of the *classical* concept of the particle, but also makes it possible to generalise and deepen it, infusing it with new content unknown to the classical theories. This new content stems from the need to account in theory for the wave properties of microobjects.

Quantum formalism, which differs qualitatively from the formalism of classical theories, describes mathematically the state of affairs in physics intrinsically linked with the biunial and at the same time integral corpuscular-wave nature of microobjects. It has symbols which denote not numbers (as in classical formalism) but more abstract mathematical concepts (operators), which, generally speaking, are not subject to the commutative law of multiplication. In quantum mechanics, every physical quantity is provided with an operator such that the values of the latter yield the possible values of that quantity, while its own functions describe the corresponding states of the object (system). The very definitions of the impulse and co-ordinate operators already contain, in potential form, the uncertainty relation (for the impulse and the co-ordinate),[1] which reveals that in the quantum state (mathematically expressed by a wave function) the proper values of the co-ordinate and impulse operators cannot coexist, i.e. it is asserted in effect that quantum mechanics does not deal with the "classical" particle.

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[1] See V. A. Fok, "Quantum Mechanics". In: *Fizichesky entsiklopedichesky slovar*, Vol. 2, Moscow, 1962, p. 317.

Thus, in quantum mechanics–and this is demonstrated above all by quantum formalism–the corpuscular and wave ideas cannot converge in the classical manner. In terms of classical physics, the expression "corpuscular-wave dualism" can have, as is evident from the foregoing, the following meanings: (1) *either* a particle *or* a wave, (2) *both* a particle *and* a wave. But in terms of quantum formalism, both these meanings make no sense. We have to find, to use Bohr's expression, an "irrational" form of uniting the corpuscular and wave concepts. If such a form exists, what then is its logical meaning?

The specificity of uniting the corpuscular and wave concepts in quantum mechanics is brought into focus in the specificity of *quantum* probability–one of the fundamental concepts of quantum theory. It was introduced by Born and further developed by Bohr, and it means that processes in material systems are subject to probability laws. In accordance with this interpretation, the movement of the particle is linked with the wave process which represents the propagation of a probabilistic wave. The Schrödinger equation controls the probabilistic wave, i.e. it makes it possible to determine the probability of any variation of the temporal course of the phenomenon in the corpuscular process.

Probabilities in quantum mechanics differ radically from probabilities in classical theories. In the latter they express the existence of circumstances that are accidental in relation to the phenomena under study, and so they do not enter directly into the laws of these phenomena. The exaggeration of this state of affairs, characteristic of the metaphysical viewpoint, leads to a subjectivist interpretation of chance and probability (Laplacian determinism). The situation is entirely different in quantum mechanics, where probabilities are regarded as components of the basic laws of nature (the Schrödinger equation) and their introduction reflects the objectivity of the potential which exists under certain conditions. The probability laws of quantum mechanics are laws of the behaviour not of "classical" particles and not of "classical" fields, but of material systems which unite the properties of particles and fields in a specific way.

The idea of the "probabilistic wave" in quantum mechanics as a way of uniting the corpuscular and wave concepts may seem artificial, but it will strike one as perfectly natural if a few experiments (not *gedanken* experiments) are analysed. In a machine-gun experiment, for instance, the statistics of flying bullets are judged from the picture of random hits on the target. In an experiment involving diffraction of successively emitted electrons the statistics of electron behaviour are inferred from the random arrangement of spots on the screen (the traces of electron hits), which form a diffraction picture if the experiment lasts long enough. Comparing the two experiments, we can say that the probabilistic behaviour of the electron conforms to the wave law (which cannot be said about the behaviour of the bullet). The diffraction picture formed by electron traces indicates that the electron does not move like a "classical" particle, but like a particle possessing wave properties simultaneously with corpuscular ones. Indeed, the spot on the screen is an indication that the electron has corpuscular properties; the diffraction picture formed by the particles forces us to conclude that the electron passing through a diffraction system interacts with the system as a whole (i.e. it behaves like a wave formation) rather than with one or a small number of atoms (as a "classical" particle would have done). Thus, the electron passes through a diffraction system not like *just* a particle or *just* a wave, but like an object characterised by integral corpuscular-wave properties.

It is very important to establish what the indivisibility of the corpuscular-wave properties of the electron implies, or, more broadly, what is meant by the dialectical unity of the corpuscular and wave properties of matter. This can be demonstrated by the following example. Examining Young's interference experiment (it is assumed that the installation screen is made of a substance which produces a noticeable photoelectric effect), which demonstrates the corpuscular nature of light even on interference bands, Born denied that it was "an experiment in which waves and particles are demonstrated simultaneously".[1] But if we reflect on Born's line of argument (he asserted in particular that "to speak of a particle means nothing unless at least two points of its path can be specified experimentally; and similarly with a wave, unless at least two interference maxima are observed"),[1] then it becomes clear that Born's statements in fact refer to the *"classical"* particle and wave. Indeed, to understand the phenomena in Young's experiment one must not apply the concepts of particle and wave in the classical interpretation.

This, in fact, is what Born proved in his arguments, although he intended to demonstrate something quite different. Here we must already apply the concepts of *quantum* theory, which differ qualitatively from the classical concepts. The concept of the particle in quantum theory undoubtedly differs from its classical analogue, and Young's experiment is a curious demonstration of the point.

The distinction between the *quantum* concepts of particle and wave and the analogous *classical* concepts is that the quantum concepts are relative within the bounds of quantum theory, whereas classical concepts are absolute within the bounds of their theory. This means that, to describe the behaviour of a microobject, it is necessary to consider the instruments of observation (relativity to the instruments of observation), whereas in classical physics it is possible to ignore this aspect.[2] The difference springs from the fact that in quantum theory moving objects are examined in terms of the unity of their opposite corpuscular and wave properties, while classical theory allows of the unity of waves and particles but only in terms of their coexistence, or parallel existence, in a model that is subject to the laws of the classical theory.

We are entitled to draw the conclusion that dialectical unity, in which relative opposites must unite and do unite, differs radically from the unity of opposites, in which the

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[1] M. Born, *Atomic Physics*, London-Glasgow, 1963, p. 103.

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[1] *Ibid.*

[2] For the concept of relativity to the instruments of observation see V. A. Fok, "On the Interpretation of Quantum Mechanics". In: *Philosophical Problems of Modern Natural Science. Papers of the USSR Conference on Philosophical Problems of Natural Science.*

latter are preserved absolute and immutable. The combining of opposites to form a dialectical unity does not lead to any formal logical contradictions (this follows from the definition of dialectical unity). This kind of combining presupposes that a deeper theory than the one in which absolute opposites appear is emerging or has already emerged, a theory with new basic concepts and principles. In this theory the combining opposites become aspects of a new concept. Thus, the concept of the particle in quantum mechanics "retains" the feature of discreteness characteristic of the classical concept of the particle, but "loses" the property of moving along a trajectory and the property of individuality. These "losses", strictly speaking, are indications that wave properties are combined with corpuscular ones when reference is made to objects of quantum mechanics (which in quantum mechanics itself is expressed through the uncertainty relation for the impulse and the co-ordinate).

Summing up the logical content of what has been said about dialectical unity, we may note that this unity is governed, generally speaking, by the formula "both yes and no", and, as applied to the problem of corpuscular-wave dualism, by the formula "*both* a particle *and* a wave". This formula cannot and does not lead to formal logical misunderstandings, since in quantum mechanics the concepts "particle" and "wave" imply reciprocally relative concepts, while in classical physics they are absolute concepts. In terms of modern logic, it is particularly clear that the formula "both a particle and a wave" leads to no logical absurdity. This expression belongs to the metalanguage, whereas the expression "either a particle or a wave" belongs to the language of classical theories. From this viewpoint, quantum mechanics is, in a sense, a metatheory of classical mechanics. It is quantum mechanics that enables us to establish the limitations on the applicability of classical mechanics, its principles and basic concepts, and also to consider other questions pertaining to classical mechanics as a theory in its entirety (for example, the question of the adequacy of the concepts of objective reality admissible in classical mechanics).

Thus, the restrictions to which the classical concept of the particle is subjected in quantum mechanics are neither a restriction of cognition nor a confirmation of the positivist thesis that the question of objective significance of the empirically observable is meaningless. Such "restriction" actually represents deeper cognition of the corpuscular properties of matter, taking into account its intrinsic wave properties which the classical theories describing particles ignore. In accordance with this "restriction", the concept of the particle is generalised and deepened, discarding its classical form in the process.

Let us draw some general conclusions. When physical science proceeds to the cognition of the world of atomic phenomena and the subatomic world, or to the cognition of the world of stellar systems and galaxies, when physical knowledge of the macrocosm and microcosm is synthesised in the true philosophical meaning of the term, what is needed is a thorough-going and universal flexibility of concepts reflecting the eternal development of the objectively real world. Lenin's extremely concise and profound comments entitled "On the Question of Dialectics", summing up the basic ideas which he expressed in the *Philosophical Notebooks*, show clearly that such thorough-going flexibility is only characteristic of dialectical thinking. "The splitting of a single whole and the cognition of its contradictory parts ... is the *essence*... of dialectics....

"The condition for the knowledge of all processes of the world in their *'self-movement'*, in their spontaneous development, in their real life, is the knowledge of them as a unity of opposites. Development is the 'struggle' of opposites....

"The second *alone* [the conception of development as a unity of opposites.–*M.O.*] furnishes the key to the 'self-movement' of everything existing; it alone furnishes the key to the 'leaps', to the 'break in continuity', to the 'transformation into the opposite', to the destruction of the old and the emergence of the new."[1]

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[1] V. I. Lenin, "On the Question of Dialectics", *Collected Works*, Vol. 38, pp. 359, 360.

The passage "On the Question of Dialectics" seems to have been specifically intended by Lenin for the new physics and for the solution of philosophical problems arising in it. This is clearly borne out by the transformation of the original quantum ideas into a logically sophisticated physical theory –quantum mechanics.

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In this paper we have tried to emphasise the significance of Lenin's philosophical works for the advancement of 20th-century physical science. The greater the time span between their origin and the present, the more clearly we see their true content. Not one of Lenin's ideas pertaining to philosophical generalisations and inferences from the new physics lies fallow. The dialectical truths discovered by Lenin are now assisting the progressive development of science and will continue to do so in the future.

C. F. Powell

PROMISE AND PROBLEMS OF MODERN SCIENCE[1]

Developments in Particle Physics

I suppose that most people would now agree that one of the outstanding features of our times is the headlong advance of science and technology and that it is in these fields that the human creative intelligence today finds one of its chief means of expression. A country not involved in some aspects at least of advanced science tends to be outside the mainstream of human developments with the most serious consequences for its intellectual life and its productive power.

Nuclear and particle physics, and the associated subjects are among the main growing points of science and are concerned with our deepest penetration into the structure of the material Universe. From the time of classical antiquity it has commonly been assumed that there would one day be an end to the process of delving deeper into the nature of matter. But such a position can no longer be asserted and it is now not unreasonable to suppose that there are no "atoms" in the old Greek sense of the word:–"that which cannot be cut".

The discovery of large numbers of particles, less stable but not less significant than the electrons, protons and neutrons of our familiar world, and their arrangement into ordered families in a way so reminiscent of the Mendeleyev Table of a hundred years ago, demonstrate conclusively that we have entered fundamentally new domains. I recently recalled the astonishing remark made by Lenin in *Empirio-Criticism* in 1909, when the electron was the only known elemen-

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[1] The author prepared this paper for the Russian edition of this book (Moscow, Mysl Publishers, 1969).

tary particle. At a time when the whole scientific world tended to think of fixed unchanging particles he said: "The electron is inexhaustible."

The great generality of these advances and their profound implications give us confidence that the subject will continue to be one of the principal areas of advance in fundamental science for many years to come; and that the new picture of the constitution of matter which will be established will have resounding effects upon the whole of natural philosophy.

In response to the challenge of the subject, and its great promise, large resources in men and money are now being devoted to the national and international institutions housing the great accelerators and associated equipment indispensable for present studies in particle physics. The most powerful states are still able to build great machines from their own resources and there are substantial advantages to the physicists of any country in having their own accelerator. But for the smaller states it is difficult to find the means in men and money for the construction and effective exploitation of machines of this magnitude and a widely ranging collaboration has been established in Europe at CERN, Geneva.

Changes in the Style of Work

It is difficult for a scientist brought up in the style and traditions of thirty or forty years ago to visualise, without seeing them in action, the immense changes in the method of work which these institutions represent. They involve thousands of people, and are the embodiment of the most sophisticated technology, of the most beautiful precision engineering, of the most advanced science, and they pose most stringent problems in planning and management.

Several decades ago, research in particle physics still had all the charms of individual creation. A man or woman might still have the idea for an experiment, construct the apparatus, with the assistance perhaps of a good mechanic, make the observations, and write an account of the work. It was still even possible to conceive of an experiment and carry it

out, with materials immediately to hand, in the space of a few weeks.

An artist enjoys similar advantages, and scientists are very reluctant to abandon that close and satisfying method of work until the growing complexity of the subject and the inescapable sophistication of the methods indispensable for significant investigation force them to do so.

During the 1930s, we began to see a different pattern emerging with the introduction of the particle accelerators.

The change was greatly stimulated by the development of nuclear energy for peace and war, the experience gained by a whole generation of physicists of operations on an industrial scale, and the necessity of working together in large teams.

So it was in particle physics that we first saw something of the tone of the science of the future, of the style of work which we may expect to prevail in more and more branches of science as the techniques develop. But what is the justification for such enterprises, which make great demands on money and scarce manpower?

Promise of Modern Science

It has always been difficult to assess the implications of fundamental advances in science in their early stages, for we fail to see beyond the horizons of our own times. There is a remarkable passage from a lecture made by Clerk-Maxwell more than a hundred years ago: "For us who know only the spirit of our own age, and the characteristics of contemporary thought, it is as impossible to anticipate the general tone of the science of the future as it is to predict the particular discoveries it will make. Experimental science is continually revealing to us new features of natural processes and we are thus compelled to search for radically new forms of thought for their description."

It has often been remarked that it took 50 years for Faraday's experiments in electromagnetism to reach practical fruition. Another example is provided by the developments of the 1920s and early 1930s, which saw the birth of quantum mechanics and the incorporation within its framework of the theory of relativity. The concepts which were then introduced seemed strange and esoteric at the time, and of little practical importance; they have now pervaded the whole of science and are of fundamental importance for whole industries. It is similarly difficult for us to assess the consequences which will flow from the developments of recent years. They will surely be very profound, but all our experience suggests they will far exceed our most daring expectations.

It is sometimes said that for the practice of the future, the deeper penetration on which we are now engaged is unlikely to have great implications since the processes are remote from those which are the most significant for our ordinary experience. This seems to me to be too narrow a view. Even if they do not contribute greatly to developments in industry as we know it, and I think they will and do, it is one of the functions of the most sophisticated science to give rise to radically new industries, undreamt of within the framework of our present perspectives.

Taking into account the fairly recently discovered astronomical objects such as "quasars" and "exploding galaxies", in which there are prodigious sources of energy, estimated to be sometimes as great as 10^{62} *ergs*, which cannot be accounted for in terms of conventional nuclear processes, and the most suggestive regularities among the newly discovered particles, who would assert that in a hundred years' time, if we do not destroy our whole civilisation, we shall not have understood and mastered new sources of energy immensely more productive than nuclear sources of power?

Or who would set a limit to the perspectives which are emerging from the tremendous advances coming from the application of radioactivity to chemistry, medicine and biology? If we fail to think imaginatively about the possibilities arising from the advancement of science, and the means to realise them, who will? Who can?

But our present knowledge in many of these new fields is still rudimentary, like that in the early days of discoveries

about electricity, when the main facts were the twitching of a frog's leg under electrical stimulus, or the lightning discharge. Who could then have foreseen that such phenomena, so completely remote, as it seemed, from practical application, would one day provide an indispensable element for the whole of our civilisation?

Of course, it is in the nature of fundamental discoveries that they cannot be foreseen and that we can have no assurance of all the consequences which will flow from them. The new feature of our situation is that the resources required by science are substantial both in men and treasure. We should be careful to distinguish what is assured and what can be reasonably anticipated in making a case for great new scientific enterprises and be prepared continually to assess their significance and to run them down if our hopes seem unlikely to be realised. But if we fail to act with imagination and boldness, very grave consequences will certainly ensue.

At the present time the great states devote about three parts in 1000 of their gross national product to fundamental science, and this fraction is increasing. But how dominant a role will science play in our culture in a hundred years' time? It has sometimes been remarked that, starting at present levels, and if the proportion of our resources going into fundamental science doubles as at present every eight or ten years, then in a hundred years' time there will be nothing left for anything else but fundamental science.

To be too concerned by such a prospect at our present rate of expenditure on science reminds me of the father who, being informed by his wife that their son has increased in weight during the first year of life from 3 to 10 kilos, exclaims in alarm that if the child continues to grow at that rate, he will weigh as much as the whole earth by the time he is forty. Some scientists have suggested that the proportion spent on fundamental science should level off at about six parts in 1000 of the GNP; others, that in a hundred years we may devote 50 per cent of our resources to it in a situation where, as in the institutions supporting the accelerator, the distinction between science and technology has largely disappeared. It is difficult to find a firm basis for distinguishing between these very divergent predictions, but I would think it most unlikely that in twenty-five years' time, we shall keep expenditure down to 1 per cent of the GNP.

But the fruits of profound scientific advances are not confined to the material benefits which arise from them more or less directly in the form of radically new industries. The whole of science and technology, theory and practice, constitutes a most complex organism with innumerable concatenations, and we shall need all the wisdom we can muster to ensure a balanced development. But in our era, the history of science demonstrates the indispensable role, in the advancement of science as a whole, of our basic understanding of the constitution and interaction of the elements of matter at different levels according to the sophistication of our understanding. It seems most unlikely that a real understanding of the new realm in the hierarchy of "elementary particles" which we now seem to be entering can fail to have a similar significance for the general body of science.

Again, it is an essential feature of the institutions supporting the great national and international accelerators that they work in the most intimate collaboration with the scientists in our universities and other institutions of higher learning. This is of great value to the international institution, but it also has the consequence that the tone of the university departments of science involved, and the quality of the thinking and teaching within them are stimulated by the fact that they are peopled by men and women engaged in work at the frontiers of knowledge, whose imagination is, in a phrase of Bacon's, "being stretched and enlarged to take in the image of the Universe as it is discovered". This stretching and enlarging process produces confident and lively minds, capable of inspiring young people with their own enthusiasm for science and technology.

So I would say that the justification for great expenditures upon fundamental science has three aspects. First, because of its effect on the general body of science and on our scientific world outlook; secondly, for the practical consequences which flow directly and indirectly from the advances in science generally in the form of radically new industries and improvements in current practice; and thirdly, from the fact that the pursuit of knowledge is an essential element in contributing to a healthy tone in our universities and institutions of higher learning; that this can only be ensured if the people in them are engaged in exacting investigations on the frontiers of knowledge, and is of crucial importance for our whole culture.

Difficulties Arising from the Changing Methods of Science

It is sometimes said that the science of about fifty years ago was the science of the "pre-historic" scientific epoch. It is a phrase which makes me very uneasy. It implies too little acknowledgement that we see farther because we too stand on the shoulders of giants. It is, of course, true that there are great advantages in having sufficient resources. Madame Skłodowska-Curie, in a discourse at the Sorbonne in 1924, remarked: *"Il est vrai que la découverte du radium a été faite dans des conditions précaires, et le hangar qui l'a abritée apparaît revêtu du charme de la légende. Mais cet élément romanesque n'a pas été un avantage: il a usé nos forces et retardé les réalisations. Avec les moyens meilleurs, on eût pu réduire à deux ans les cinq premières années de notre travail et en atténuer la tension–l'expérience du passé ne doit pas être perdue pour l'avenir."*

But while it is a great advantage to have the tremendous resources which are now available, it is not a virtue, and we shall be judged by what we achieve with them–by the quality and tone of our inspiration. We are in a situation where we can afford to be neither complacent nor arrogant.

I see the science of the past seventy years as a kind of Golden Age, and our principal task as being to ensure its continuation. In the past, periods of the highest achievement have been short and precarious. The principal figures are themselves unique; and so also is the complex of situations and influences which make up the historico-social background. In our times, if science and technology have a tremendous impact on our societies, it is no less true that they are dependent on the general tone of the society in which they exist, on prevailing attitudes towards science, on the esteem in which it is held. And there are a number of disturbing signs of the time which should teach us not to take for granted an automatic progression. The provision of adequate resources is not the only thing necessary for distinguished scientific work. It has long been recognised that it also requires great determination, passion and imagination. There is an illuminating passage from Erasistratus:

"Those who are altogether unaccustomed to investigation are, at the first exercise of their intelligence, befogged and blinded and quickly desist owing to fatigue and failure of intellectual power, like one who without training attempts a race. But he who is experienced in making experiments, twisting and turning and worming his way through, does not give up the search, I will not say day or night, but rather his whole life long. He will not rest but will turn his attention to one thing after another which seems relevant to his problem, until he arrives at the solution."

This passage characterises the kind of intense enthusiasm which has always been the spur to imaginative scientific work, and it is an attitude we should be concerned to preserve in the greatly changing circumstances of our times. It is not only essential for the advancement of science in the era of great scientific enterprises but the best recipe for a humane, productive and satisfying life. It ought to be an aim for the industry of the future. But great science can never prosper without it and there are some dangers that we shall lose it. I see it as a great danger that science is tending to become dehumanised.

There are, in the first place, though they are not the most important factors, the difficulties arising from the inescapable transformation in the scale of operations in the most sophisticated sciences and the quite new demands on scientists which follow from them. They are required to work as members of a team, for long periods away from their homes and families, and they commonly play only a modest part in a large enterprise the nature of which often imposes a severe

discipline, long hours, careful and realistic planning and a strict adherence to a determined time-table.

We have already seen a similar transformation on the passage from handicraft to factory production and modern large-scale industry. There it often has the consequence that a factory operative finds no outlet for his creative imagination in his work, and his real life begins only when he is relieved of the tedium of labour. The analogy between modern science and industry should not be pressed too far, for in science we rarely do things twice in the same way, but certainly such an attitude is incompatible with penetrating scientific work.

It may be remarked that it is a problem which has been overcome in the past. The building of the Parthenon made relatively greater economic demands on Athens than large scientific enterprises on our own society. If you make large-scale drawings of the Parthenon and try to duplicate it, you get a building, but one manifestly lacking in genius. The original is in effect a gigantic work of sculpture and the subtlety of line is lost even in geometrical drawings on the largest scale.

I am told that each column in the original building was in the charge of a master mason who, with his artisans, worked on it for about a year. It is clear that they understood the essential importance of what they were doing for the whole enterprise; and that the work made satisfying demands on their taste and skill. *L'expérience du passé ne doit pas être perdue pour l'avenir.* We must maintain sufficiently interesting and challenging conditions of work in our scientific enterprises to produce really creative results.

In the great institutions for particle physics we seem at present to be succeeding, for the subject continues to attract a growing number of the best of the young people who devote themselves to science, and this is living testimony to the promise and vitality of the subject. The Parthenon was built before the fatal division between architects and builders had come about, and it is an important fact about our great scientific institutions that the planning and the execution are all in the hands of scientists. As with the Parthenon, we seem at present to be able to organise the work into groups in a way which does indeed give satisfying scope for skill and originality, and we must make sure that we continue to do so.

Dangers for the Advancement of Science

But there are more serious features in our situation. First, the benevolent role of science as the instrument for human advancement, which was clearly enunciated by many of the early protagonists of science in our era, is now seriously called into question. This carries great dangers in a situation where the development of science may be limited more by the supply of gifted people attracted into it rather than by financial limitations on the available resources. There is in some countries a turning away of young people from science to what they feel to be more innocent pursuits. They cannot fail to see that in spite of the great material benefits which have followed in the rich countries from the development and application of science, and its potentialities for good on a world scale in the future, there is little indication that these possibilities are being realised. On the contrary, the rich countries are becoming richer and the poor, poorer; not only in nutrition and technology, but in science itself.

Far from becoming the great creative element in a new world culture, science is tending to be more and more confined to the scientifically advanced states and this tendency is reinforced by the migration of important sections of the most gifted of the youth, from their own countries where they are indispensable for its advancement, towards the richer countries, where alone can be found the means for significant investigations in the subjects of their choice. And whereas the developments in the poor countries are slow and halting, indeed we hardly understand how to give aid effectively, a very large segment of the body of science in the advanced countries, backed by immense material resources, is engaged in the production of armaments and an increasing development of more and more lethal weapons of mass destruction.

These tendencies apply unequally in different countries, but, unless effective steps are taken to counteract them, they will be very damaging for the advance of science on a world scale in the future. In the interest of science itself, therefore, not to speak of wider and even graver implications, it is important that some scientists at least, and the more the better, should show themselves to be more than narrow specialists indifferent to the consequences of their discoveries; and should actively contribute towards resolving some of the grave and profoundly difficult problems raised by the headlong advancement of science, which hang like a thundercloud over everything we think and do, by giving some of their time and energy to their resolution. If we do not secure the peace of the world, our whole societies are in jeopardy, but it is possible for science to lose its inspiration even without a general war with nuclear weapons.

It is unnecessary for me here to labour another point that, in the most general sense, fundamental science and technology are indispensable elements in our culture and that in our times it is not sufficient for an educated man who aspires to be an administrator, or to occupy a position of power, to be well acquainted with the humanities or the fine arts only. But in some countries science is in fact held in little regard, and such a point of view is tacitly assumed or even explicitly stated. It is of crucial importance that all over the world science shall be cultivated as a great instrument for human advancement; that its place in our educational systems and in our societies generally shall be strengthened. In many countries including my own, the great majority of the population gain little acquaintance with science in the schools and it is almost outside the common culture.

There is a final point. I have spoken of the losses associated with the migration of the young students from poorer to richer centres. Even more serious is the fact that in an era where we need all the intelligence we can find, many potentially bright intelligences are being destroyed, especially in the early years of life, even in the relatively well-to-do states. In my own country, for example, it is estimated that the intelligences of something like 30 per cent of the children will never be cultivated because of the social conditions in which they live. A school inspector once stated that a large section of the children under five entering some schools are already conditioned not to listen because in their homes most of the communication with their parents is in the form of admonition or invective. In many countries where poverty prevails and parents are under greater stress, the proportion must be much larger.

Role of International Scientific Institutions

The establishment of international scientific centres can make a contribution to the resolution of some of these problems. Experience shows that, when they are well organised and sufficiently independent, the fact of nationality, far from raising difficulties, adds greatly to the strength of such institutions. Nothing binds men together like effective collaboration in attacking difficult and worthy tasks; and the joint effort is strengthened by the various qualities in which different nations excel.

Great international scientific undertakings, when well conceived and organised, can help to promote mutual understanding and sympathy among nations. They can help small states to provide stimulating conditions of work for some of their most gifted young people without promoting their emigration; and thus allow the most advanced science to be more closely integrated with their own culture. They can even arrest and reverse what we call the "brain-drain" and help in replacing it by a mutually advantageous two-way exchange.

There are encouraging signs that a wider co-operation is being established around both the national and international enterprises. There is a concern to co-ordinate our efforts so that we match our machines to the talent available internationally, and do not waste money and manpower.

I suppose it is impossible to see how a truly world society will be brought into being, but it is sure that it will only be established after long experience of successful collaboration in many fields. I would like to think that it is in the sciences, where we work together so effectively and profitably, that some of the first steps in this direction are being taken. Perhaps we may hope that the institutions for particle physics, and similar enterprises in other disciplines, may lead to the creation of a great international academy devoted not only to the advancement of science on a world scale but also contributing to the establishment of a peaceful world in which the aims of science to be the instrument for promoting human welfare may be realised.

Sh. Sakata

SOME PHILOSOPHICAL PROBLEMS OF THE THEORY OF ELEMENTARY PARTICLES[1]

> Natural scientists may adopt whatever attitude they please, they are still under the domination of philosophy.
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> *F. Engels*

Three Viewpoints Concerning Elementary Particles

The correct answer to the question of what elementary particles are will only be possible when the present theory of elementary particles is given a more perfect and elaborate form. Nevertheless, the investigators of elementary particles need *some* view of these particles to start with. Such a viewpoint affects the understanding of matter and nature; it determines the world outlook and the methodology of elementary particle research. Modern physicists hold various views about elementary particles. They may be roughly divided into three groups:

(1) The metaphysical viewpoint, which regards elementary particles, like Democritus' atoms, as the primary elements of matter. The proponents of this viewpoint hold the laws of the motion of elementary particles to be absolute laws and the quantum field theory to be an eternal theory.

(2) The positivist viewpoint, which treats elementary particles as no more than concepts constructed for the convenience of the description of physical phenomena. The adherents of this viewpoint believe the goal of physics to be the establishment of correspondences between experimental data.

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[1] This paper was written for the Russian edition of this book (Moscow, Mysl Publishers, 1969).

(3) The dialectical viewpoint, according to which each of the concepts "molecule", "atom", "atomic nucleus" and "elementary particle" corresponds to a certain level in the infinite levels of the structure of nature. Every level is subjected to its own laws of motion.

The first viewpoint falls within metaphysical materialism. It recognises elementary particles to be objective reality, but represents a metaphysical dogma, since it considers elementary particles to be the primary elements of matter, uncritically accepting a view that is only justified at a certain stage in the development of experimental techniques.

The second viewpoint is a positivist one and is linked with idealism. Despite the fact that this viewpoint is opposed to the first one, it is essentially its concomitant; the second viewpoint is also doomed to dogmatism. One may say that the majority of contemporary physicists vacillate between the first and the second viewpoint.

The third viewpoint is based on dialectical materialism. Engels insisted, as far back as the latter half of the 19th century, that atomistic concepts should be understood as levels in the structure of matter. He wrote in the *Dialectics of Nature*: "The new atomistics is distinguished from all previous to it by the fact that it does not maintain (idiots excepted) that matter is *merely* discrete, but that the discrete parts at various stages (ether atoms, chemical atoms, masses, heavenly bodies) are various *nodal points* which determine the various *qualitative* modes of existence of matter in general. . . ."[1] The development of nuclear physics in the 20th century has fully confirmed the correctness of this statement.

The situation in atomic theory early in this century was so much like the modern situation in the theory of elementary particles that these two periods in the development of physics could be described in the same words—one need only substitute the word "atom" for the expression "the elementary particle" and the expression "Newtonian mechanics" for the expression "the quantum field theory".

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[1] F. Engels, *Dialectics of Nature*, Moscow, 1976, pp. 293-94.

The controversy between Boltzmann, Planck and other physicists holding the first view and Ostwald, Mach and others representing the second is well known as the contradiction between atomistics and energetics. The poverty of philosophy was the cause of the recurrence of such useless controversies at the time when the existence of the electron was discovered and the study of its properties began. Physicists firmly believed at the time in the immutability and indivisibility of the atom and regarded Newtonian mechanics as an eternal theory embracing all motion from celestial bodies to atoms.

But a long series of important discoveries (the electron, Roentgen rays, etc.) and particularly the discovery of radium, "the great revolutionary", destroyed these illusions and caused the crisis of science described by Poincaré in his book *La valeur de la science.* At a time when physicists holding the first point of view were in confusion, the proponents of the second viewpoint appeared on the scene, but they too were powerless to save physics from crisis.

Lenin gave a profound analysis of this crisis in his book *Materialism and Empirio-Criticism.* He emphasised that, to overcome the crisis, physics had no choice but to accept the third point of view. But none of the physicists at the time adhered to that viewpoint. Later, nature itself compelled physicists to grope along the path foreseen by Engels and Lenin. The hierarchical structure of matter was discovered (the atom–the atomic nucleus–the elementary particle), as well as laws of motion dominating the newly discovered levels, i.e. the theory of relativity and quantum mechanics. Engels once said that nature is the touchstone of dialectics; in accordance with this thesis, the correctness of the dialectical conception of nature was revealed in the physicists' spontaneous practice.

When physics reaches into spheres of phenomena at a new level of nature, the laws and concepts formulated for the previous level cease to be effective, and then we can only rely on experimental data. It is therefore natural that the investigation of the new level begins with describing phenomena. But if at this stage we lost all belief in the old through our blind passion for the investigation of new phenomena, we should end by embracing positivism, which doubts the objective reality of things and restricts itself to pure empiricism. That is precisely the reason why the second viewpoint was so widespread early in the 20th century and the positivist tendency was so strong within the Copenhagen school when quantum mechanics was created. But the genuine development of physics, resulting in the discovery of a great number of facts, is compelling scientists to revise their conservative positions. It is overcoming the empiricism of individual scientists, is revealing the structure of the atom and is discovering the laws of motion dominating the new level of matter, e.g. quantum mechanics. Professor Mitsuo Taketani[1] called the stage of cognition at which the structure of the objects behind phenomena is revealed "the stage of the study of substance", and the stage of knowledge at which the various phenomena of the new level are understood and its own laws are discovered he called "the stage of the study of essence". He pointed out that the increasingly deep cognition of nature by man is a dialectical process developing through three successive stages in a spiral—"the study of the phenomenon", "the study of substance", "the study of essence". This doctrine of three stages suggested by Taketani is based on the hierarchical structure of nature, i.e. on the dialectics of nature, and represents an effective methodology that could be created only by the proponents of the third viewpoint. The present situation in the theory of elementary particles differs from the previous atomic theory in particular in that physicists adhering to the third viewpoint have appeared.

Views on Elementary Particles and the Copenhagen Interpretation of Quantum Mechanics

One of the reasons for the widespread view, adopted by many physicists, that the elementary particles are the primary elements of nature is the fact that the theory describing

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[1] See M. Taketani, *Some Problems of Dialectics,* Tokyo, 1948 (in Japanese).

the generation, annihilation, dispersion and decay of elementary particles is the quantum field theory based on the point model. Strictly speaking, one can view elementary particles as mathematical points only when a large-scale domain is considered and the inner structure of the elementary particles is so minor that it can be ignored. However, when this theory, with its mathematical apparatus, developed and achieved a measure of success, scientists often tended to ignore the approximate nature of the theory and easily succumbed to the illusion that the object itself was a mathematical point. In this case the mathematical points represent, as it were, structureless primary elements. This necessarily entails the conclusion that elementary particles are also the primary elements of matter. That elementary particles are geometrical points is quite absurd.

Many physicists, however, do not perceive the strangeness of this statement, falling into a mathematical mysticism reminiscent of the mysticism of the Pythagorean school. Some physicists, who take a step further towards positivism and believe in the omnipotence of mathematical equations, remain content with the observation that the results of the equations tally with their experiments.

This position on the part of modern physicists is ultimately linked with the Copenhagen interpretation of quantum mechanics, which is widespread among them. A characteristic feature of this interpretation is that, in describing the movement of a certain system and positing the Schrödinger equation as given, it merely considers, on the basis of complementarity logic, the question of how a certain phenomenon is to be inferred from that equation. In reality, however, when we desire to apply quantum mechanics to a particular object, we ought to begin with the Schrödinger equation. Then what we need is "substantial knowledge", i.e. the knowledge of what elements make up the given object and what forces act between them. Taking the atomic system as an example, we may prove that first the knowledge of the structure of the atom was obtained, i.e. it was established that it consists of an atomic nucleus and moving electrons with electrical forces acting between them, and only later was the Schrödinger equation deduced, which governs the movements of atomic particles. Bohr described this point as the "principle of conformity" and gave a correct assessment of its heuristic value.

On the basis of his doctrine of the three stages of cognition, Taketani indicated this point as a necessary one in the construction of physical theories and emphasised its significance.

The Copenhagen interpretation, based on the logic of complementarity, can be successfully applied while we are dealing with a field where "substantial knowledge" has been obtained. Indeed, its wide recognition was due to the fact that quantum mechanics was originally applied to systems of atoms. Since atomic structure was known beforehand, the "substantial knowledge" was a constant and it could be regarded as given. It may be said that this situation, having arisen due to certain historical factors, caused a positivist underestimation of "substantial knowledge" and the rejection of the model.

On the other hand, the trivial logic of the complementarity principle is helpless when physics reaches out into new fields where fresh "substantial knowledge" is necessary. We have only to recall the failure of the Copenhagen school in the study of atomic nuclei. Despite the great dislike the majority of physicists felt for the introduction of new elementary particles, a great role in further developments was played by the discovery of neutrons and the progress of the meson theory. The complementarity principle proved to be the logic of the observer and not of the active participant, so to speak.

Materialist philosophers have on many occasions far back into the past criticised the positivist nature of the Copenhagen interpretation. This criticism proved fruitless, as the critics themselves were in the position of observers. Since recent indications of the possibility of a new interpretation of quantum mechanics by Bohm, Vigier, Takabayasi and others, the debate on the problem has been renewed. In my view, one should first and foremost go back to the position of practice and give a correct assessment of the interpretation suggested by Taketani.

An important development in this field has to be indicated. Quantum mechanics revealed an intimate connection between the object observed and the instrument of measurement. Of special note is the Neumann theory, which posits the independence of the measurement results from the demarcation line between the object observed and the measuring device. If we expand this theory in accordance with the Copenhagen interpretation and assume that the measuring device is reduced to the "abstract ego" of the observer, we shall be compelled to believe that the excitation of the state of the object following the measurement is caused by the "interference of the subject". This is just one example of the positivist nature of the Copenhagen interpretation. In opposition to this, Taketani[1] pointed out the error of insisting on the mobility of the demarcation line and stressed that the limitation on the mobility of the demarcation line lies on the border between the microscopic and the macroscopic domains. In that case, the excitation of the state caused by observation may be viewed as an objective process and the claims of idealism may be rejected. The correctness of this prediction was proved by Green through a simple model.[2] Neumann's mistake was to apply quantum mechanics to the measuring device, although the latter is a macroscopic system. This reveals the failure of non-dialectic thinking which ignores the hierarchical structure of matter.

Believing as they did that "hidden parameters" were the cause of the statistical nature of quantum mechanics, Bohm and other scientists intended to demonstrate the possibility of a causal interpretation in the classical sense. These attempts, repeatedly made by authors strongly attached to the outdated concepts of classical physics, do not in themselves yield any substantial results. Indeed, the "hidden parameters" prove to be superfluous within the domain of the applicability of quantum mechanics even without Neumann's mathematical proof. Heisenberg once said that attempts to find the "hidden parameters" now resemble the attempts to find "the end of

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[1] See M. Taketani, *op. cit.*

[2] See H. S. Green, *Nuovo Cimento*, No. 5, 1958, p. 880.

the world" after the voyages of Columbus and Magellan. This is absolutely correct at the quantum level. The error of the Copenhagen school is rather that it does not recognise the existence of the subquantum level, regarding quantum mechanics as the ultimate theory. New significance can be attributed to the work of Bohm and others only in connection with subquantum level problems, i.e. the problems of the inner structure of elementary particles.

A recent attempt to postulate a structured elementary particle was viewed by physicists as pernicious. This can be explained as a kind of spreading of the "Copenhagen fog" arising from the philosophy of complementarity. Of course, the point model of elementary particles has long been criticised on account of the divergence difficulty. But doubts about the point model had to do with its mathematical, rather than physical, aspects, that is, they had nothing to do with the structure of its object. Some physicists attempted to find a mathematical procedure for eliminating divergence, but no one was willing to attempt a solution stemming from the idea of a subquantum level beyond the elementary particles.

Scientists who consider elementary particles to be the primary elements of matter regard the quantum field theory as being eternal too. In their view, physics will come to an end in the near future if the divergence difficulty is overcome. This conviction grew after Professor Tomonaga and others discovered the method of renormalisation, that is, a method for avoiding the difficulty of divergence in an ingenious way. However, if one takes a deeper view of the problem, the error becomes apparent: for renormalisation to be realised, one must have overcome the difficulty of divergence in one way or another. What is more, only interactions having a special form called "the first series" can be renormalised, and it hardly seems possible to find a guarantee for ensuring these conditions in quantum field theory.

Bohr was the first to express the view, in 1930, that the quantum field theory was not final. At the time the only known structural elements of matter were electrons and protons while the quantum field theory was represented by quantum electrodynamics, describing the interaction between these particles and the electromagnetic field. In the Faraday Lectures of the Chemical Society of Great Britain Bohr, on the one hand, pointed out the achievements of quantum mechanics, and, on the other, indicated its defects and limitations. Then he mentioned the ratio of the proton mass to the electron mass and the magnitude of the electromagnetic interaction constant as problems insoluble within the framework of quantum field theory. Now that the number of types of elementary particles has grown considerably and new interactions, strong and weak, have been discovered, these two problems are generalised in the problem of constructing the mass spectrum of the elementary particles and the structure of their interaction. These two aspects were introduced into quantum field theory as "substantial knowledge"; there is no principle for determining their form, i.e. no *causa formalis* in quantum field theory.

Generally speaking, any theory contains random elements. If one is willing to accept randomness as a manifestation of necessity, one has to investigate a deeper level than the one studied by the given theory. In the dialectical conception of nature "primary" elements of matter do not exist and, moreover, "final theories" cannot be recognised. If, against our will, we consider a certain theory to be final, we shall have to conclude that all the random elements in the theory are given by "Providence", in which case science will cease to develop and theology will take its place.

The Dialectical View of Elementary Particles and the Composite Model

In 1956 I suggested a composite model[1] of the elementary particles on the basis of the dialectical view that the elementary particles are one of the levels in the structure of matter, and also using the Taketani methodology pointing to the transition from the "stage of the study of the phenomenon" to the "stage of the study of substance". In this model three of the elementary particles of the baryon and meson family, namely the proton, the neutron and the λ-particle, are considered to be "fundamental" and the rest, to be made up of these particles and the corresponding antiparticles. In this case, transmutation of elementary particles caused by strong interaction is ultimately explained through division and combination of the basic particles. This reminds one that the divisions and combinations of atoms are viewed as causes of chemical reaction. Therefore, the assumption of the existence of "fundamental" particles in accordance with the Nakano–Nishijima–Gell-Mann law is compared with the arrangement of atoms according to the laws of constant composition and multiple ratios. This model attracted some attention as it served as the "substantial" basis for the strong interaction structure and, moreover, allowed of an explanation of the mass spectrum of composite particles and predicted the existence of the resonance particles that were then being discovered.

Since then the accumulation of much experimental data on resonance particles and the development of the group-theoretical method have proved the correctness of the composite model, on the one hand, and shown the need for some modifications, on the other. As regards the classification of the baryon family in particular, Gell-Mann and Neumann have pointed out that the proton, the neutron and the λ-particle would be better ascribed to the octet together with the Σ- and Ξ-particles. If this proposition is correct, the real proton, neutron and λ-particle should not be regarded as the basic particles of the composite model: one has to assume that "more fundamental particles" with similar properties exist. At present there are many ways of answering the question "What are the real fundamental particles?", and an unequivocal conclusion cannot be arrived at.[1] The scheme of quarks suggested by Gell-Mann is the simplest and the closest to my model. "Quarks" have many strange properties such as divided

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[1] See Sh. Sakata, "New Concepts of Elementary Particles", *Voprosy filosofii*, No. 6, 1962.

[1] See my paper in the Supplement to *Progress of Theoretical Physics*, Extra Number, 1965.

electrical charges, etc. This need not arouse anxiety, as quarks belong to the subquantum level. I am more worried about the present spread of the group-theoretical method and the dominant erroneous view of symmetry as the ultimate principle and the belief that the introduction of "substance" in the shape of "quarks" is nothing short of finding such a principle.

Models of elementary particles will undoubtedly change their concrete form with the development of experimental techniques. The position of fixing a certain form and firmly adhering to it is a metaphysical one having nothing in common with the dialectical viewpoint. However, the "method of the composite model" based on the dialectical conception of nature and the view of elementary particles as one of the levels in the structure of matter must be infinitely developed in opposition to positivist philosophy. Lenin, as a great philosopher, pointed out that the electron is also inexhaustible.

V. S. Barashenkov and D. I. Blokhintsev

LENIN'S IDEA OF THE INEXHAUSTIBILITY OF MATTER IN MODERN PHYSICS

The beginning of this century was marked by a succession of brilliant scientific discoveries. These discoveries, involving as they did the most fundamental concepts about the world around us, were intimately connected with general problems of philosophy.

The paradoxical nature of these discoveries, which radically changed the customary view of the structure of matter and the properties of time and space–a view that seemed self-evident–and some unjustified concepts of the structure of certain basic physical notions, as well as the fuzziness of the philosophical views of the world gave rise to a number of erroneous philosophical conclusions and generalisations. One such conclusion had to do with the unjustified identification of mass and matter (its "quantity"). Matter was reduced to the concept of the electromagnetic field (it should be recalled that the development of the electronic theory brought about the conclusion that particle mass is of electromagnetic origin), and the field itself was viewed as an immaterial entity. Many people believed that in this way physics had established the fact of "the disappearance of matter".

Lenin was not a physicist, but, being a brilliant philosopher, he succeeded in eliminating the difficulties that seemed insurmountable to physicists. In his book *Materialism and Empirio-Criticism* and other writings Lenin showed with the utmost clarity that the demarcation line between materialism and idealism is not determined by the origin of the electron's mass–electromagnetic or otherwise. He wrote: " 'Matter disappears' means that the limit within which we have hitherto known matter disappears and that our knowledge is penetrating deeper; properties of matter are likewise disappearing which formerly seemed absolute, immutable, and primary (impenetrability, inertia, mass, etc.) and which are now revealed to be relative and characteristic only of certain states of matter."[1]

Developing this idea, Lenin went on to formulate the celebrated thesis of the "inexhaustibility of the electron", which implies that the scientific cognition of the electron may proceed indefinitely, continuously yielding new results about reality. This vital philosophical principle exerted a profound influence upon the *Weltanschauung* of several generations of physicists and is now one of the basic methodological principles of physical research. There are no absolutely simple "elementary" objects in nature; all physical objects possess an infinite number of various properties and a complex inner structure. At each new stage of research this structure may prove to be entirely different from what the physicist had to deal with previously.

It was more than six decades ago that Lenin first advanced the idea of the "inexhaustibility of the electron". Since then the scope and depth of our knowledge of the structure of matter have grown tremendously, and investigation of this problem draws on the vast resources of modern technology, so that experimenters' laboratories look rather like big industrial enterprises.

In the following we shall attempt to show how Lenin's idea of the "inexhaustibility of the electron" is reflected and developed in present-day physics and what new philosophical problems are raised through the detailed development of the idea.

As these problems have been partially treated in a paper by one of the authors,[2] we shall deal primarily with problems whose significance became apparent only recently.

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 260.

[2] See D. I. Blokhintsev, "V. I. Lenin's Book *Materialism and Empirio-Criticism* and Contemporary Concepts of the Structure of Elementary Particles", *Uspekhi fizicheskikh nauk*, Vol. LXIX, No. 1, 1959, p. 3.

The Concept of the Spatio-Extended Particle

Despite the wide popularity won in the early years of the 20th century by statements that "physics has proved the disappearance of matter", such statements were untenable and unfounded from the purely physical point of view, irrespective of the naive identification of mass and matter.

The magnitude of the electromagnetic mass of an electron as obtained from the formulae of electronic theory proved to be infinitely great; the experimentally observed value of mass or, in general, any finite value could only be obtained if the electron were taken to have spatial parameters other than nought. However, all attempts to construct a theory of extended electrons came into immediate conflict with the propositions of the theory of relativity: in a theory of this kind signal velocity invariably turned out to be greater than that of light, c. Therefore it was possible to speak of the electromagnetic origin of particle mass only by overlooking the concomitant howling physical contradictions.

Difficulties remained in the quantum theory as well. All the numerous attempts to build up a relativist invariant theory of extended particles or to localise the superrelativistic velocities of signals in the supersmall spatio-temporal areas $\Delta x \leqslant l$, $\Delta t \leqslant l/c$ were unsuccessful. The most complete study of these difficulties was made in the so-called non-local theories. A great number of such theories are currently known; their common feature is that in all cases an elementary length l is introduced in a certain manner (distinguishing one concrete version of the theory from another); this length determines the scale of the time-space area $(\Delta x \leqslant l,\ \Delta t \leqslant l/c)$, in which the superrelativistic signals may travel ("the non-locality area").

The introduction of elementary length is proving to be critical for modern theory; the difficulties that arise permeate literally all aspects of the theory. Involved here are problems relating to relativist invariance (the mathematical compatibility condition, ordering with respect to time, superrelativistic velocities), problems pertaining to quantum-mechanical description (unitarity of dispersion matrix, definiteness of metrics), problems of convergence of matrix elements, problems of gradient invariance (when charged particles are involved), and so on.

Particularly difficult for non-local theories is the formulation of conditions ensuring macroscopic causality (i.e. causality in the areas $\Delta x \gg l$, $\Delta t \gg l/c$), when microcausality is destroyed and simultaneously the unitarity of dispersion matrix is to be retained. (It should be recalled that the condition of unitarity of the dispersion matrix guarantees the normalisation of total probability of all possible processes.)[1]

It has been demonstrated by a number of authors that, generally speaking, a non-local theory may be formulated in a way that will eliminate or allay most of the difficulties pointed out above; it appears that many of these difficulties are not fundamental but rather result from a simplistic generalisation of the apparatus of the point particle local theory. Formulations that are equivalent to each other in local theory prove to be absolutely non-equivalent with respect to the possibility of their non-local generalisation. The origin of some difficulties in non-local theories can be traced to an unhappy choice of the initial local formulation.

Contemporary non-local field theories are, as yet, mathematical models incapable of interpreting or predicting real physical phenomena. The overall situation is further complicated by the fact that experiment so far has given no indication of the existence of any non-local effects; non-local theories are therefore constructed in such a way that they could be identified with the usual local theory in all areas accessible to modern experimental study. This is the only factor determining the value of the l constant. Contemporary non-local theories are essentially studies in certain new mathematical forms with old physical content.

An analysis of the difficulties of present-day field theory forces the conclusion that, to overcome these difficulties, some essential modifications will have to be introduced concerning its basic concepts–those of field, particle, time, space, etc.

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[1] For details see D. I. Blokhintsev, "Non-Local and Non-Linear Field Theories", *Uspekhi fizicheskikh nauk*, Vol. LXI, No. 2, 1957, p. 142.

At the same time contemporary quantum theory predicts (and this has been borne out by experiment) that elementary particles do have spatial characteristics, although in a different sense from what was indicated earlier. A free, non-interacting particle is merely a mathematical abstraction. Actual particles always interact with vacuum fields and, in accordance with the uncertainty relation, each of them is enveloped by a dynamic "cloud" of virtually emitted and absorbed particles. In the interaction between elementary particles themselves or between elementary particles and the electromagnetic field, the presence of such clouds is effectively revealed as the relativistically invariant structure of such particles–the "spreading" of their electric charge, magnetic moment and mass, which becomes increasingly complex as we go over to the area of ultrasmall scales.

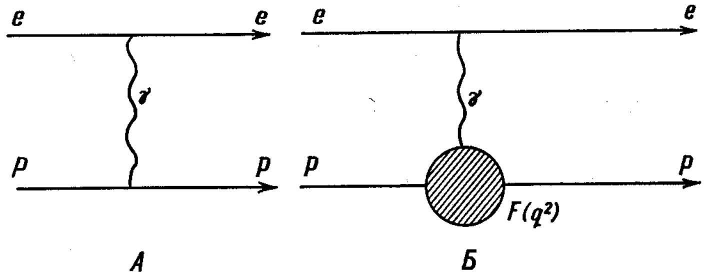

Fig. 1.

A–a diagram of the dispersion of a point electron by a point proton is the virtual photon); *B*–a similar diagram of the dispersion of a point electron by a proton enveloped by an extended "cloud" of virtual particles; $F(q^2)$–the relativistic form-factor describing the "cloud" structure; q^2–the square of the four-dimensional vector of the transmitted impulse equal to the difference between the four-dimensional impulses of the proton before and after the collision

From the mathematical point of view, this kind of structure can be described by means of certain relativistically invariant functions, known as form-factors, at the nodes of the Feinman diagrams, corresponding to interaction points (Fig. 1). The expressions describing interaction assume in this case the most general form possible within relativistic invariant theory. The type of form-factors $F(q^2)$ is determined by the comparison of experimental data with the theoretical formulae for interaction cross-sections. It is significant that, although virtual interaction with vacuum fields leads to form-factors, the theory remains essentially local in its structure and still contains divergent expressions.

In particle interactions at comparatively great distances, i.e. in the order of the size of the virtual cloud, $r \sim 10^{-13}$ *cm*, when the recoil effect is small (recoil energy $T_{\text{recoil}} \ll$ particle mass M), the process may approximately be regarded as non-relativistic. In this case it is easy to show[1] that the Fourier transformation of the experimental form-factor

$$\rho(\bar{x}) = \frac{1}{(2\pi)^3} \int\limits_{-\infty}^{+\infty} F(\bar{q}^{-2})\, e^{i\bar{q}\bar{x}}\, d^3 x$$

represents a corresponding spatial distribution of the electric charge, magnetic moment or mass within the particle. (Since $q_4 \sim T_{\text{recoil}} \simeq 0$, then $q^2 \simeq \bar{q}^2$, and the integral is three-dimensional; the ρ function depends therefore only upon spatial co-ordinates). If, on the other hand, the recoil is not small, the ρ function appears to be dependent not only on the spatial co-ordinates, but also on time, and, what is more, it cannot be expressed in any simple manner through the squares of the wave functions $/\varphi_{\text{init.}}/^2$ and $/\varphi_{\text{fin.}}/^2$ describing the distributions of charges and masses within the particle before and after interaction; the ρ function is in this case determined in a complicated integral manner by the interference of wave functions of the initial and final states of the particle.

The difficulties grow in scope as we pass on to the sphere of very high energies (i.e. very small collision parameters), where it becomes necessary to take into account virtual processes corresponding to a great number of new form-factors, the so-called four-tails, five-tails, etc. For example, in the well-known experiments of Hofstadter, taking into account the next two-photon approximation to electron dispersion on the proton, there arise about twenty new form-factors ("four-tails") corresponding to the amplitudes of the virtual Compton effect (Fig.2). It will be seen that in present-day relativistic quantum theory the spatial image of an extended particle is an approximate one, of a dynamic rather than geometrical character. One is left with a persistent impression, however, that the basic physical concepts–those of time-space, field and particle, which we use in the analysis of the structure of elementary particles–may prove to be untenable "within" structured particles.

It was pointed out above that there are as yet no experimental grounds for giving up the ordinary spatio-temporal notions for the region of scales of the order of $\Delta x \leqslant 10^{-13}$ *cm*, $\Delta t \leqslant 10^{-23}$ *sec.*[1] Nevertheless, at the present stage of the development of science, the statement of the feasibility of the so-called extraspatial and extratemporal forms of the existence of matter is far from meaningless. If one conceives of time and space as the forms of the existence of matter that reflect respectively the stability and mutability of its being, then space and time are universal forms of the existence of matter, since the world is nothing but moving matter.

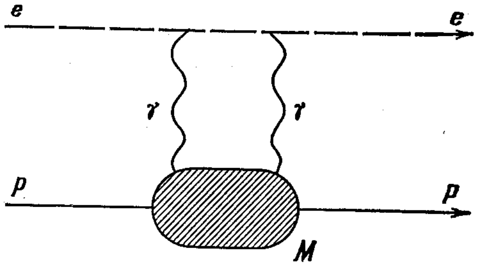

Fig. 2

Diagram of the next, two-photon approximation in the dispersion of a point electron over an extended proton.

Due to invariance considerations the amplitude *M* may be written as the sum of twenty terms, each of them containing an unknown function. These unknown functions, like the form-factors in Fig. 1, have to be defined from comparison with the experiment. The rough approximation of amplitude *M* can be worked out with the help of models.

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[1] See D. I. Blokhintsev, V. S. Barashenkov and B. M. Barbashov "The Structure of Nucleons", *Uspekhi fizicheskikh nauk*, Vol. LXVIII, No. 3, 1959, p. 417.

[1] See D. I. Blokhintsev, "On the Interaction Between the Microsystem and the Measuring Instrument," *Uspekhi fizicheskikh nauk*, Vol. XCV, No. 1, 1968

Apart from that, space and time are often (and in physics practically always) taken to mean forms expressing the structural correlations of the coexistence of phenomena and state changes. This approach assumes that at the given material level the distinction between two adjacent points (objects) x_1 and x_2 and two successive moments (states) t_1 and t_2 makes sense. But the properties of "adjacency" and "succession" are concrete and extremely specific properties of structure that do not exist at all times. From this point of view, one may pose the question of "extraspatial" and "extratemporal" forms of the existence of matter: the microscopic and macroscopic forms of its being may differ substantially. In other words, what we have here is the possibility of a new stage in the cognition of space and time as objectively real forms of any being.

The study of possible generalisations of the ordinary image of space-time is an important task of philosophical and physical research. It would not be out of place here to recall Lenin's programmatic statement concerning Engels that "a revision of his natural-philosophical propositions is not only not 'revisionism', in the accepted meaning of the term, but, on the contrary, is an essential requirement of Marxism".[1]

Exploration of new ground in this direction is, in a way, represented by the study of quantified space-time. These theoretical schemes operate in the curved impulse space. The corresponding co-ordinate space-time exists only asymptotically—for great distances and time intervals. The realisation of the idea of quantified space-time, however, is still facing serious difficulties, just like the non-local theories.

The Present-Day Picture of the Structure of Elementary Particles

In view of the difficulties involved in giving a consistent treatment to the problem of the structure of microobjects, different models have gained currency in elementary particle physics. Of course, all model approaches are essentially limited and applicable only to the description of quite definite aspects of the objects under study, but at present this is the only way of understanding and assimilating the rapidly growing flow of experimental data.

Instead of going into details about the various concrete models for the structure of elementary particles, we shall just point out that the contemporary picture of the inner structure of the nucleon, the elementary particle that is best known at present, is quite remote from the naive notion shared by most physicists just ten years ago that the structures of the proton and the neutron are extremely alike and differ primarily in the electric charge sign in virtual meson clouds. Experiments in hydrogen and deuterium dispersion of fast neutrons and the analysis of slow neutron beam dispersion in the electron shells of atoms have shown convincingly that the structures of the proton and the neutron are quite different even at the periphery and are determined by complex resonance interactions of virtual particles. The importance of these interactions was realised fairly recently, after the discovery of a large family of supershortlived resonon particles. Before that, experimental data concerning the structure of nucleons seemed to be a field full of enigmas and contradictions.

Analysis of numerous experimental data on the electromagnetic interactions of particles with nucleons and some facts about strong interactions of this kind compel one to believe that inside nucleons at distances of the order of the Compton nucleon wave-length, $r \sim 2 \cdot 10^{-14} cm$, the density of the electric charge, magnetic moment and mass increases abruptly forming a sort of kernel (core) in the centre of the nucleon. Of course, in view of the above-mentioned difficulties in describing the spatial structure of particles, these conclusions should merely be regarded as roughly qualitative; the fact, however, that they result from a great many experiments is convincing proof of their reality.

We see that as we enter ever deeper layers of matter the difference in the scale of characteristic details of the structure is levelled out. In atoms there is a many-order difference between the size of the electron shell and the nucleus, where-

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 251.

as in the nucleon the peripheral shell and the kernel differ in size by several times only. Substantial progress in understanding the structure of elementary particles was made owing to the development of unitary symmetry. This method, in particular, proved to be effective in linking up the structural properties of such apparently different particles as the nucleon and hyperons, π-, η-, and K-mesons, etc.

Somewhat unexpected results were obtained in the experimental study of the π-meson structure. The mean geometrical parameters and charge distribution over the periphery of this particle prove to be very close to what we know of the proton. Admittedly, this conclusion is subject to modification, as experimental data on the π-meson are not very precise yet.

From the standpoint of quantum field theory, it is to be expected that all elementary particles, the electron, γ-quantum and neutrino included, have an inner structure determined by virtual interactions with the vacuum, but the structure of particles unaffected by strong interactions, as distinct from the nucleon and the π-meson, is mainly concentrated somewhere in the region of

$$\Delta x \leqslant 10^{-16}\ cm.$$

To explain this, we shall consider the virtual process of electron dissociation into a μ-meson and a neutrino+antineutrino pair:

$$e \rightleftarrows \mu + \nu + \bar{\nu}.$$

The interaction determining this process is a weak one and is characterised by the Fermi interaction constant G. This constant may be linked with the length

$$l = \sqrt{G\hbar c} \simeq 10^{-16}\ cm.$$

It may be demonstrated that if the lengths of the de Broglie waves in this phenomenon are close to $10^{-16}\ cm$, this "weak" interaction becomes stronger than electromagnetic interactions. In that case it becomes absolutely clear that at distances of $\Delta x \leqslant 10^{-16}\ cm$ one cannot meaningfully consider the electron without taking into account fundamentally new phenomena involving mesons and neutrinos. The cloud of such particles will be more dense than the cloud of virtual particles formed around the electron by electromagnetic interactions.

Experimental research of ultrasmall spatio-temporal regions of the order of $\Delta x \leqslant 10^{-16}\ cm$ and $\Delta t \leqslant 10^{-26}\ sec$ requires particles with energies of the order of $\geqslant 10^5 GeV$, which will be far in excess of the possibilities of acceleration techniques for a long time to come and will only be available in cosmic ray experiments, where precision of measurements is very low owing to the rarity of cosmic particles with very high energies (let us recall that present-day accelerators are used to study object of the order of $\Delta x \geqslant 5 \cdot 10^{-15}\ cm$; the 70 GeV proton accelerator at Serpukhov brings the lower limit of this scale down by a factor of 1.5 approximately).

Strange as it may seem, the study of the inner structure of the electron, that apparently most "simple" and most ordinary of elementary particles, is likely to be undertaken only in the rather distant future. But this may also be seen as a fortunate circumstance. With a great degree of precision the electron may be regarded as a point, and that means that it can be used as a good instrument for probing the structure of other, heavier particles. (Strictly speaking, the electron is always enveloped with a cloud of electron-positron pairs of the $r \sim 10^{-11}\ cm$ characteristic size; owing to the small electromagnetic interaction constant $\alpha = 1/137$, however, emission of such pairs is comparatively rare and their cloud is so "transparent" as compared, for instance, with the density of meson clouds around the nucleon that it may simply be ignored.)

Experiments with electrons are at present the main source of our knowledge of the structure of nucleons and mesons.

The Structure of Elementary Particles and the Concept of Elementariness

The experimental discovery of nucleon structure presented in quite a new light the problem of the elementariness of particles. Earlier, "elementary" particles were taken to include the simplest microobjects out of those known which in all measurable processes behave as a single whole.[1] The nucleon described by the form-factors clearly does not fit this definition. At the same time it is impossible to distinguish some simpler elements within the nucleon, at the present stage at any rate. In all interactions that we know at present, both real and virtual, groups of particles that are now commonly called elementary are transmuted into particles that are just as elementary and it is impossible to distinguish objects having "different degrees of elementariness". Structural elements prove to be just as complex here as the whole itself; in this sense, one may say that nucleons "contain other nucleons within themselves".

It should be noted that despite the strangeness of this conclusion it is only a concrete realisation of the well-known mathematical proposition that the infinite set contains subsets that are equipotential to the original set. As applied to the nucleon, it means just this: we *assume* that any virtual nucleon may virtually dissociate into *precisely* the same infinite number of virtual particles as the original nucleon.

Understandably, this assumption is only true for strongly interacting particles and is quite wrong, for example, in electrodynamics, where members of expansions corresponding to sequences of virtual particle dissociations rapidly decrease in proportion to the degrees of the fine structure constant $\alpha = 1/137$. Of course, as applied to strongly interacting particles, the assumption of a long series of successive non-fading dissociations (let alone the idealisation involving an infinite number of elements within a sequence) is also only an assumption, but its possible violations are far beyond the limitations of modern measurement precision.

It should also be emphasised that in all cases involving statements that a certain particle *consists* of other particles–e.g. the π-meson consists of the nucleon and the antinucleon –this must be perceived in terms of virtual dissociations, the mass defect being so great that any real dissociation of the particle is out of the question. In this respect, the π-meson is radically different from the deuteron, for instance, whose mass

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[1] See L. D. Landau, Y. M. Lifshits, *Field Theory*, Moscow, 1948, p. 34 (in Russian).

defect is only about one-thousandth of its mass so that it can really be viewed as consisting of a proton and a neutron.

Moreover, even in the case of particle decay (e.g. $\pi \to \mu + e$), one cannot say that the ultimate particles are parts of the original one. That would only be true if the bonding energy (mass defect) were considerably lower than the masses of particles participating in the reaction and if the component particles did not lose their individuality within the whole they form (as is the case in the deuteron).

At present, the group of elementary particles is believed to include all particles whose decays of *any* kind, both real and virtual, involve mass defect comparable in magnitude with the mass of the original particle or the masses of the decayed particles. This definition is little more than a practical criterion, but it is quite sufficient for determining unequivocally the group of elementary objects, which, however, proves to be quite large and includes many different particles.

The existence of so great a number of objects that have to be treated as elementary "blocks" (and their number is rapidly increasing) inspires a feeling of uncertainty in the researcher. The discovery of unitary symmetry has made it possible to unite fairly large groups of particles within separate families whose members are different states of one particle, so that the number of essentially different elementary particles has decreased considerably. Even so, the number remains very large.

From this viewpoint, the quark hypothesis looks very attractive, as it permits us to represent *all* the strongly interacting particles as consisting of two types of particles only, quarks and antiquarks, each of them having three different states. For example, the π-meson consists of a quark and an antiquark; the *K*-meson, also of a quark and an antiquark, but in other states; the nucleon, of three quarks, etc.

Quarks are the simplest objects of the SU_3 and SU_6 group symmetries just as the nucleon is the simplest multiplet of the isotopic group. Just as all atomic nuclei can be built out of nucleons, so all the strongly interacting particles may be constructed out of quarks, with the (very essential) difference that mass defect will in this case be many times greater than the masses of composite particles. From the point of view of the magnitude of their mass defect (the density of their packing, so to speak) and their position in the unitary groups, quarks may now be regarded as the most elementary of all physical objects known at present, as the next and more profound level of the material world.

It is noteworthy that simple models which seem extremely naive at first glance and use non-relativistic equations for the description of quark interactions within particles often lead to excellent agreement with experiment and provide a remarkably easy and natural explanation for many peculiarities of elementary particles and their interactions. Yet, as a rule, attempts to achieve greater precision immediately destroy the agreement between experiment and theory. One is left with the impression that the quark hypothesis in its present form reflects in an extremely primitive and rough manner some fundamental and as yet completely vague laws of the ultrasmall regions and is very far from the real state of things. Apparently, we can only see the dim outlines of something that is completely unlike everything that we have so far dealt with, and so any attempt to describe that "something" in terms of familiar concepts immediately results in contradictions.

Another remarkable fact is that quarks seem to be completely unrelated to particles unaffected by strong interactions: neither the π-meson nor the electron nor the neutrino can be represented as "consisting" of quarks. Against the background of the quark hypothesis, leptons and photons seem very foreign objects.

It must be noted that all attempts to find quarks in a free state experimentally have so far failed. This "failure" confirms the view often stressed by one of the present authors (D. Blokhintsev) that quarks are a method for describing the states of complex strongly interacting particles (nucleons and mesons), and are not independent objects of the microworld.

Still another circumstance linked with the concept of the elementary particle compels one to ponder deeply. It may be demonstrated[1] that direct transference of the modern field theory into the ultrahigh energy region (and thereby into the region of ultrasmall spatio-temporal magnitudes) results in the conclusion that the very concept of the particle in this field is untenable: interaction energy in this case turns out to be much greater than the energy corresponding to the rest mass of the particles, so that the entire procedure of secondary quantification through which particles appeared in modern field theory becomes contradictory. At the same time, we cannot give up the concept of the particle without destroying the foundations of the mathematical apparatus of modern theory.

Thus we see that physics, in proceeding to the study of the deep layers in the structure of matter, is faced with a large number of substantial difficulties and contradictions. The elementary particle actually proves to be extraordinarily complex, and advances in the study of its inner structure require enormous efforts that are in any case just as great as those of the astronomers studying the remote depths of the Universe. The technology involved is just as complex. Just as astronomers need very complex telescopes, so physicists require complex accelerators. Some theoreticians believe, however, that they will be able to manage without accelerators. But the entire experience of cognition shows that it is impossible to embrace the whole of the microworld within a theory that is based on experimental data pertaining to only a limited region of the microworld. New experiments will be needed to reveal the specificity of the deeper regions. We can only speak of the limited regions of the Universe that have been really studied and for which real laws may be formulated. We therefore believe that it is extremely important to understand Lenin's ideas about the inexhaustibility of elementary particles as this helps to choose the right working method.

Macrophenomena in the Microworld

Proceeding from Lenin's works on materialist dialectics, it is natural to believe that great surprises await us in the small-scale regions, where modern theory leads to absurd results.

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[1] See D. I. Blokhintsev, "Non-Local and Non-Linear Field Theories", *Uspekhi fizicheskikh nauk*, Vol. LXI, No. 2, 1957, p. 142.

There are grounds for believing at present that the quark mass, if it exists at all, is at least ten times as great as that of the nucleon. The study of the resonance interaction of elementary particles is resulting in the discovery of ever heavier resonance particles with masses considerably exceeding that of the nucleon. Just how far can this increase in the mass of microobjects go? May a situation not arise in which ultra-small spatio-temporal regions will yield objects with macroscopic masses? In other words, is the gap between the microworld and the macroworld really so wide?

This gap might exist if the transition to the extremely high-energy regions involved infinitely small interaction cross-sections of elementary particles. In that case high energies would be of no consequence for the microscopic phenomena, in other words, particles would become transparent at high energies. One might say that the nucleons cease their mutual interaction, and even if the bombarding microparticle has a very high energy it is its "personal affair", since it does not interact with other particles. In that case the microworld would be separated from the macroworld by a very real barrier.

Experiment indicates, however, that strong interaction cross-sections at very high energies apparently remain constant or do not, in any case, decrease to any appreciable degree. Thus, the nucleon-nucleon interaction cross-sections remain approximately constant up to energies of the order of $10^{18}\,eV$.[1] These energies are milliards of times greater than the nucleon's own energy. Collisions of such nucleons yield enormous numbers of newly born secondary particles. Collisions of particles of sufficient energy might, therefore, in principle give rise to the birth of stars, speaking figuratively —not in the way physicists in laboratories understand the process, but in the way astronomers do.

Nevertheless, this possibility is ruled out for the real cosmic particles (at any rate in that part of the Universe that is at present available for observation), as their energy is automatically cut off somewhere at the 10^{20}-$10^{22}eV$ level due to energy losses in interactions with the photons of the relict thermal radiation of the Universe.

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[1] See V. S. Barashenkov, *Interaction Sections of Elementary Particles*, Moscow, 1966 (in Russian).

Apparently, there are also some limitations on the magnitude of virtual particle energy; otherwise it would be difficult to understand the fact that magnitudes expressed in theory by divergent energy integrals prove to be finite in reality. From this viewpoint, there is little likelihood of "macroscopic phenomena" in the microworld that would be noticeable to any degree.

Proceeding from the ideas of the general theory of relativity, M. A. Markov has indicated another region where the microworld and the macroworld may come very close to each other.[1]

According to the theory of relativity, for a closed world with radius R the distance is determined by the formula $r = R\sin\chi$, where the χ parameter takes on its value between 0 and π. Accordingly, the surface of the three-dimensional sphere in this world is

$$S = 4\pi R^2 \sin^2\chi.$$

S is obviously at its maximum when $\chi = \pi/2$ and is further reduced to a point when χ increases to the value of π. It also appears that intrinsic gravitational energy exactly makes up for the non-gravitational mass of the bodies enclosed within the sphere S so that the complete energy equals zero—just as it should be for a closed Universe.

Consequently, if one is to consider the Friedman Universe, which is just slightly open in the sense that $\chi = \pi - \delta$, where δ is extremely small, the mass of "the whole Universe" may equal, for instance, that of the neutron and for an external observer the behaviour of "such a Universe" in relation to the forces affecting it will not differ from that of a particle having a mass equal to that of the neutron.

Although the results of this kind of reasoning should not, of course, be taken too literally, as it does not give any consideration to the quantum nature of microscopic phenomena

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[1] See *Proceedings of the 13th International Conference on High-Energy Physics*, Rochester, 1966.

and makes the extremely bold assumption that the laws of the theory of relativity as we know them now will be valid up to very small distances, it is nevertheless apparent that the gap between the microworld and the macroworld may not be as deep and wide after all as it might seem at first glance. In any case the study of phenomena taking place in the microworld leads to a discussion of cosmic problems and, vice versa, an analysis of cosmological problems quite unexpectedly proves to be connected with the fundamental problems of elementary particle physics.

The electron really is proving to be inexhaustible.

Conclusion

It is clear how significant Lenin's words about the inexhaustibility of the electron are. His idea is essentially the working programme of the whole of elementary particle physics at present.

At the same time it should be borne in mind that Lenin, as a great dialectic philosopher, emphasised that the problem of knowledge is primarily the problem of practice; the practical criterion is the most important one here. Using Engels' terminology, one may say that the process of cognition is the transformation of the "thing-in-itself" into a "thing-for-us". On this road one may encounter striking phenomena that may appear to contradict all previous knowledge. And it is in these regions that the correct philosophical interpretation of practical results is particularly important. Unlike other philosophical systems, dialectical materialism does not oppose modern science as a set of rigid propositions given once and for all; its content is enriched and its form changed with every great scientific discovery.

One may say that the atom and the atomic nucleus have largely become a "thing-for-us". We are now witnessing the transformation of the deeper layers of elementary particles from the "thing-in-itself" into a "thing-for-us". It is quite clear that Lenin foresaw, in general outline, precisely this course of the development of knowledge.

V. A. Fok

QUANTUM PHYSICS AND PHILOSOPHICAL PROBLEMS

"With each epoch-making discovery even in the sphere of natural science it [materialism] has to change its form."[1] These words, written by Engels and quoted by Lenin, are widely known. Now, quantum physics, undoubtedly, constitutes such an epoch-making discovery and thus obliges the scientist to examine new problems in the theory of knowledge. More than that, a correct interpretation of quantum mechanics as a physical theory is impossible until correct answers to epistemological questions arising in this field are found.

The problems we are speaking of concern the fundamental philosophical question as to the relationship of the objects of the external world to the perceiving subject. In our analysis of these problems we should be guided not only by the general doctrine of materialist philosophy that consciousness presupposes the existence of matter, but also by the doctrine that all demarcation lines in nature are conditional and relative.

Epistemological Significance of the Difference in the Ways of Describing Physical Objects

The notions treated in the theory of knowledge are usually subdivided into two categories: (1) the subject, with his consciousness, mental capability and power of perception,

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[1] Frederick Engels, "Ludwig Feuerbach and the End of Classical German Philosophy". In: Karl Marx and Frederick Engels, *Selected Works*, Vol. 3, Moscow, 1977, p. 349.

and (2) the objects of the external world (which are to be studied by the subject). Classical physics did not recognise essential distinctions in the ways of describing different objects in the external world; accordingly, all material objects belonged to one and the same epistemological category. But in quantum physics (physics of the microcosm) the essential role of measuring devices and instruments, considered as mediators or connecting links between objects of the external world and the human mind, was made evident. At the same time, it became clear that the construction and functioning of a measuring device is to be described in a way essentially different from that necessary for the description of the properties and behaviour of the microobject (for the investigation of which the appropriate measuring device has been designed). This difference is so fundamental that, from the epistemological point of view, microobjects and measuring devices are to be considered as belonging to different categories.

On the other hand, measuring instruments have several features in common with human organs of perception. For many purposes the human eye functions as a sufficiently precise measuring instrument, and the use of eyeglasses, a microscope or a telescope does not introduce any change in principle, but just greatly improves the possibilities and the accuracy of observations. An estimate by eye-inspection differs only in the degree of precision from a measurement made with an instrument. The pupils of Academician S. I. Vavilov even managed to state the perception of quantum fluctuations of light by the eye. Similarly, there is no difference in principle between the estimation of the weight of a body by muscular effort and its determination with the help of a balance. These considerations lead us to the following conclusion. If in the study of the act of perception it is found necessary (as is the case in quantum physics) to consider the observation means as a separate epistemological category, then this category must include both the measuring instruments and the human sense organs. Accordingly, the readings of instruments and the human perceptions also belong to a common category.

We thus arrive at the conclusion that, while preserving the basic distinction inherent in materialist philosophy between mind and consciousness (or the spirit), on the one hand, and matter (in the most general sense), on the other hand, we must distinguish epistemologically between individual categories of material objects.

All these distinctions are connected with the difference in the ways of describing the corresponding notions. Thus, mind and consciousness are described in a subjective way. Undoubtedly, thought is a product of the brain; but it differs from the brain as fundamentally as an idea written down on a piece of paper differs from the paper and the ink used. The circumstance that men think with the aid of their brain, while the brain can be (and actually is) an object of investigation in biology and in physiology, does not exclude the existence of mind and consciousness as a distinct subjective category which is to be described "from the inside". This fact has always been admitted by materialist philosophy and remains in force even when epistemological distinctions between different types or categories of material objects are introduced. The novelty implied in these distinctions consists only in the separation of the perceptions of the human sense organs from the notion "subjective" and in their logical connection with the readings of measuring instruments.

On the other hand, the modifications introduced by quantum physics in the description of some categories of objects in the external world (those usually called microobjects) are of a very profound nature. In prequantum physics a common feature of all methods of description, applied to the most diverse kinds of objects in the external world, was the tacit assumption that the means of observation are non-essential and can be completely disregarded in the description. A tacit supposition was made that for any object one can always find a sufficiently "careful" method of observation which does not influence the behaviour of the object; this supposition permitted one to speak of the behaviour of the object "by itself" and thus to avoid the question of observational means as a premise for knowledge. Accordingly, in prequantum physics both categories–the means of observation and the objects observed—were unified into a single one, which approximately corresponded to the notion of the external world. Any object in the external world was described on the basis of abstractions taken from classical physics (and actually applicable only to macroscopic objects). These abstractions will be considered in more detail later.

The elucidation of the basic principles of quantum physics has shown that the ways of describing observational means, on the one hand, and of microobjects, on the other hand, are essentially different. The means of observation can and must be described on the basis of classical abstractions (with due account of the quantitative restrictions imposed by quantum mechanics). The microobjects, however (molecules, atoms, electrons, photons, all kinds of elementary particles and quasiparticles), require for their description new principles and new concepts which differ so widely from the old ones that they cannot even be expressed in the language of classical physics. To express them a new language (mathematical as well as verbal) had to be created—the language of quantum physics.

With the spread to new domains of quantal concepts and with the development of corresponding physical theories, this language has become more and more elaborate. In particular, many new ideas have arisen in connection with high-energy physics, which studies the interactions and transmutations of elementary particles. But the physical notions in this domain have not yet received an adequate mathematical formulation and are, therefore, less accessible to philosophical analysis. They will be only briefly mentioned at the end of this paper, the main concern of which will be the analysis of concepts originating in the physics of low energies with non-relativistic quantum mechanics as its theoretical basis. Even this limited domain contains so many new features in the formulation of an adequate description of physical phenomena (compared with the classical physics) that certain epistemological questions arise which cannot be allowed to remain unanswered.

Characteristic Features of the Classical Description of Phenomena

The idealisations and abstractions connected with the classical description of physical phenomena have been discussed by the author elsewhere.[1] We shall summarise here all that is most essential.

The most characteristic feature of the classical mode of description of phenomena is the assumption that all physical processes are completely independent of the conditions of observation. It was assumed that one can always "watch" a phenomenon "secretly" without interfering with it and without introducing any disturbance (we have already mentioned above the assumption concerning the existence of a "careful" method of observation). It is true that the form of a physical process "watched" from different points of view (and described in corresponding reference systems) will be different. Thus, the path of a freely falling body may appear as rectilinear in one reference system and as parabolic in another.

But the dependence of the form of a given phenomenon on the motion of the reference system has always been taken into account; this is simply achieved by the use of transformation formulae connecting the co-ordinates of different reference systems. The change in the form of a phenomenon allowing of such an accounting does not, perhaps, influence the phenomenon itself; thus, it was still possible to speak of the phenomenon's independence of the method of observation.

Quantum mechanics has shown, however, that for physical processes involving microobjects this is no longer the case; the very possibility of observing such microprocesses presupposes the presence of physical conditions that may be intimately connected with the nature of the phenomenon itself. The fixation of these physical conditions is not just a matter of

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[1] See, for example, V. A. Fok, "Quantum Physics and the Structure of Matter", *Structure and Forms of Matter*, Moscow, 1967 (in Russian); see also my paper "La physique quantique et les idéalisations classiques", *Dialectica*, Vol. 19, No. 314, 1965, p. 223.

indicating the reference system employed; it also requires a more detailed specification of them.

Ignoring this circumstance constitutes an abstraction that may be called the *absolutisation* of a physical process. If this abstraction is admitted, the consideration of physical processes as proceeding by themselves, irrespective of the possibility of observation (i.e. irrespective of the fulfilment of physical conditions that may be necessary for their observation), becomes possible.

The use of this abstraction is quite admissible in the study of large-scale (macroscopic) phenomena with respect to which the influence connected with the measurement is practically negligible. The absolutisation of these phenomena and processes seemed so natural that it was never explicitly stated before the advent of quantum mechanics. It was considered as self-evident that all physical processes proceed "by themselves".

This simplified the description of physical processes immensely, since there was no need to specify the observation conditions.

The whole of classical physics is based on the absolutisation of the notion of a physical process. This abstraction is one of its most characteristic features.

A further abstraction is the supposition in classical physics that one can indefinitely increase the precision of an observation. By increase of precision we mean not only a more precise measurement of a given quantity, but also a simultaneous measurement of any other quantity related to the object or phenomenon observed; this kind of precision increase may be called "unlimited refinement" of the measurement. Even in cases where the measurement of different quantities requires different observation conditions, it should be possible, according to classical physics, to combine the data obtained under different conditions into a single picture describing the physical process under investigation. The supposed possibility of simultaneously taking account of different aspects of the behaviour of the object, and of different aspects of a given physical process, constitutes an assumption that is logically connected with the assumption that a physical process is independent of the observation conditions, i.e. with its absolutisation.

The notions of classical physics lead to the conception of the state of motion of a physical system (with given degrees of freedom) as something not only absolute, but also exhaustive: when a complete refinement of observations is reached (and this is assumed possible), no further observations can add any new information.

A physical process was considered in classical physics as a time sequence of states of a system. Since for a system with given degrees of freedom the notion "state of a system" was considered as something both absolute (i.e. independent of the observation conditions) and exhaustive (i.e. allowing a complete description), it was natural to assume that the time sequence of states is uniquely described by a deterministic law. This leads to the notion of Laplacian mechanical determinism. Not only classical mechanics, but also electrodynamics was in accordance with this concept, since these theories permitted one to determine the state of the corresponding (mechanical or electrodynamic) system at any time from its initial state onwards. Einstein's relativity theory of 1905 did not contradict determinism, although it introduced many new notions. The position of unambiguous determinism was somewhat shaken by classical thermodynamics, because the theoretical deduction of its principles on the basis of statistical physics is impossible without introducing the concept probability. But the inapplicability of unambiguous determinism and of the related concepts (the absolute character of physical processes and the possibility of their unlimited refinement) became most evident in quantum mechanics, the basic ideas of which we now intend to discuss.

Limitations of the Classical Way of Describing Phenomena and the Sphere of Its Application

Fundamental physical facts, like the dual, wave-corpuscular, nature of light and of matter, constitute convincing evidence for the assertion that the classical way describing phenomena cannot be applied to microobjects. At the same time, it cannot be simply discarded, since an objective description requires as a basis (which may be used either directly or indirectly) something approximately independent of the way the observation is performed, and this is just the "absolute" mode of description used in classical physics.

To apply reasonably the classical, absolute method of description, one must first of all establish its limits. We shall repeat here the well-known line of reasoning that led to the Heisenberg inequalities, which may be regarded as fixing these limits.

Consider one of the simplest phenomena–the motion of a material point of mass m. According to classical dynamics, the state of motion of a material point at any instant of time is defined by the values of its co-ordinates x, y, z and its momentum p_x, p_y, p_z. It would, however, be inadmissible to consider simultaneous values of both sets of quantities without taking into account the actual possibilities of measuring them; but the possibilities are limited by quantum effects. These quantum effects manifest themselves, for example, in the interaction of the particle with photons of light falling on it. The essential circumstance is that a photon, though characterised by wave parameters, is at the same time a bearer of energy and momentum, i.e. a bearer of the attributes of a "particle of light". The wave parameters are: the frequency ν (or the angular frequency $\omega = 2\pi\nu$), the wave-length $\lambda = \frac{c}{\nu}$, and the wave vector k showing the propagation direction and having the absolute value $k = \frac{2\pi}{\lambda} = \frac{2\pi\nu}{c} = \frac{\omega}{c}$, where ω is the angular frequency. Denoting by h' the value of Planck's constant h divided by 2π (so that $h = 2\pi h'$), we may write the connection of the energy of a photon E and its momentum p with the wave parameters in the form

$$E = h'\omega; \quad p = h'k, \tag{1}$$

where the constant h' is given as

$$h' = 1.05 \times 10^{-27}\ erg \cdot sec. \tag{2}$$

The relation (1) connects the wave and corpuscular properties of a photon; the right-hand sides of this relation contain the quantities ω and k defined by means of interference phenomena, while the quantities on the left-hand sides, E and p, characterise the photon as a particle.

Thus, the relation (1) reflects the wave-corpuscular dualism of a photon as a light particle. This wave-corpuscular dualism is not a specific property of photons, but is a general property of all particles. Heisenberg has shown that the localisation of a particle in a small region of space requires the fulfilment of physical conditions that are unfavourable for the measurement of the momentum of the particle (i.e. for the localisation of the particle in the momentum space) and vice versa. This conclusion is quite natural, because the use of light with a small wave-length, which is favourable for the localisation of the particle in the co-ordinate space, implies the use of high-energy photons, capable of giving the particle a great impetus and thus greatly impeding its localisation in the momentum space; on the other hand, an experiment with low-energy photons implies the use of light with a large wave-length, and thus leads to a broadening of all diffraction bands, which is an obstacle to the localisation of a particle in the ordinary (co-ordinate) space.

Quantitatively, Heisenberg's result may be expressed in the form of the inequalities

$$\Delta x \Delta p_x \geqslant h'; \quad \Delta y \Delta p_y \geqslant h'; \quad \Delta z \Delta p_z \geqslant h', \tag{3}$$

where the quantities Δx, Δy, Δz give the dimensions of the localisation domain in the co-ordinate space x, y, z, while the quantities Δp_x, Δp_y, Δp_z characterise the localisation domain in the momentum space p_x, p_y, p_z. These inequalities are called the Heisenberg inequalities; they show that a particle cannot, by its very nature, be simultaneously both in the co-ordinate and in the momentum space.

To the Heisenberg inequalities (3) the relation

$$\Delta t \Delta (E' - \mathrm{E}) \geqslant h' \tag{4}$$

can be adjoined; this relation connects the uncertainty in the change of the energy of a particle with the uncertainty in the time instant when this change has taken place. According to the relation (4), the act of energy transfer cannot be precisely localised in time. Relation (4) may be called the Heisenberg-Bohr relation. The Heisenberg and Bohr relations (3) and (4), taken together, specify the domain in which the classical ("absolute") way of describing physical phenomena is applicable. Since the Planck constant is very small, this description is, undoubtedly, applicable to macroscopic bodies. But its significance is not limited to this case. The absolute mode of description plays a prominent part in the study of quantum processes as well, since it is to be applied to the measuring instruments the readings of which constitute the basis of the study of atomic objects. The experimental conditions (also for experiments on atomic objects) are always described in the classical, "absolute" way.

Returning to what was said in the second section, we are now able to give a more precise definition of the means of observation as mediators between human consciousness and the atomic objects investigated, by giving the mode of their description. *The means of observation must be described on the basis of classical abstractions, but with due account of the Heisenberg and Bohr uncertainty relations.*

Relativity with Respect to Means of Observation as a Basis for the Quantum Mode of Describing Phenomena

The new mode of describing physical phenomena must take into account the actual possibilities of measurements connected with microobjects. We never ascribe to objects any properties (and any states of motion) that cannot be observed and specified. It is thus necessary to draw special attention to the conditions necessary for observation and specification. We have to consider the construction and functioning of the measuring devices that create the physical conditions in which the subject is placed. As noted above, the measuring devices and physical conditions must be described classically, by fixing the values of the parameters that describe them. Of course, these parameters can be fixed only with a precision

consistent with the Heisenberg inequalities; otherwise we would violate the limits of the actual possibilities of the measuring instruments' design.

A microobject manifests itself in the interaction with the measuring device. Thus, the track of a particle becomes visible only as a result of an irreversible avalanche-like process in a Wilson cloud chamber or in a photolayer; and during this process the particle loses its energy by ionising the air or the photolayer, so that its momentum becomes indefinite. The result of the interaction between an atomic object and a classically described measuring device is, accordingly, the basic experimental element, the systematisation of which (on the basis of appropriate suppositions as to the properties of the object) is the aim of the theory: from the consideration of such interactions the properties of an atomic object are deduced, while the predictions of a theory are formulated in terms of the interaction results to be expected. This statement of the problem permits the introduction of quantities describing the object itself, irrespective of the measuring device (such quantities as charge, mass, spin of a particle, and also more intricate properties of the object described by quantum operators); at the same time it allows various approaches to the object: the object may be characterised by those of its properties (e.g. wave-like or corpuscular) that manifest themselves under external conditions created by the given measuring device.

The new statement of the problem enables us to consider the case where different aspects and different properties of the object do not manifest themselves simultaneously, i.e. where a refined description of the behaviour of the object is impossible. This situation arises if different properties of the object (e.g. the capacity of an electron for interference and for localisation) require for their manifestation mutually exclusive external conditions.

Following Bohr, we may use the term *complementarity* to specify those properties that manifest themselves (in their "sharp" form) only under mutually exclusive conditions, while under attainable conditions they manifest themselves only partially, in a "milder" form (e.g. approximate localisation, allowed by the Heisenberg inequalities, in the co-ordinate space and in the momentum space). There is no point in considering simultaneous manifestations of complementary properties in their sharp form; this is the reason why the notion of "wave-corpuscular dualism" is self-consistent and devoid of contradictions.

By adopting as a basis of the new form of description the results of interactions between a microobject and a measuring device we introduce a new and important notion, *relativity with respect to the means of observation,* which is a generalisation of the old and well-known notion of relativity with respect to a reference frame. This form of description does not mean that we consider the object as something less real than the measuring instrument or that we are trying to reduce the properties of the object to those of the instrument. Quite the contrary, description on the basis of the notion of relativity with respect to the means of observation gives a much more adequate and subtle objective characterisation of the microobject than was possible on the basis of the idealisations used in classical physics. This more subtle characterisation requires a more highly developed mathematical formalism—the theory of linear operators, their eigenvalues and eigenfunctions, the theory of groups and other mathematical concepts. The application of this formalism to problems of quantum physics leads to a theoretical explanation of many fundamental properties of matter that defied description on the basis of classical notions. But—no less important for us—the physical interpretation of the mathematical tools involved in this formalism leads to some general conclusions of profound interest. In particular, it leads to a generalisation of the conception of the state of a system on the basis of probability and potentiality.

The Notions of Probability and Potentiality in Quantum Physics

If we admit that the act of interaction between the object and the measuring instrument is the true source of all our judgements on the properties of the object and if we take as a basic principle of the description of phenomena the relativity with respect to means of observation, we necessarily introduce in the description of the atomic object, its state and behaviour an essentially new element, namely the concept of probability and the accompanying concept of potentiality. The concept of probability is to be regarded as an essential element of the description and not as an indication of the incompleteness of our knowledge; this follows already from the fact that, for given external conditions, the result of the interaction of the object with the measuring instrument is (in the general case) not predetermined unambiguously, but has only some probability. A series of such interactions leads to a set of statistics that corresponds to a definite probability distribution. This probability distribution reflects the potentiality existing in the given conditions.

Let us consider an experiment performed on a given physical system that would allow us to make predictions concerning future interactions with measuring devices of different types. Such an initial experiment includes preparation of the system (e.g. preparation of a beam of electrons with a given energy) and also the creation of the external physical conditions to which the system will be subjected after its preparation (e.g. passing the electron beam through a crystal). Sometimes it is expedient to consider the preparation and the creation of the external conditions as two different stages of an experiment, but they may also be regarded as a single initial experiment performed with the purpose of obtaining predictions (prognoses). The initial experiment always refers to the *future.*

The method of preparation and the external conditions in the initial experiment are described classically, but its result (which must include a complete characterisation of the potentiality existing under given circumstances) requires new, namely, quantum mechanical, means for its formulation. To get an idea of the problems that are soluble by these means, let us consider how the potentiality existing in the given conditions is realised.

First of all, we must bear in mind that the concluding experiment, in which these possibilities are realised, can be performed in different ways according to the type of measuring (recording) instrument used, and that different types of instrument used in the final experiment (as a rule) exclude one another. As in the initial experiment, the construction and functioning of the instrument are to be described classically. Different types of final experiment and of the corresponding measuring instrument may be briefly characterised by the kind of physical quantities (co-ordinates, momentum, etc.) that can be measured in this way.

We see that, for a given initial experiment, there is still a free choice of the type of final experiment (and of the corresponding instrument). In any case, the final experiment refers to the *past* (and not to the future, as does the initial one) and may be called a *verifying* experiment, since it is designed to verify the predictions following from the initial experiment.

Let us assume that the type of verifying experiment is fixed. How are its results to be formulated? We must always keep in mind that we are concerned with *potentialities* created in the initial experiment and realised in the verifying experiment. For a given type of verifying experiment, these potentialities are described as a probability distribution for the corresponding quantity (to be more exact, for the values of this quantity obtainable in the verifying experiment). What is to be verified is thus a probability distribution. It is clear that this cannot be done by a single measurement, but requires a repetition of the whole experiment (with one and the same method of preparing the object and under identical external conditions). The set of statistics obtained as a result of this repetition permits us to draw conclusions on the probability distribution in question.

The complete experiment (the accomplished experiment, permitting a comparison to be made with the theory) includes both the initial and the final experiment, which are to be performed not once, but many times. We stress again that for a given initial experiment (given initial conditions) there are different types of final experiment (different quantities can be measured), and that each type has its own corresponding probability distribution.

The task of a theory is thus to characterise the initial state of the system in such a way as to make it possible to deduce from it the probability distributions for any given type of final experiment. This would give a complete description of the potentialities contained in the initial experiment. Since the final experiment may correspond to a later time instant (and not to the same instant as the initial one), the theory must also furnish the time dependence of the probability distributions and the corresponding potentialities. The laws governing this time dependence will play the same part as the laws of motion in classical physics.

Mathematical Formalism of Quantum Mechanics and the Degrees of Freedom of Physical Systems

A description of physical phenomena that is to be based on the concept of potentiality and which is to take into account relativity with respect to the means of observation will require an elaborate mathematical formalism.

There is, first of all, the problem of the possible values of the quantities measured. This problem can be solved on the basis of the theory of linear operators: for each quantity measured a self-conjugate linear operator is introduced such that its eigenvalues give the possible values of the quantity. This correspondence between physical quantities and linear operators includes the case of discrete eigenvalues (point spectrum) as well as the case of continuous eigenvalues (continuous spectrum). It is worth noting that the term "spectrum" was used in the theory of linear operators and in physics (optical spectra) even before the establishment of the connection between the notions corresponding to the two meanings of the term.

The concept of the eigenfunction of an operator leads to the more general notion of a *wave function depending on time* and describing the potentialities that are appropriate to the given physical system under given circumstances. The wave function satisfies a differential equation the form of which is directly connected with the form of the operator for the total energy of the system; the existence of this connection is due to the fact that the law of the conservation of energy is valid in quantum mechanics as well. The differential equation for the wave function is an equation of the first order with respect to time; that is why the wave function is unambiguously determined by its initial value. By means of this wave function (and using the eigenfunctions of operators corresponding to the physical quantities to be measured) all probability distributions related to the given physical system are expressed. It can be shown that these probability distributions are such that the Heisenberg relations are automatically satisfied.

The construction of the energy operator constitutes an essential step in the theory of a given system. The first thing to do here is to introduce degrees of freedom appropriate to the system. It would seem to be most natural to take the degrees of freedom that correspond to the classical picture of the system. For example, in the case of an electron, one would take the degrees of freedom of a classical material point and accordingly consider the wave function of an electron as depending (for a given time instant) on three space co-ordinates. But recourse to the analogy with classical theory may turn out to be insufficient. The very concept "degrees of freedom" is to be understood in a more general sense than in classical theory; it should not be reduced to variables relating to the movement in space, but should permit the introduction into the wave function of any other (quantum) variables describing the nature of the object. Thus, in the case of the electron it is necessary to introduce, even in the non-relativistic approximation, an intrinsic moment of momentum defined by special operators, known as "spin"[1]; this degree of freedom is particularly important when formulating the properties of a many-electron *system*, e.g. the system constituted by the electronic shells of the atom. In the relativistic approximation we are obliged to go much further along the path of introducing new degrees of freedom, and we have to consider the electron as part of an incomparably more complicated system that includes the positrons. One is perforce reminded of the foresight of Lenin, who spoke of the inexhaustibility of the electron when quantum mechanics did not exist.

Quantum physics, with its new principles of description of phenomena, opened up new possibilities for introducing degrees of freedom previously unknown, and these possibilities are essential for the understanding of even the most simple and most fundamental physical regularities. Thus, the chemical properties of atoms, formulated by Mendeleyev in the form of the periodic system of elements bearing his name, received their theoretical explanation only after the discovery of electronic spin and after the formulation of the Pauli principle (according to which the wave function of an electronic system must be anti-symmetrical with respect to an interchange of the co-ordinates and spin variables of any pair of electrons). The properties of electronic systems also constitute the foundation for the explanation of many macroscopic properties of solid bodies (crystals, semiconductors) that cannot be explained on the basis of classical physics.

The laws of quantum physics apply not only to particles in the classical sense (having a non-vanishing rest-mass), but also to particles with zero rest-mass, such as photons. As compared with electrons, the photons have two peculiarities: in the first place, they can easily be emitted and absorbed, so that an assembly of photons must be considered as a system of an indefinite number of particles; in the second place, for a fixed number of photons their wave function must be symmetrical (unlike the wave function of a system of electrons).

The quantum theory of the electromagnetic field which includes photon theory is called quantum electrodynamics.

Pursuing the line of development of the photon theory that has connected the concepts of field and particle (or quasiparticle), theories of other quasiparticles have been evolved, e.g. a theory of elementary sound oscillations (phonon theory). These theories, together with that of electronic systems,

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[1] The expressions "spin" and "intrinsic moment of momentum" remind one of classical analogues, but they are not to be understood literally, as some kind of the electron's rotation.

have found application in the physics of solid and fluid bodies. The properties of semiconductors, as well as the phenomena of superfluidity and superconductivity of some fluids, observed at extremely low temperatures, cannot be conceived without recource to quantum laws.

The introduction of new degrees of freedom (spin above all) has played a decisive role in the theory of the electron. Still more important is the question of new degrees of freedom in high-energy physics and in investigations concerning the interactions and mutual transformations of elementary particles. These new degrees of freedom are often expressed in the form of symmetry properties and transformation properties of the wave and field functions. The study of their connection with space-time transformations and with the transition of particles to antiparticles opens up new prospects in the quantum field theory. This domain of quantum physics is far from being completed, but even now it is evident that the new principles for the description of phenomena first introduced in quantum mechanics are just as important in the quantum field theory.

Concluding Remarks

On the basis of quantum physics we have endeavoured to show the need to describe phenomena by methods that are based on the concepts of relativity with respect to observation means and of potentialities. The use of new (quantum) methods does not exclude, but only supplements or restricts the applicability of the old (classical) methods which are based on the notions of absolutisation and unlimited refinement. The old methods have their own domain of application.

As mentioned above, quantum physics possesses an elaborate mathematical formalism. A consistent physical interpretation of this formalism is only possible on the basis of the concepts of relativity with respect to means of observation and potentialities; this fact completely justifies the introduction of epistemological distinctions between physical objects that are to be described by the methods of quantum physics

and ordinary (macroscopic) objects that only need a classical description.

The question now arises: can other objects exist in nature, such that their description requires specific methods? It might be that an instance of such objects is given by living organisms. The problem of the relation between a living organism and the surrounding medium bears some resemblance to that of the relationship between an atomic object and a measuring device: an organism is characterised by its own properties, which are not reducible to those of the medium, but it cannot exist independently and irrespectively of the surrounding medium.[1] When the problem of life has at last been solved and when adequate methods for describing living organisms have been found, then a host of ideas will no doubt be generated that will be new in an epistemological sense as well. But this set of concepts will not abolish the notions of quantum and classical physics, but will only complement them and confine the domain, where they are adequate, to inanimate nature. This problem reminds us again of the conditional and relative character of all demarcation lines in nature.

Questions related to the theory of knowledge can also arise in the study of phenomena of quite another scale and character, namely, in the domain of cosmology. The leading physical theory here is Einstein's theory of gravitation. The first question to be discussed is, therefore, the question of the limits of applicability of this theory. Is it legitimate to apply the theory where it leads to qualitatively different properties of space and time than those on which it was originally based (for instance, where it gives a zero value for the speed of light)? Is it also legitimate to extend the usual notions of space and time to indefinitely large space-time regions, ascribing to them the properties that formally flow from the theory, and not analysing the possibilities of observation?

We think it wrong that physical concepts which are ap-

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[1] See V. A. Fok, "Living Contacts Between Physicists and Philosophers Contribute to the Development of Science", *Methodological Problems of Science*, Moscow, 1964, p. 234 (in Russian).

plicable in a domain where certain observation means exist are extrapolated to a domain where these observation means are no longer adequate. Let us quote the following example from the realm of the microcosm. In this domain a simple space-time concept like the orbit of an electron turned out to be inapplicable. It seems quite possible that there are limitations for cosmologically vast space-time regions as well.

Any physical theory–even one as magnificent as Einstein's theory of gravitation–must necessarily have its own limits of applicability and cannot be extrapolated indefinitely. At some stage of development it becomes necessary to introduce essentially new physical concepts that are adequate to the nature of the objects under investigation and to the appropriate means of their cognition; at this stage the limitations inherent in the theory become evident and new epistemological questions arise. The ideas of dialectical materialism formulated by Lenin with great clarity and generality must continue to serve as guidelines in the solution of these problems.

A. D. Alexandrov

SPACE AND TIME IN MODERN PHYSICS IN THE LIGHT OF LENIN'S PHILOSOPHICAL IDEAS

In his book *Materialism and Empirio-Criticism* Lenin outlined the reasons for the philosophical crisis that was developing in physics at the time and also indicated a way out of this crisis through the transition from the old, metaphysical materialism to dialectical materialism. Lenin wrote: "It is mainly because the physicists did not know dialectics that the new physics strayed into idealism."[1] Physics "is giving birth to dialectical materialism"[2] but it is advancing without seeing clearly its "final goal", gropingly, and sometimes even with its back turned to the "final goal".[3] Defending materialism, Lenin explained and developed further the critical, progressive nature of dialectical materialism, its fundamental propositions concerning relative and absolute truth, the criterion of practice in cognition, and the limited nature of any conception of the structure of matter, and any picture of the world arising at any stage of development of science. Dialectical materialism does not recognise any absolutes, with the exception that there exists an external world and human consciousness reflects it. "Dialectical materialism insists on the approximate, relative character of every scientific theory of the structure of matter and its properties. . . ."[4]

Now that physics has incorporated the general theory of relativity, involving a profound transformation of time and

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 262.

[2] *Ibid.*, p. 313.

[3] *Ibid.*

[4] *Ibid.*, p. 261.

space conceptions, and quantum mechanics, involving a revision of basic concepts, including the concept of an individual definite object (since electron identity changes this fundamental concept); now that the possibility of the most "inconceivable" discoveries and "crazy" theories has become a matter of everyday experience for physicists, as has the conception of the advance of physics through a series of relative truths and increasingly profound theories, Lenin's ideas have been confirmed and assimilated by the majority of physicists from the experience of their science. Physics "has given birth to dialectical materialism", and any scientists who have not yet understood it have not done so because of their philosophical narrow-mindedness or dislike of dialectical materialism as the philosophy of the communist movement.

We shall consider in general outline the conceptions of time and space contained in the theory of relativity, using them as illustrations of physics giving birth to dialectical materialism. We also intend to show that the true significance and content of this theory are best understood in the light of the ideas of dialectical materialism as defended and developed by Lenin. Lenin's influence in this sphere was, incidentally, pointed out by authors who contributed to a deeper understanding of the theory of relativity and defended it against the erroneous interpretations and attacks of those who were unable to approach the theory (not in word, but in deed) from the position of dialectical, and not metaphysical, materialism, as well as those who could not overcome positivist interpretations of the theory.[1]

Space in Mathematics

Geometry emerged from practical life and achieved the form of a deductive system, as presented in Euclid's *Elements*, only as a result of a fairly long development. Having begun as a practical science, it evolved into a mathematical theory. It was introduced into physics in a finished form. Space was conceived of as an empty receptacle for bodies and phenomena, possessing by itself, as it were, the properties registered in Euclidean geometry. Originally, however, geometry was, in effect, the first chapter in physics, and it became a part of pure mathematics only through the total abstraction of spatial forms and relations from their material content. It should be remembered that Euclid's presentation of geometry does not contain co-ordinates. Co-ordinates, or, in terms of relativity theory, spatial reference systems, appeared in geometry only with Descartes, some nineteen centuries after Euclid.

Time, whose exact measurement was worked out from observation of the heavenly bodies, entered the general laws of mechanics as formulated by Galileo and Newton. In fact, the concept of absolute simultaneity is in complete accordance with Newton's mechanics. In it there are no fundamental limitations on the velocity that can be imparted to a body—once a small body is affected by a sufficiently great force. Therefore, a "signal" like a shot may travel from one place to another at any speed. Accordingly, the error in comparing the time at these different points may be infinitesimally small. But a quantity smaller than any given one equals zero. This means that the uncertainty in comparing the time at different points equals zero, i.e. the simultaneity of events separated by space is absolute.

Absolute Euclidean space and absolute time flowing everywhere in the same way took firm root in human concepts. Together with the immediately given conception of time and space, it even resulted in Kant's declaring time and space mere *a priori* forms of perception, having no bearing on the external world of "things in themselves". The space abstraction, born of practice and shaped by mathematics, was transplanted from material reality into consciousness.

Soon after Kant, however, Lobachevsky expressed the idea that geometry stands in a certain relation to material reality and, furthermore, one cannot contend beforehand that the properties of real space will be the same as those described

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[1] See, for instance, V. A. Fok's work ***The Theory of Space**, Time and Gravitation* (Moscow, 1961, p. 18, in Russian), where the author points out that his general attitude towards Einstein's theory "was influenced by dialectical materialism, especially by Lenin's book *Materialism and Empirio-Criticism*".

by Euclidean geometry.[1] Later Riemann formulated the same idea and explicitly posed the question of the genesis and substantiation of the metric properties of space. In his famous work *On the Hypotheses Lying at the Foundation of Geometry* Riemann wrote: "Therefore, either that real element which creates the idea of space must build a discrete multiformity, or one must look for the basis of metric relations somewhere outside, in the binding forces affecting that real element. The solution of these problems can only be found if, by proceeding from the conception of phenomena existing at present and confirmed by experience, the basis of this conception founded by Newton, one begins gradually to elaborate it under the impact of those facts that cannot be explained in it; such research as has been done here ... can only be useful if it prevents progress and successes in the cognition of the connections of things from being impeded by the limitations of concepts and deep-rooted prejudices."[2] Riemann seems to have suggested what was done by Einstein, who, in perfecting Newton's theory, used the Riemann geometry, while his theory of relativity resulted in the elucidation of the question posed by Riemann about the basis for the metric relations in space.

Soon after Riemann, Helmholtz[3] deduced the metric properties of space from the properties of motion of solid bodies and thereby presented in a clear form the physical foundations of geometry, on which it was actually based at its inception. What is meant by the properties of motion of solid bodies is the properties of a group of such motions. Uniformity of space in this respect means the possibility of free motion of a solid body. In Riemann's theory, however, this was only a particular case realisable in the Riemann spaces of constant curvature.

The development of various geometrical systems (affine, projective, etc.) side by side with the Euclidean system revealed their common basis, which is that each of them is defined by an appropriate group of transformations. A given geometry, from this point of view, is defined as the theory of those properties of figures that are invariant with respect to the transformations of the given group. Figures that are translatable into each other by these transformations are considered to be equivalent. For instance, in affine geometry all ellipses are equivalent. The properties of figures may be described by arbitrary co-ordinates; permitted transformations are represented in different co-ordinates in different ways, but these are only different representations of the group which defines the given geometry.

Like Riemann's theory, these ideas were applied in mathematics to spaces of any number of dimensions. But the Riemann theory, as was pointed out earlier, while permitting of heterogeneous spaces, could not be covered by this group definition of geometry. A synthesis of both approaches was given later, after the construction of the general theory of relativity, by the French geometer E. Cartan. But, within the framework of the ideas outlined above, mathematics prepared the formalism that was instrumental in formulating the theory of relativity. Mathematics investigated various possible spaces as general forms of multiformities of monotype phenomena or states (such as the configuration space of a mechanical system, the colour space, etc.). Mathematics treats space as it is usually understood as just one of these forms. The investigation of its specific properties was the task of physics and not mathematics. The concept of space thus acquired two interpretations, the mathematical and the physical.

Foundations of the Theory of Relativity

Dialectical materialism provided a general definition for space and time in their physical sense, as forms of the existence of matter. Lenin defended this view in his argument with Kantianism and subjective idealism. The form of

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[1] See, for example, N. I. Lobachevsky, "New Elements of Geometry with a Complete Theory of Parallel Lines", *Collected Works*, Vol. 2, Moscow-Leningrad, 1949, p. 200 (in Russian).

[2] B. Riemann, "On the Hypotheses Lying at the Foundation of Geometry", *On the Foundations of Geometry. A Collection of Articles*, Moscow, 1956, p. 324 (in Russian).

[3] See H. Helmholtz, "On the Facts Lying at the Foundation of Geometry", *On the Foundations of Geometry*, pp. 366-82.

the object is not something external to it; it belongs to the object and is defined by the object itself, if it were not cast into this form by forces external to it. Therefore, the forms of existence of the material world constitute its structure, determined by its fundamental properties and not something like an envelope in which the world is contained. Accordingly, a rational theory of space and time necessarily deduces their properties precisely as properties of such a general structure from the very properties of matter. This was the source of geometry–it reflected first and foremost the properties of relations of solid bodies determined primarily by the possibility of their movement. Time and space concepts in Newtonian physics were also intimately connected with the laws of motion of bodies established by classical mechanics. In particular, as was pointed out above, the concept of absolute simultaneity was based on the possibility of throwing a body with any desirable speed. However, as often happens in science, these connections were not sufficiently perceived, since this was not prompted by concrete physical tasks. Space and time were conceived of as given forms independent of matter, as it were. What was discovered by physics fitted these forms quite well.

But this state of affairs could not last forever. The laws of electromagnetism formulated in the Maxwell equations were not entirely in keeping with the laws of mechanics. In mechanics, the basic property of space and time, their uniformity, was expressed in Galileo's relativity principle, including the geometrical relativity principle of Euclidean geometry. This principle may be defined as the equivalence of all orthogonal co-ordinates, and Galileo's relativity principle as an extension of this geometrical relativity principle, the essence of the extension being that systems of orthogonal co-ordinates remain equivalent even in their uniform and rectilinear movement with respect to each other. The somewhat vague notion of equivalence may be precisely expressed in the language of transformation groups. The general laws of mechanics are invariant with respect to transformations translating one system of orthogonal co-ordinates into any other that is in uniform and rectilinear motion with regard to the given system. As for time, it always remains constant except for the changes in the starting point and the unit of measurement, that is, the only admissible transformations as regards time were the transformations $t^1=at+b$, or, when measurement units and the starting point are constant, $t^1=t$. All such transformations of orthogonal co-ordinates and time constitute a Galileo group; the really important point, however, is not that it is orthogonal co-ordinates that are transformed (the co-ordinates may be of any kind), but the group itself, the choice of co-ordinates only determining a particular representation of the group.

Since physics was dominated by the view that any physical phenomenon was ultimately of a mechanical nature, Galileo's relativity principle had to be treated as a universal one, pertaining to any laws and not just the laws of mechanics.

The laws of electromagnetism, however, as expressed in the Maxwell equations, were not invariant with regard to the Galileo group. In 1904 the transformations satisfying the Maxwell equations were found by Lorentz. As is now known, it turned out that time could not be regarded as invariable in these transformations if one proceeded from one system to another, moving with respect to the first one.

The choice, in fact, was this: *either* Newton's mechanics with Galileo's relativity principle and absolute time *or* Maxwell's electrodynamics; these choices entail either the fall of the relativity principle or of absolute time. A clear understanding of this dilemma was, of course, the starting point of Einstein's thinking.

Actually the problem was never presented in that way before Einstein. There were various attempts to formulate the laws of electrodynamics in a way that would be in agreement with the experimental data and classical mechanics. But none of these attempts yielded satisfactory results. In particular, the famous Michelson experiment aimed at revealing the movement of the earth with regard to ether proved to be of no avail. It was demonstrated thereby that the relativity principle held good for electromagnetic phenomena too, and that it was impossible to define absolute uniform rectilinear motion here as well as in ordinary mechanics. The problem thus actually consisted in the proper formulation of the laws of electrodynamics. Accordingly, Einstein gave this title to the paper that laid the foundations of the theory of relativity: *Towards the Electrodynamics of Moving Bodies.* In resolving the dilemma formulated above–either mechanics or electrodynamics and, consequently, either relativity or absolute time–he sacrificed mechanics and absolute time.

"It is, of course, sheer nonsense to say that materialism ... necessarily professed a 'mechanical', and not an electromagnetic... picture of the world...."[1] Why can we not accept the laws of electromagnetism as fundamental? Space and time are forms of the existence of matter and their properties should, therefore, be deduced from the laws of the motion of matter and not ascribed to them as given from the outside. Why should a deeper knowledge of the motion of matter not bring about a change in the laws of time and space that we have cognised, i.e. of the general laws of the spatio-temporal relations of physical processes?

We do not insist that this was Einstein's train of thought. We only wish to draw attention to the fact that it corresponded to what had been expressed in general terms by Lenin. One should not be afraid of the "disappearance of matter", the "collapse of basic principles", the relativity of such fundamental magnitudes as time or mass. Lenin wrote: " 'Matter disappears' means that the limit within which we have hitherto known matter disappears and that our knowledge is penetrating deeper; properties of matter are likewise disappearing which formerly seemed absolute, immutable, and primary (impenetrability, inertia, mass, etc.) and which are now revealed to be relative and characteristic only of certain states of matter."[2] "...Dialectical materialism insists on the approximate, relative character of every scientific theory",[3] and consequently, of the proposition about absolute time, in particular.

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works,* Vol. 14, p. 280.

[2] *Ibid.,* p. 260.

[3] *Ibid.,* p. 261.

However, if we reject absolute simultaneity, we still have to give some definition of the concept. The source of this new definition is obvious: if we accept the electromagnetic picture of the world as fundamental, the definition must be based on electromagnetic processes. Besides, we may think back to practice and accept, accordingly, the following epistemological principle: a definition has a physical meaning, if it is linked to a possible experiment. An exchange of signals is a *Gedankenexperiment* that is possible in principle. Einstein made it the basis of his famous definition of simultaneity, and this became the cornerstone of his constructions.

This epistemological principle was also used by Einstein in proving the general theory of relativity,[1] while the *Gedankenexperiment* method later played an important role in the analysis of the foundations of quantum mechanics. The method was not new, of course: *Gedankenexperiments* were widely used, for instance, in proving thermodynamics and in deducing the thermal radiation laws. The novelty lay in the fact that the *Gedankenexperiment* became an accepted procedure for establishing the fundamental possibility of defining physical concepts. The sources of this principle may be traced back to Marx's *Theses on Feuerbach,* where he placed special emphasis on the role of practice, saying that "the dispute over the reality or non-reality of thinking which is isolated from practice is a purely *scholastic* question".[2]

This principle, however, was interpreted by a number of physicists in a positivist, rather than materialist, spirit. A definition of a physical concept was presented as a relative agreement on the choice of concrete procedures of measurement. One author even claimed that Einstein's achievement lay in clarifying the need for an agreement as to what events should be considered simultaneous. If taken literally, the statement is absurd, of course, since one may "simply agree" to consider any events as simultaneous. The point is that a concept definition has some real meaning only when it re-

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[1] See A. Einstein, "Foundations of the General Theory of Relativity", *The Principle of Reativity,* Moscow-Leningrad, 1935 (in Russian).

[2] Karl Marx, "Theses on Feuerbach". In: Karl Marx and Frederick Engels, *Collected Works,* Vol. 5, p. 3.

flects something essential in nature. And the existence of the "something essential" is not just a matter of convention. The task of a genius is to grasp the essential and express it in a definition. Simultaneity in Einstein's definition is not something conventional, but a very general real relationship of events objectively determined by their interaction through radiation. Events emit "signals" regardless of conventions and experiments, and these signals determine the material links between phenomena. An abstract form of this connection is expressed in the concept of temporal simultaneity and sequence. In his work Einstein stressed the idea that his definition could be consistently implemented in his theory, which means that it reflects certain essential general properties of reality.

The definition of simultaneity entails a specification of the time t and, consequently, of a system of spatial and temporal co-ordinates x, y, z, t, pertaining to some body–the basis of the system assumed to be at rest.

Further considerations, as Einstein indicated, are based on the principle of relativity and the principle of constant light velocity. The first is the Galileo principle extended to embrace all physical phenomena, not just mechanical ones. In fact, only the second principle, postulating electromagnetic phenomena as the more fundamental, is new. From these two principles the Lorentz transformations are deduced, as well as their inferences for kinematics, electrodynamics and mechanics.

The theory of relativity, thus constructed, established the relativity of all or almost all the magnitudes that were regarded as absolute in classical physics. Absolute time and absolute space were abolished. Time and space have a definite meaning and allow of definite measurement only with regard to a reference system.

Absolute Space-Time and Relativism

We assume that the world exists and has definite properties regardless of the reference system with which these properties are associated or in which they are manifested. Thus,

in ordinary geometry the projections of a given body are different in different planes, but the body itself has a definite form which yields different projections only in relation to different planes. It may be remembered that Euclid's presentation of geometry did not contain any co-ordinates, i.e. reference systems. So is not a theory of space and time possible without reference systems? And are not space and time themselves, as well as other quantities whose relativity was established by Einstein's theory, only manifestations of something non-relative and absolute in different reference systems?

Lenin wrote that "in (objective) dialectics the difference between the relative and the absolute is itself relative. For objective dialectics there *is* an absolute *within* the relative. For subjectivism and sophistry the relative is only relative and excludes the absolute."[1]

The theory of relativity revealed the connection between space and time. This connection is implied already in the invariance of the velocity of light. This velocity is the ratio of distance to time and, accordingly, its invariance and equivalence in all systems signify a universal relationship between spatial and temporal quantities. The absolute must be contained not in space and time in themselves, but in their combination. Minkowski realised that and expressed it in the opening words of his famous lecture "Space and Time". "The conceptions of time and space that I would like to develop before you have arisen on an experimental physical basis. Therein lies their strength. Their tendency is a radical one. From this moment, time *per se* and space *per se* must retreat completely into the shadows and only a kind of union between them may yet preserve their independence."[2]

As a geometer, Minkowski considered the theory of relativity from the standpoint of principles already well developed in geometry, implying the definition of a given geometry in terms of a theory of invariants of the appropriate group

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[1] V. I. Lenin, "On the Question of Dialectics", *Collected Works*, Vol. 38, p. 360.

[2] H. Minkowski, "Raum und Zeit", *Physikalische Zeitschrift*, No. 3, 1909, p. 104.

of transformations. For the theory of relativity, these are the Lorentz transformations. Therefore, we speak of a geometry defined by this group. The group operates in a four-dimensional "space", since four co-ordinates—x, y, z, t—are involved. The totality of all the "places" (x, y, z) at different time instants t forms a unified multiformity—space-time. It is this space-time that represents the absolute form of the existence of matter.

Commenting on the name of the "relativity postulate" applied to the requirement of invariance in relation to the Lorentz group, Minkowski said: "As the meaning of the postulate is that the world conveyed through phenomena is a four-dimensional world in space and time, but the projections of this world on space and on time may be conceived with a certain freedom, I would rather give this proposition the name of *the postulate of the absolute world* (or, world postulate, for short)."[1]

Spatio-temporal relations and properties of bodies and processes do not depend on the reference system, but are merely differently manifested in different systems. Generally speaking, physical quantities depending on the reference system and relative in this sense are a kind of projection of more general quantities independent of the reference system. Accordingly, Minkowski gave a four-dimensional interpretation of the laws of relativistic mechanics and electrodynamics. In this way, he developed a deeper understanding of the theory of relativity and, moreover, introduced greater clarity into its mathematical formalism.

Nevertheless, Minkowski's view of the theory of relativity was not fully comprehended by physicists. The relativistic viewpoint, which considered every phenomenon in its relation to a definite reference system, was more acceptable, firstly, because that was the actual position of the experimenter or observer and, secondly, because a theoretician too analyses phenomena by using a certain system of co-ordinates. But there was also a third point—the fact that positivist philosophy in principle recognises as real only that which is immediately given in observation; everything else contained in physical theories is interpreted as a construction linking up observation data rather than a reflection of reality. From this viewpoint, Minkowski's four-dimensional world is nothing but a scheme, reflecting no reality over and above that already expressed in the original presentation of the theory of relativity. Therefore, Minkowski's objection to the term "postulate (theory) of relativity" and his proposal to replace it with the term "postulate of the absolute world" do not appear to be fully justifiable.

Thus, two approaches to the theory of relativity have emerged here. The first approach is that of Minkowski, based on the conception of space-time as a real absolute form of the existence of the material world. The second is purely relativistic; its main point is the choice of a reference system.

The philosophical tendencies of these two approaches can be traced quite easily. The source of the second trend is Berkeley and, later, Mach, whose views influenced Einstein, as he himself admitted. One may refer to a paper by R. Dicke who points out this connection, quoting Berkeley, Mach and Einstein.[1] The quotations do not deal with Berkeleianism and Machism in a direct philosophical sense, but only with relativity of motion. In the very idea of relativity of motion there is neither Berkeleianism nor Machism, but Berkeley was quite a consistent philosopher, so that his views of motion conform to his general philosophical principle: "To be is to be perceived." Thus, relativism rejecting the absolute goes back to Berkeley and carries on his tradition in physics.

Lenin's main objective in *Materialism and Empirio-Criticism* was, first, to show that the contemporary forms of subjectivist philosophy, whether Machism or some other variety, were merely a continuation of the Berkeleian tradition and, second, to explain the dialectical materialistic position and defend it against all attempts to combine it with any varieties of subjectivist philosophy. Lenin's book has, therefore,

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[1] H. Minkowski, *op. cit.*, p. 107.

[1] See R. H. Dicke, "The Many Faces of Mach", *Gravitation and Relativity*, New York-Amsterdam, 1964, pp. 122-23.

a direct bearing on these two tendencies in the interpretation of the theory of relativity. Underlying these tendencies in physics are philosophical tendencies.

Of course, mathematically, the relativistic viewpoint is equivalent to the "absolute world" viewpoint just as, let us say, the co-ordinate formulation of the laws of Newtonian mechanics is equivalent to their vector formulation. Minkowski did not construct a new theory, but only gave a more profound interpretation of Einstein's theory. But the conception of what is primary and basic determines the direction of thought not only in the task of the theory itself, but also in the search for, and the understanding of, its possible applications and generalisations. The differences between the two viewpoints were important in the transition to the general theory of relativity and led to a discussion that is not over yet. Errors in interpretations of theory, involving at times an inability to take into account obvious and indisputable facts, resulted mainly from failure to grasp the real dialectics of the relative and the absolute. When some schools of physics stray towards reactionary philosophy, they do so mainly because the physicists do not know dialectics. Physics was giving birth to dialectical materialism, but the delivery was very painful. In short, everything was proceeding as Lenin had predicted. We shall see the truth of this now, as we consider the general theory of relativity and the various views of it.

The General Theory of Relativity

Despite the overall success of the theory of relativity, gravitation still resisted inclusion in the theory, although such an attempt was undertaken by Poincaré in his very first work, in which he developed a theory of relativity simultaneously with Einstein, that attempt being later repeated by Minkowski and others. It took ten years for the problem to be solved by Einstein through generalisation of the theory of relativity, which came to be called "special", as distinct from the new, general one. The general theory of relativity is a theory of space-time, explaining gravitation through the dependence

of the structure of space-time on the distribution and movement of masses of matter.

In the special theory of relativity, space-time is "flat", uniform and isotropic. All spatio-temporal relations and properties and, according to the relativity principle, all physical laws are invariant with regard to the Lorentz transformations. But in the general theory of relativity this is only approximately true and holds for small regions; on the whole, space-time is not uniform and not isotropic and the relativity principle is not realised. The difference of the structure of space-time from the "flat" space-time of the special theory is determined by the distribution and motion of masses of matter. And that structure determines, in its turn, the motion of masses as if it were under the influence of gravitational forces, that is, masses of matter determine the structure of space-time and, thereby, their own motion. Gravitational field is not actually a force field–it is nothing but the difference between the structure of space-time and flat metrics, a curvature tensor field. Since the structure of space-time obviously depends on the distribution of masses of matter, one may say that the structure itself is not absolute and even space-time is not quite absolute in this sense. As for the separation of space and time, it becomes even more relative, and on a very large scale it may even prove to be impossible in a precise and unambiguous sense. The only absolute is the material world as a whole, while all its forms, manifestations, etc. are relative in one sense or another. So Lenin was quite right in emphasising that dialectical materialism did not recognise any absolutes with the exception that there exists the material world and we reflect it in our consciousness, which ascends from one relative truth to another, perceiving in this movement an ever greater share of objective absolute truth.

In constructing the theory of gravitation, an essential difficulty had to be overcome, namely, the choice of reference systems, systems of spatio-temporal co-ordinates. In the special theory there existed preferential systems–the intertial ones; the laws of nature for these systems have the simplest form: they do not include any references to quantities that are specifically characteristic of these systems. The systems are naturally connected with the every structure of flat space-time, just as ordinary orthogonal co-ordinates are naturally connected with the properties of the Euclidean plane.

The rejection of the flat space-time entails the unpleasant consequence that the concept of an inertial system becomes meaningless; it only remains meaningful for small regions as a first approximation, the more so because the structure of space-time is not a preset one, and it is, therefore, impossible to indicate in advance the grounds for preferring some co-ordinates to others. Accordingly, one had to start with any co-ordinates without attributing to them any advantages as compared with others. In other words, all systems of co-ordinates in general had to be *a priori* recognised as equally acceptable, and spatio-temporal relations and generally all physical laws had to be expressed in any co-ordinates. Since the general form of equations which is suitable for any co-ordinates is called covariant, the requirement formulated here is called the covariance principle. A meaningful choice of a system of co-ordinates that is best suited to a certain space-time structure is only possible *a posteriori*, when that structure has been sufficiently well defined.

This situation first arose in classical mechanics, when Lagrange formulated the laws of mechanics for a system of material points not in the orthogonal co-ordinates of these points, but in "generalised co-ordinates" selected in such a way as to take into account beforehand the connections imposed on the system. In geometry arbitrary co-ordinates first appeared in the work of Gauss, who developed a theory of geometry for an arbitrary curved surface, where arbitrary co-ordinates were introduced for such a surface. All equations there were written in a form suitable for any co-ordinates, i.e. in covariant form. As for preferential co-ordinates, they may be determined by the properties of the surface and the character of the figure under consideration.

Thus, the choice of arbitrary co-ordinates and the requirement of covariance do not, in principle, constitute anything new and do not have any physical content. Co-ordinates in any space may, in principle, be chosen in an arbitrary way. The advantages of some co-ordinates over others emerge

only in a concrete situation which they are used to describe.

But in constructing the general theory of relativity, however, the transition to arbitrary co-ordinates appeared so revolutionary that it was accorded the status of a special principle, called the general principle of relativity. This principle was formulated as the principle of the equal acceptability of all reference systems irrespective of the motion of bodies with which these systems were associated. In particular, equal acceptability of the Ptolemy and Copernicus systems was proclaimed. It was sometimes even contended that the primary task of the general theory of relativity was not to produce a theory of gravitation that would be in agreement with the theory of relativity, as was actully the case, but to formulate the laws of physics in a form suitable for an arbitrary system of co-ordinates, i.e. in covariant form.[1]

But soon after Einstein's main work on the general theory of relativity appeared, Kretschmann pointed out that the "general principle of relativity" is not a physical principle or law, but merely a requirement for writing equations in covariant form, which, as has already been said, is nothing new. After Minkowski gave a four-dimensional formulation of the laws of relativistic kinematics, mechanics and electrodynamics, the task of writing equations expressing these laws in any co-ordinates was reduced to simple formal transformations. Any co-ordinates are applicable to any theory, be it classical mechanics, the special theory of relativity or any other, and the problem of writing equations in covariant form is a purely mathematical one.

Einstein agreed with Kretschmann's remark. Nevertheless, the conviction that the general principle of relativity had special significance remained. It seemed as if there were no grounds for debate, but the debate still continued. In particular, the argument continued as to whether or not the Ptolemy and Copernicus systems were equally acceptable, despite the fact that the controversy had long been resolved, one would have thought, by experience. It is clear (and it was

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[1] See, for examle, A. Einstein and L. Infeld, *The Evolution of Physics*, New York, 1954.

already clear enough to Ptolemy!) that the movements of the heavenly bodies could be described in different systems of co-ordinates. We always describe this motion with regard to ourselves, for example, when we speak of sunrise, when we say that the moon is high in the sky, and so on. In short, all this is absolutely trivial.

At the same time, experience shows that the laws of physics are different in relation to the geocentric and the heliocentric systems of reference; in the first system these laws contain a reference to the rotational velocity of the earth. Accordingly, phenomena of one and the same type have a different course in relation to this system. This is manifested on the earth in the erosion of the right banks of rivers in the northern hemisphere, in the rotation of the Foucault pendulum and other effects. Consequently, both systems are applicable, but they are not equally acceptable in the same sense as inertial systems (within the limits of preciseness of classical mechanics or the special theory of relativity). In inertial systems physical laws do not contain quantities distinguishing the systems themselves, whereas the geocentric system does contain such a quantity (angular velocity); accordingly, events run a different course with regard to this system. The effect of the uniform flight of an aircraft cannot be registered inside the plane itself, whereas on the earth, inside a closed room, one can register the effect of the earth's rotation.

Let us compare the principle of covariance and the principle of relativity in general form. The former requires that laws should be expressed in equations in a form suitable for any co-ordinates. This is achieved through the explicit introduction in equations of quantities characterising a system of co-ordinates. For instance, if we use oblique co-ordinates on a surface, the formulae include the angle between the co-ordinate axes. When an equation is written in some given co-ordinates, its covariant form is easily obtained. All one has to do is to replace the given co-ordinates by arbitrary functions of any other co-ordinates and make appropriate transformations of other quantities contained in the equation, if these quantities depend on systems of co-ordinates at all (like

the corresponding vectors, for example). We are, therefore, dealing here with a purely mathematical operation. Understandably, the equations obtained are not concretely defined, since they contain arbitrary functions. It is the choice of these functions that determines the choice of a certain co-ordinate system and, accordingly, of the concrete form of the equation. Since the concrete form of the equation changes with the transformation of co-ordinates, the general form of the equation suitable for any co-ordinates is called covariant, that is, co-transformational.

When co-ordinate systems are realised physically, the dependence of a concrete equation on a co-ordinate system means that the law governing the course of the phenomenon in relation to that system depends on it. Thus, equations concerning a rotating system include its angular velocity, and phenomena depend on that velocity.

As for the principle of relativity, its physical meaning is that phenomena in relation to definite systems proceed in accordance with identical laws. The mathematical expressions of these laws do not, therefore, contain quantities distinguishing these systems. In the transition from one system to another the equations do not change at all, i.e. they are *invariant, not just covariant* with regard to transformations of co-ordinates from one of the systems considered to another. The relativity principle of Einstein's theory is mathematically expressed in the requirement of invariance of the Lorentz transformations. Thus, the covariance principle and the relativity principle are quite different things. The former concerns a purely mathematical requirement, while the latter reflects a law of nature consisting in the property of uniformity, according to which phenomena in different systems proceed in a similar manner.

In the general theory of relativity the principle of relativity or Lorentz-invariance is only locally and approximately true, and, owing to the non-uniformity of space-time, there are no transformations, generally speaking, in which physical equations would be invariant. They always include quantities characterising the structure of space-time and simultaneously a system of co-ordinates (the constituents of the metric tensor *gik*). The difficulty, in fact, is precisely that these quantities simultaneously express two different things –the structure of space-time, i.e. something "absolute" and independent of the system of co-ordinates, and the properties of the co-ordinate system itself, i.e. something relative. It is impossible to divide this within the framework of the mathematical formalism usually applied in Einstein's theory.

Since the structure of space-time itself, however, proves to be variable, it may be regarded as a kind of physical field. Abstracted from it, space-time is nothing but a four-dimensional space possessing no metrics, no properties except for continuity (and "differentiability": it proves to be a differentiable four-dimensional multiformity). From this viewpoint, *all co-ordinate systems are equally acceptable simply because any possible grounds for distinguishing between them are ruled out in advance.* The general principle of relativity is realised, but only due to the trivial fact of abstraction from any specific properties of space-time. The concept of accelerated or non-accelerated motion also becomes meaningless, because some measure is needed for defining acceleration, and in a space without metrics such a measure is simply lacking. Therefore, it is meaningless to speak here of the equal acceptability of differently moving systems of reference, as the very concept of their motion is incomprehensible. When there is no structure at all, no conception of time exists. The motion of a point is simply represented by a line in a four-dimensional multiformity, and one line is no better and no worse than any other, since there are no grounds for distinguishing between their properties.

Thus, all physics disappears here; there is only one physical point left: space-time is, in general, a four-dimensional multiformity. But this holds true for the special theory of relativity and for classical mechanics as well as for the general theory of relativity. The "general principle of relativity" is equally valid for all these theories. It does not express anything more than the requirement of covariance again, as it consists precisely in the need for writing equations in a form suitable for arbitrary co-ordinates.

The specificity of the general theory of relativity is only

revealed when the structure and the metrics of space-time are introduced. Non-uniformity of this structure is the specific feature of this theory. In short, its essence lies not in the "general principle of relativity" and not in an arbitrary choice of a system of co-ordinates, but in specific assumptions about the structure of space-time. In other words, the essential point is not relativity, but the absolute–the properties of space-time, independent of reference systems and co-ordinates.

More on the General Theory of Relativity

Despite the fact that everything outlined above concerns either firmly established facts or purely mathematical inferences, the controversy about the general principle of relativity has been going on for more than fifty years and is, apparently, nearing a happy ending.[1] The controversy reflects the two conflicting views of the essence of the theory of relativity that have been presented above. One of the viewpoints, the relativistic one, considers any phenomenon, in particular spatio-temporal relations and properties, only in relation to a definite system of reference, so that any motion in this view is only relative. The other view originates with Minkowski and takes as its basis space-time itself, the processes themselves in their proper spatio-temporal, four-dimensional form, so that their association with a system of reference is something secondary. The motion of a body is interpreted as a mode of existence–its four-dimensional spatio-temporal trajectory–and is, therefore, also absolute. Only "projections" of motion in various reference systems are relative. For instance, inertial motion, free fall in a gravitational field, represents a geodesic line in four-dimensional space-time,

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[1] R. Feynman in his book *The Character of Physical Law* (London, 1965, p. 97) writes: "Many people have proposed that really the earth is rotating relative to the galaxies, and that if we were to turn the galaxies too it would not make any difference [compared with those existing in inertial systems.–*A.A.*]. Well, I do not know what would happen if you were to turn the whole Universe.... We cannot say that all motion is relative. That is not the content of relativity."

i.e. a line whose curvature equals zero. Accelerated motion is represented by a line with non-zero curvature. Curvature is a non-relative quantity characterising the line itself irrespective of any co-ordinate systems. It is not at all surprising, therefore, that processes occur differently in systems in accelerated motion, and that co-ordinates associated with such systems are not on the same level as those associated with bodies in inertial motion. Motion is not only relative, it is also absolute. It is, one might say, the relation of the given body not only to other isolated bodies, but to the whole structure of space-time. In simpler terms, the statement of the relativity of any motion is no more meaningful than a statement of the relativity of lines on a surface: it is all the same whether we speak of an arc of a circle or a section of a straight line. (But the absolute difference between an arc and a section is, of course, determined by their relation to the structure of the surface; the actual difference between the relative and the absolute is relative.)

The relativistic viewpoint, as has been pointed out, originates with Berkeley, who wrote this, for instance: "If every place is relative then every motion is relative, and as motion cannot be understood without the determination of its direction which in its turn cannot be understood except in relation to our or some other body." And further: "Let us imagine two globes, and that besides them nothing else material exists, then the motion in a circle of these two globes round their common centre cannot be imagined. But suppose that the heaven of fixed stars was suddenly created and we shall be in a position to imagine the motion of the globes by their relative position to the different parts of the heaven."[1]

But Berkeley's reasoning is logically meaningless. Indeed, if "nothing else material exists" but the two globes, then there is no connection between these globes, even space outside the globes does not exist. For what is space that is *absolutely* empty and in which different places are, therefore, indistinguishable? It is, therefore, logically meaningless to speak of some motion of imaginary globes in an absolute vacuum.

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[1] Quoted from *Gravitation and Relativity*, p. 122.

When the stars have been "created", the definition of motion becomes possible not just because there are stars, but because there is light which alone permits the establishment of connection between the two given globes and the stars.[1]

Space (space-time) is not empty; it is filled with radiation and other fields, and that is what makes judgements of motion possible. In all discussions of empty space it is tacitly assumed that there are different places in it, that it consists of points. But what do point A and point B mean if nothing, literally nothing, distinguishes them? Consequently, "empty space" itself is no more than an abstract image of "filled space" where the concept retains only the fact that points in space are somehow different. This distinction is the last trace of matter, and when it disappears, the points cease to be distinguished, the concept of points A and B vanishes and with it vanishes space itself. Space in mathematics is defined as a set of elements called points and not as absolute emptiness.

But if we take into account that space (space-time) is filled with matter, that it is, in fact, a form of the existence of matter, the general structure of the connections between the elements of matter, then the motion of the body in space is its "place" in this structure. It is a four-dimensional trajectory and is therefore just as absolute as a line on a surface is "absolute". The fact that there are equal lines that may be matched or that a given line is represented by different equations in different co-ordinates does not affect the existence of the line as a definite object. Just as definite is the motion of

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[1] A similar mistake was made by Einstein himself in his discussion of the relative motion of two bodies around an axis passing through their centre (see A. Einstein, *The Principle of Relativity*, "Foundations of the General Theory of Relativity". He left out of account the fact that the very judgement of the rotation of one body with respect to another is only possible when these bodies are materially connected. The observer on one of these bodies sees the other body because there is light. Thus, a radiation field is assumed, and in that case the rotation of the body is defined in relation to that field as well. Therefore, one need not have recourse to Berkeley's stars or Mach's remote masses to distinguish which of the two bodies is "really" rotating, and not just in relation to the other one. But if we exclude the radiation field, we also exclude the concept of the rotation of one body in relation to another!

an individual body in space-time, which exists just as the body itself exists. Indeed, there are no "instantaneous" bodies, as Wells explained in *The Time Machine* even before the theory of relativity had appeared. A body is extended both in space and in time; it is a spatio-temporal object. Its temporal extension is, one may say, its motion. In different aspects and different systems this motion may appear in different forms: as uniform in relation to the given system or as accelerated in relation to another system, just as a circumference is represented as a quadratic equation in orthogonal co-ordinates and as a linear equation in polar co-ordinates with their centre coinciding with that of the circle.

So we see that relativism exaggerates the significance of relativity, divorcing it from the absolute, from matter, and thereby falling into error. This reminds us of Lenin's profound remark that "from the standpoint of *dialectical* materialism ... philosophical idealism is a *one-sided*, exaggerated... development (inflation, distension) of one of the features, aspects, facets of knowledge into an absolute, *divorced* from matter, from nature...".[1] Relativism in physics, taken by itself, is not yet idealism. It is only a one-sided exaggeration of the relativity discovered by Einstein's theory; it divorces the relative from matter, for example, where it forgets radiation filling space and serving as the basis for judgements concerning the mutual movement of bodies. (Of course, apart from radiation, connections between bodies may be established by other fields or by "transference" of particles.) But relativism in physics is linked with Berkeleianism and it is in itself a way to Berkeleianism if it is driven too far, which no physicist can do if he is to remain a physicist, i.e. a student of nature and not of his own perceptions. One can say that even Berkeley's famous definition *Esse est percipi* presupposes the existence of light, through which a remote object is perceived. Otherwise there is no object, but perception only, and we come to solipsism.

V. A. Fok, a specialist in the theory of relativity, was

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[1] V. I. Lenin, "On the Question of Dialectics", *Collected Works*, Vol. 38, p. 363.

especially insistent and consistent in attacking relativism. As is clear from V. A. Fok's words quoted at the beginning of this paper, his views were formed under the influence of Lenin's book *Materialism and Empirio-Criticism.* As evidence of acute differences between physicists in their understanding of the theory of relativity, we shall quote from the preface to a comprehensive treatise on the general theory of relativity written in 1960 by Synge: "...The geometrical way of looking at space-time comes directly from Minkowski. He protested against the use of the word 'relativity' to describe a theory based on an 'absolute' (space-time), and, had he lived to see the general theory of relativity, I believe he would have repeated his protest in even stronger terms. However, we need not bother about the name, for the word 'relativity' now means primarily Einstein's theory and only secondarily the obscure philosophy which may have suggested it originally. It is to support Minkowski's way of looking at relativity that I find myself pursuing the hard path of the missionary. When, in a relativistic discussion, I try to make things clearer by a space-time diagram, the other participants look at it with polite detachment and, after a pause of embarrassment as if some childish indecency had been exhibited, resume the debate in their own terms. Perhaps they speak of the Principle of Equivalence. If so, it is my turn to have a blank mind, for I have never been able to understand this Principle.... Does it mean that the effects of a gravitational field are indistinguishable from the effects of an observer's acceleration? If so, it is false. In Einstein's theory, either there is a gravitational field or there is none, according as the Riemann tensor does not or does vanish. This is an absolute property; it has nothing to do with any observer's world-line. Space-time is either flat or curved.... The Principle of Equivalence performed the essential office of midwife at the birth of general relativity, but, as Einstein remarked, the infant would never have got beyond its long-clothes had it not been for Minkowski's concept. I suggest that the midwife be now buried with appropriate honours and the facts of absolute space-time faced."[1]

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[1] J. L. Synge, *Relativity: the General Theory*, Amsterdam, 1960,

The following explanation is due concerning the principle of equivalence. The disappearance of gravitational forces in a freely falling system was one of the starting points of Einstein's theory. But when it has been assumed that space-time is flat in the infinitely small, the principle of equivalence as the possibility of excluding gravitational forces turns out to be simply a physical expression of a well-known theorem of the Riemannian geometry. Therefore, in Einstein's theory itself this is no more of a principle than any other geometrical theorem. Relativism involves an inadequate understanding of simple mathematical facts, and even major physicists are not free from such errors.

Let us also clarify what is meant by the principle of relativity. A physical law defines the connection between some characteristics of some phenomena or of one phenomenon. For simplicity's sake, let us imagine that we are dealing with two characteristics or systems of characteristics which we shall designate x and y. The law is represented as the dependence $F(x, y)=0$. That is not quite exact, however, as conditions under which this dependence is manifested have also to be taken into account. Therefore, designating the totality of such conditions by A, we must write the symbolic equation expressing the law in this form:

$$F(x, y; A) = 0. \tag{1}$$

Furthermore, we must analyse the conditions themselves. First, we may distinguish here the "background"–the invariable conditions that are usually only assumed. Let us designate them by B. This may be space-time in general or, for example, the gravitational field of the earth in the given place, etc. Second, the conditions include the system S, relative to which phenomena are registered and the characteristics x, y are themselves determined. The phenomena may be regarded as occurring in the system S. A system of spatio-temporal co-ordinates is linked to it, functioning as a reference system. Third, there are also conditions C within the system itself which are determined relative to the system and may vary, determining the concrete course of the phenomenon. Thus, the entire complex of conditions is represented as $A=(B, S, C)$ and accordingly equation (1) is written

$$F(x, y; B, S, C) = 0. \tag{2}$$

If for a certain class of systems S the dependence expressed here is the same in all systems, then S does not enter (2) and the law has the form

$$F(x, y; B, C) = 0. \tag{3}$$

In this case the law does not depend on the system S and the equation is invariant with regard to the transition from one system to another. If this is true for a class of phenomena P and systems S, it may be said that the principle of relativity is realised for these phenomena and systems. Thus, the classical Galileo principle holds good for mechanical phenomena and inertial systems.

But the very distinction between background B, system S and conditions C is relative and, to a certain degree, arbitrary. Generally it is always possible to include the system in the conditions C: the phenomenon occurs against the background B under conditions C, including the fact that it occurs in the system S. From this viewpoint, the general equation (2) assumes the form (1), as S is included in C, and the principle of relativity seems to be realised here. But that is only so for the trivial reason that the systems themselves are included in the variable conditions C.

If we restrict ourselves to the special theory of relativity, the metrics of space-time is fixed. It is unnatural, therefore, to include it in the variable conditions C: it is an element of the invariable background and it is, naturally, included there. Exactly the same is true for the classical theory, the only difference is that, according to this theory, the background is different–not the Minkowski space-time, but Euclidean space combined with absolute time.

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pp. IX-X. L. Infeld's memoirs and my answer to him provide more evidence for the controversy and the inability of some major physicists to break away from relativism; see L. Infeld, "Pages from a Physicist's Autobiography", *Novy mir*, No. 9, 1965; A. D. Alexandrov, "Truth and Error", *Voprosy filosofii*, No. 4, 1967, p. 76.

But in the general theory of relativity the metrics is not constant, it depends on physical conditions. Therefore, it cannot be included in the background in the general constructions of the theory. On the other hand, when the conditions are fixed, the metrics is fixed as well. In that case it is natural to include it in the given background. For instance, close to the earth, the gravitational field and, correspondingly, the structure of space-time may be regarded as fixed, and co-ordinates may be introduced that are naturally associated with the earth; in considering the solar system, it will be natural to introduce co-ordinates associated with the sun; in considering the model of the Universe with a uniform distribution of masses, completely different co-ordinates turn out to be preferential. In short, co-ordinates of one type or another prove to be preferential, depending on conditions and, accordingly, on the concrete structure of space-time determined by these conditions. The degree to which such special co-ordinates may be arbitrary and, accordingly, the degree to which the relativity principle is realised for them, albeit approximately, depend again on the conditions and the things we choose to ignore or take into account in our constructions.

Relativity is relative—that is the essential point here. All things in the world are more or less relative. But relativity itself is only an aspect, a facet, of the absolute, and contains the absolute in it just as, for example, the relativity principle expresses a certain non-relative property of the world—the uniformity of its structure, if only for small regions and as an approximation. The essence is in the dialectics of the relative and the absolute, without which a deep understanding of the theory of relativity and of modern physics in general is impossible. Interpretations of the theory of relativity have strayed into idealism or simply into error because the interpreters did not have a good command of dialectics. Other interpreters recoiled from the stigma of idealism and, also failing to understand dialectics, tried to eliminate all relativity or revert to the old conceptions of space and time, as Janossy did, for instance.

Thus we can see that Lenin's general ideas concerning dialectics have a real and essential significance for the understanding of physics.

What Is Space-Time!

The question posed in the title may seem to be idle, as the answer to it has already been formulated: space-time is a form of the existence of matter. But the question that we really have in mind is this: how is this form of the existence of matter to be precisely defined? What we need is not an answer on a general philosophical level, but one that would form the basis for constructing a theory of space-time. Naturally, the answer should be contained within the theory of relativity which is the theory of space-time, but it has yet to be extracted from the theory.

The form of the object is, in fact, nothing but the totality of the relations between its components. We are therefore dealing with the material connections of elements of the world the totality of which determines space-time.

The simplest element of the world is what is called an event. This is a "point" phenomenon like the instantaneous flash of a point lamp or, using the graphic images of space and time, a phenomenon whose extension in space and time can be ignored. In short, an event is similar to a point in geometry, and, imitating Euclid's definition of a point, we may define an event as a phenomenon whose part is nothing; it is an "atomic" phenomenon. Any phenomenon or process is represented as a definite connected totality of events. From this viewpoint, the whole world is regarded as a set of events.

Disregarding all the properties of an event except for the fact that it exists, we represent it as a point, a "world point".[1] Space-time is the set that includes all the world points. But space-time thus conceived does not have any

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[1] An event defined as an atomic phenomenon cannot be regarded as a world point. A world point combines indivisible events or, in other words, aspects of a single event (but in this case the event is no longer atomic). For instance, it takes two particles to make a collision. Cf. Wittgenstein's concept of an atomic fact.

structure yet–it is merely a set of events retaining only the property of existence as different events. All the other properties are ignored and no relations between events are assumed. We may introduce the concept of the continuity of a sequence of events, adopting it from immediate perception or providing some appropriate definition for it. In this case, space-time will simply be a four-dimensional multiformity in the topological sense. Space-time, i.e. a set of events without any concrete properties, without any structure but the one determined by the relation of continuity, is precisely the background of the general theory of relativity. But we do not stop here: we may determine the structure and the continuity of space-time, proceeding from the most general and basic relationship between events that there is in the world –the motion of matter.

Every event in some manner or other affects other events and is in turn affected by other events. In general, effect is motion, connecting one event with others through a series of intermediary events. The physical nature of effect may be extremely diverse; we can conceive of it as the propagation of light, the emission of a particle, etc. Naturally, it need not be immediate, but may proceed through a number of agents. The motion of a small body represents a series of events in which preceding events affect subsequent ones. In physical terms effect may be defined as transmission of momentum and energy. These concepts appear then as primary, which is essentially correct, since momentum-energy is the basic physical characteristic of motion and effect. But as we abstract events from their concrete properties, so we also conceptually abstract effect from its concrete properties except that it is a relation between events possessing the properties of the general relation of precedence (anti-symmetry and transitivity). With a view to axiomatic construction of the space-time theory, the concepts of event–world point and effect–precedence are taken to be basic and not subject to definition. Events influenced by a given event A form the "domain of the effect of event A". These domains define a certain structure in the set of all events. It is, of course, tantamount to the structure which is determined by the relations of effect themselves. This structure is the spatio-temporal structure of the world. In other words, space-time itself may be defined like this:

Space-time is the set of all events in the world abstracted from all its properties except those that are determined by the effect of some events upon others.

The effect of one event upon another is the elementary form of causal relationship, its "atom" or "quantum", as it were, just as the event itself is an "atomic" event. The above can, therefore, be put in these less precise, but more expressive, terms: *the spatio-temporal structure of the world is identical with its cause-and-effect structure taken in appropriate abstraction.* That abstraction consists in ignoring all the properties of phenomena and their causal relationship except for the fact that phenomena are composed of events and their interactions, of the effect of some phenomena upon others.

There is a purely mathematical proof that the above definition of space-time really is possible within the framework of the theory of relativity.[1] The relations of effect, unaccompanied by any properties (even that of continuity), really do define the Minkowski four-dimensional space in the special theory of relativity. The definition of space-time in the general theory of relativity requires a certain addition, which may be formulated as the local fixation of definite scales (pairs of infinitely close events that are ascribed an interval of definite magnitude between them).

The above definition of space-time is just a concrete and precise expression of the fact, recognised by modern physics, that space-time is a form of the existence of matter. Matter itself in its motion and, thereby, in the interaction of its ele-

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[1] A. D. Alexandrov, "A Contribution to Chronogeometry", *Canadian Journal of Mathematics*, Vol. XIX, No. 6, 1967, pp. 1119-28. This was proved for the first time in: A. D. Alexandrov, "Lorentz Transformations", *Uspekhi matematicheskikh nauk*, Vol. V, No. 3 (37), 1950, p. 187. See also A. D. Alexandrov and V. V. Ovchinnikova, "Notes on the Foundations of the Theory of Relativity", *Vestnik Leningradskogo universiteta*, No. 11, 1953. Later (1964) the same result was obtained by E. C. Zeeman.

ments determines its spatio-temporal form. This definition is impossible within the framework of classical physical concepts. It was believed, in classical physics, that effect may be transmitted at an arbitrary velocity. The domain of the possible effect of the given event, therefore, embraces, in principle, all the events following it in time. As a result, the effect relationship does not define anything, but mere succession in time. The classical conceptions of absolute sequence in time and absolute simultaneity conform to these notions. As for the quantitative definition of the time t and space geometry, they must be determined by something else. Moreover, no definition of space and time is generally known which would be just as brief and precise as the definition of space-time given above and which would conform to the concepts of classical physics. The very possibility of such a definition represents an enormous advantage of the theory of relativity and shows how profound its understanding of the fundamental forms of the world is.

The system of effect relationships determines space-time and thereby all possible relative times and all possible relative spaces with their geometry. A definition is, naturally, given first for space-time, i.e. the absolute form of the world, and not separately for space and for time, which are only relative aspects of this form. In a few words and without any detailed explanations, one may say that space is a set of parallel series of events, connected by effect relations. A point in space is not something elementary–it is determined, in simple terms, by a number of events occurring in the given place; to be more precise, the "given place" itself is fixed by this series of events. The relationship between different points of space, its geometry, is naturally determined by the structure of space-time, i.e. by effect relationships. In its turn, time at the given place may be defined as a series of events fixing that place, so long as we abstract ourselves from all the properties of these events except for those that are determined again by effect relationships–not, of course, within the given series of events, but by the totality of effect relationships influencing these events and exerted by these events. Agreement between different local times and, through that,

some relative time embracing the whole world is again defined by effect relationships. (It may be noted, incidentally, that the general foundation of Einstein's definition of simultaneity comes to light here. It has been proved that any definition of simultaneity subject to the natural requirements of symmetry and transitivity and based only on the effect relationships in their general structure is necessarily equivalent to the Einsteinian one. This is true, of course, of the space-time of the special theory of relativity only, as Einstein's definition is inapplicable in the general theory.)

Our definition of space-time may be used as the basis for constructing a theory of relativity. For that, it will be necessary, of course, to impose appropriate requirements on the structure of effect relationships or, equivalently, on the structure of effect domains.[1] But we shall not dwell on these problems here.

Going back to the beginning of the paper, we can see that the definition of space-time given here and the definition of space with its geometry indicated later contain an answer to Riemann's question concerning the causes of metrical relations in space. They lie in the very existence of causal connections between phenomena. Effect relations determine the structure of space-time and, by the same token, the metrics of space, geometry.

Thus, the theory of relativity has answered the most profound questions posed by its predecessors concerning space and time, the foundation of the metrical properties of space, the connection between the properties of space and time and the properties of matter itself, the nature of universal gravitation, etc. A profound understanding of the theory itself and its answers to the questions indicated above, however, is only to be achieved if one is guided by the general ideas, developed by Lenin. It has been our goal to demonstrate this fact.

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[1] See A. D. Alexandrov, "The Space-Time of the Theory of Relativity", *Jubilee of Relativity Theory, Proceedings*, Basel, 1955.

V. A. Ambartsumyan and V. V. Kazyutinsky

DIALECTICS IN MODERN ASTRONOMY

Twentieth-century astronomy is undergoing a great upheaval, comparable perhaps with the Copernican revolution. It has been caused by the discovery of fundamentally new objects in the Universe, such as the active nuclei of galaxies, quasistellar radio sources (quasars), etc. Phenomena occurring in these cosmic bodies have proved to be quite unusual and necessitated a radical revision of many astrophysical, cosmogonic and cosmological conceptions and theories, throwing doubt on the universal nature of fundamental physical laws known at present. It is not impossible that the study of the Universe will result, in the not too distant future, in a new revolution in physics.

An enormous role in the interpretation of the essence of the processes taking place in modern astronomy was played by the ideas of dialectical materialism developed by Lenin in his books *Materialism and Empirio-Criticism* and *Philosophical Notebooks.* Following these ideas, science has succeeded in analysing the most complex philosophical problems posed by modern astronomy and, moreover, in presenting some fundamentally new concepts of the structure and evolution of the Universe.

On the "Strangeness" of Astronomical Discoveries in the 20th Century

As Lenin pointed out, a characteristic feature of the development of physics early in the 20th century was the transition from the ordinary to the extraordinary, to the "strange" and impossible from the viewpoint of "common sense". The same feature is clearly characteristic of modern astronomy.

Before the 20th century the observable region of the Universe was limited to the solar system and our stellar system, the galaxy, whose structure was studied only in the nearest vicinity of the sun. Astronomers dealt with objects that had been known for at least three thousand years–planets, stars and the diffuse matter of gas and dust. Attention was focused on the study of the spatial distribution and motion of these objects on the basis of classical, Newtonian mechanics.

The epistemological premises on which astronomy was based at that time were as follows. The objective reality, matter, exists outside and independent of the subject's consciousness; it is reflected and copied in scientific concepts and theories, and it is believed to be possible to attain the classical ideal of knowledge–total and absolute knowledge of objective reality in the shape of the only possible and therefore final physical picture of the world based on Newtonian mechanics. A graphic visual mechanical model of any object, phenomenon or process may be built within the framework of this picture of the world.

It was believed that the natural sciences were in principle capable of studying "all matter", i.e. "everything that exists" in some absolute sense. That was the way in which the task of cosmology was presented, and its object, the Universe as a whole, was identified with the whole material world. The Universe as a whole was believed to be a mechanical system unlimited in space, infinite in time and always existing in an unchanged, static state.

The development of modern astronomy has shown that the simple and familiar picture of the Universe created by 17th-19th-century astronomers is in many respects remote from reality, and this has posed a number of difficult epistemological problems. The construction of relativist cosmology with its unusual concepts of curved space which cannot be visually imagined, of a non-stationary Universe expanding from a certain zero time instant when the Universe, according to A. A. Friedman's theory, was contracted to a point, and so on, might seem even more "strange" than the discovery of the divisibility of the atom. For many astronomers the method of mathematical hypothesis which was used to build the "expanding Universe" theory was highly unusual. This method is oriented towards finding the mathematical "skeleton" of a theory which is later given a concrete physical interpretation.

In 1965 a group of American radiophysicists discovered the so-called relict radiation that may have appeared when the metagalaxy emerged through an explosion.

Apart from the construction of ever more sophisticated empirical instruments for studying the Universe, astrophysics and cosmogony are now witnessing the growth of the role of theoretical instruments of investigation, particularly mathematics and theoretical physics. Furthermore, we have realised the dependence of the concrete conclusions of astrophysics and cosmogony on the existing system of physical knowledge. Changes in physical theoretical conceptions, and new empirical data from laboratory physics have inevitably led to a revision of astrophysical and cosmogonical notions, including those that have been regarded as almost eternal truths requiring merely the elaboration of details.

For the proponents of traditional concepts, the discoveries of non-stationary (unstable) objects in the Universe were unusual and impossible.

Some stages in the development of galaxies proved to be distinctly unstable. For instance, enormous emission of energy occurs in radiogalaxies owing to explosions in their nuclei. The discovery of a similar explosion in one of the nearest galaxies by the American astronomers A. Sandage and C. Lynds (1963) was a genuine sensation. An even more grandiose phenomenon is the quasistellar radio sources (quasars), discovered in 1963 by the American astronomers M. Schmidt, J. Greenstein and T. Matthews. In explosions in galactic nuclei energies are emitted of the order of 10^{59}-10^{60} *ergs*. It was also discovered that, in addition to many distinctly quasistationary groups and conglomerations of galaxies there is a multitude of strikingly non-stationary groups and conglomerations of galaxies which expand and fairly quickly disintegrate; they must have emerged fairly recently. The expansion of stellar associations and of some groups and conglomerations of galaxies permitted the discovery of a most

important law of cosmogonic processes: cosmic objects, both stars and galaxies, at the moment of their formation receive great kinetic energy, which in many cases results in the diffusion of such groups.

These discoveries finally undermined the dominant age-old dogma of a gradual and smooth cosmic evolution. They induced the conclusion that the idea of the "big bang" with which the observable Universe began is inadequate and must be supplemented by the concept of many "bangs" occurring at different points and at different times.

The specific features of the development of modern astronomy led to attempts at interpreting its results in the spirit of subjective and objective idealism. Subjective idealist interpretations of modern astronomy were caused by the same epistemological reasons which, as Lenin showed, gave rise to "physical" idealism: (1) the increased role of mathematics in the description of nature; (2) raising the principle of the relativity of our knowledge to an absolute. Specifically, the following propositions were advanced: the fact that mathematics, in particular the mathematical hypothesis method, makes it possible to establish the essential features of the astronomical picture of the Universe means that the subject "imposes" a number of complex mathematical laws on nature. And the successive changes of different conceptions, hypotheses and theories in astronomy signify, in the subjective idealists' view, that the conclusions of astronomy have no bearing on objective reality. Completely different was the cause of objective idealist speculations concerning modern astronomy, speculations that were based on the unexpectedness, "strangeness" and the unimaginable character of the new conceptions in astronomy. There were attempts to interpret this fact as proof of the supernatural character of the Universe. And the presence of the time instant $t=0$ in the theory of the "expanding Universe" was viewed as indisputable "scientific proof" of the act of creation of the material world which appears secondary with respect to the "world spirit".

The untenability of these "inferences" was revealed by dialectical materialism—the only philosophy that is in line with the modern development of the natural sciences, including astronomy. One of the basic epistemological propositions of dialectical materialism is that cognition, active in character, reflects objective reality, the development of science contributing to the ever greater preciseness of knowledge and its adequacy to the various aspects of the objective world.

As far as the role of mathematics in the study of the Universe is concerned, it is obvious that the increasing multiformity of the new phenomena discovered by astronomy and the resultant need for generalisation of the results of astronomical observations make it necessary to use ever more powerful and complex mathematical apparatus. A mathematical theory of any phenomenon studied by astronomy is, however abstract it may be, in the final analysis, a *generalisation* of certain empirical data. Thus, mathematics in astronomy is, first and foremost, an instrument for the investigation of real phenomena.

Furthermore, as we conduct ever more sophisticated experiments and observations we ask more and more questions of nature, the aim of these questions depending on the subject's interests and the existing system of knowledge. An enormous number of experiments are mounted in such a way as to elicit yes-or-no answers concerning predictions made on the basis of certain theories. Undoubtedly, this orientation of the questions asked of nature necessarily exerts a certain influence on the character of the general conceptions of nature formed on the basis of the answers thus elicited. But it is a well-known fact that in the course of experiments and observations nature in its turn confronts the subject with an even greater number of questions, sometimes extremely unpredictable. For instance, an astrophysicist studying the structure of remote galaxies is interested in the types of stars, mostly well known in our galaxy, that form them. Now, these observations may discover the flares of supernovae, thus revealing not only a new type of stellar "population", but also new processes involving the release of monstrous quantities of energy into space; the analysis of the physical nature of these processes is an entirely new problem.

It also happens sometimes that our fairly vague questions elicit from nature other extremely definite, but difficult questions. Thus, when astronomers began using radiotelescopes to observe hydroxyl monochromatic lines in order to determine the spatial distribution of OH molecules in interstellar matter, they encountered, from the outset, extremely compact sources emitting radio waves in the same spectral lines, and in this way the very interesting and difficult question of the nature of these objects emerged. It was precisely such cases when nature provided unexpected answers or posed even more unexpected questions that turned out to be the greatest stimuli for scientific progress.

The unexpectedness and "strangeness" of the most important discoveries of astronomy in the 20th century prove the untenability of subjective idealist interpretations of its results. Essentially, the same proof is provided by the fact that many of them cannot be visually imagined. "Imaginability" is linked with the specific features and conditions of the cognition of the world by man. But the phenomena under study exist independently of our consciousness and need not have a form that would be imaginable by human consciousness.

Can it be that the unexpectedness and "strangeness" of the phenomena discovered by modern astronomy are evidence of their "supernatural" character? To answer this question, it is sufficient to remember that many scientific facts and theories might at some time have appeared supernatural and ultimately caused by non-material factors. However, as natural science developed, objective idealists had to relegate their ideas about such factors to new and relatively little studied objects of cognition; those phenomena that had previously been used for all kinds of mystical speculations in actual fact proved to be subject to natural laws only. A similar fate undoubtedly awaits all modern arguments of this sort.

As for the "creationist" inferences made from the "expanding Universe" theory, they have, naturally, no bearing whatever on the physical content of the theory and result from the identification of the "Friedman Universe"–the metagalaxy–with the "totality of matter". The object of cognition in the natural sciences, however, is only the aspects and fragments of the inexhaustible material world that are singled out by the subject in his socio-historical practice. True, the object of scientific investigation of the whole and of each of the natural sciences in particular is continually expanding and our knowledge of nature is becoming ever more adequate, but this does not change the fact that, at any given moment, the natural sciences are dealing only with separate aspects of that part of the objective reality which has been isolated by the empirical and theoretical means available at the time. Cosmology in this respect has no special status among other natural sciences–"the totality of matter" (the material world as a whole) is not its object now and never will be. The very presentation of the problem is unjustified.

The various "models of the Universe" theoretically constructed in cosmology are essentially models of systems realising the varied physical conditions, phenomena, interactions, objects and scales allowed in a particular cosmological theory (i.e. "everything that exists" from the viewpoint of the given theory). These systems may in principle be identified not only with the metagalaxy, but also with physical systems of a greater scale (or even higher order), including as their component parts our metagalaxy as well as others as yet unknown.

Modern astrophysical data do not exclude the existence of other metagalaxies. But so far we do not know anything about them or about the ways in which they are connected and interact with our metagalaxy. Nevertheless, the existence of systems including not one, but many worlds (and even anti-worlds) is now assumed in some cosmological theories. Accordingly, when we speak of the Universe as the object of cosmology, we do not always have one and the same physical object in view. Models of the Universe built on the basis of different cosmological theories may correspond to different "originals".

The view that cosmology at some stage of its development will describe the "physical aspect" of the material world as a whole (everything that exists in some final, absolute sense), or even that we have approached this stage of its development, results from absolutisation of a definite and necessarily limited level of knowledge. None of these attempts undertaken in the past was successful, and the advance of natural science only provides more and deeper proof of Lenin's view of the inexhaustibility of the material world. If the existence of "Universes" of a higher order than our metagalaxy is proved, they will also have to be regarded not as "everything that exists", but only as something corresponding to a new stage in the study of the material world which will not exhaust the latter even in its basic aspects.

The Universe as the object of cosmology is, consequently, an integral aspect of "everything that exists" *as applied to a particular level of human praxis.* That which today is viewed as "non-existent" may tomorrow enter the domain of human praxis and will thus be proved to exist; it will be included in our conception of the Universe.

Consequently, the view that cosmology now studies the evolution of "all matter", "the material world as a whole" is erroneous. And that in turn signifies that the "starting point" in the evolution of the metagalaxy is not an absolute "beginning of all", but the instant when protomatter appeared out of which later all known forms of matter emerged.

Thus, the present-day developments in astronomy, as well as the development of all natural sciences, are a remarkable confirmation of the epistemological principles of dialectical materialism. Now, as before, results obtained in astronomy describe an objective reality, or rather some of its aspects, that is independent of, and external to, the subject. But nature is immeasurably richer than conceptions of nature at any given moment, and it persistently compels us to give up old conceptions and introduce new ones prompted by experience. In this sense, however "strange" modern data about the Universe might seem from the viewpoint of the previous development of astronomy, Lenin's words about the unusual and seemingly "strange" discoveries in the physics of the microcosm may well be applied to them: "All this is but another *corroboration* of dialectical materialism."[1]

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 262.

The Principle of the Unity of the World and the Principle of Development in Modern Astronomy

All the varied methods of studying the Universe are ultimately based on two vital philosophical principles–the principle of the unity of the world and the principle of development.

Both of these principles are, naturally, not applied in astronomy (as in other sciences) in their general philosophical form, in which they are abstracted from concrete content. They are modified in accordance with the specific features of the objects under study. The first of these principles substantiates the possibility, the necessity and the justifiability of extending physical laws and theories to various cosmic objects, whereas the second postulates an evolutionary approach to these objects, whose structure proves to be conditioned by their origin and development.

The structure of cosmic systems in 17th-19th-century astronomy was studied without regard for their development, while cosmogony, largely isolated from other branches of astronomy, proceeded mainly from speculative assumptions, yielding mostly hypothetical and extremely vague results. All this was due to the specific difficulties of studying cosmogonic phenomena, and to the absence at the time of sufficient empirical data on change in the Universe as well as on the possible past and future states of cosmic systems.

The unity of the world was virtually reduced to the statement of the universal nature of the laws of classical mechanics, their applicability to any object in the Universe and to the Universe as a whole ("all matter"), and the uniformity of phenomena in different parts of the Universe; some astronomers even expressed the view that the structure of cosmic systems of different orders was identical. The idea of development in astronomy first took the form of mechanistic evolutionism. In accordance with a tradition going back to the theories of the ancient philosophers, cosmic bodies and their systems were believed to have emerged through condensation of rarefied matter, all their subsequent states being almost stationary and their evolution consisting in a slow and gradual transition from one stationary state to another. The concrete form originally assumed by the ideas of the unity and development of the world was limited by the level attained at the time; it determined both the general approach to the study of the Universe and, in the final analysis, the theoretical conclusions concerning the structure and evolution of the Universe obtained on the basis of that approach.

The rapid progress of astronomy within the last few decades demonstrated the limitations of the old conceptions of the Universe and also required a radical revision of methodology that was based on mechanistic principles.

Analysis of a huge and ever increasing body of data on cosmic systems suggested the enormous qualitative variety of physical conditions and phenomena in the Universe which could not be squeezed into the narrow mechanistic framework. At the same time, the study of non-stationary phenomena in the Universe demonstrated that a profound investigation of the structure of cosmic objects was only possible after consideration of their evolution, which determines the characteristics of these objects in their contemporary state.

A description of many new phenomena discovered by present-day astrophysics was provided by new and fundamental physical theories–quantum mechanics and the theory of relativity. It was tempting to regard these theories as capable of describing the entire totality of astrophysical phenomena, both the well-known and the yet undiscovered, since the heavenly bodies consist of the same elementary particles with which the physics of the earth deals. Essentially, it was the old story all over again: the view was reaffirmed that an infinite number of natural phenomena may be described by a limited number of fundamental physical theories; this time it was the theories of modern physics. The proponents of these views assume, for example, that galactic phenomena do not constitute anything qualitatively new as compared with the phenomena in smaller-scale systems. The inference is drawn, in particular, that modern physical laws and theories can explain all stages of cosmogonic processes, including the origin and development of the planets, stars, galaxies and even the metagalaxy.

But present-day astronomy also knows a completely different interpretation of the unity and development of the world. Essentially, it is the view that there are specific structural and evolutionary laws corresponding to every level of the material world. Although cosmic objects consist of the same elementary particles as those with which the physics of the earth deals, space may lend significance to such "intimate" properties of elementary particles that are either unnoticeable or do not manifest themselves at all on the earth. Fundamental physical theories, both the well-known ones and those that have yet to be created by physics, have a domain of applicability that is in principle limited, i.e. they are universal only relative to a definite sphere of phenomena. It follows that we must take into account the possibility (and the necessity) of their revision–specification and generalisation–while investigating new domains of the material world. This does not mean that the possibilities of the existing, "old" theories will ever be completely exhausted: they still contain many and various surprises. Nevertheless, further development of physics and astronomy from this point of view will involve the formulation of fundamental theories of an ever increasing degree of generality. In other words, the principle of the unity of the world should be interpreted dialectically. This unity is inseparable from the infinite variety of the material world. The conception that the infinite variety of phenomena which astrophysics studies now and will be able to study in the future may be described by a limited number of physical laws and theories is unadequate. A more fruitful idea is that nature is multiform at the level of laws as well.

It has also become clear that the laws of the development of the object at any structural level of the organisation of matter may be conditioned by factors that are little noticed in the consideration of stationary, steady states of the object, so that attention should be focused on the search for, and the study of, non-steady states of cosmic bodies in which comparatively fast changes take place.

The differences in the interpretation of the principles of

the unity and development of the world as revealed in modern astronomy resulted in the devising of extremely diverse methodological approaches to the study of the Universe and ultimately in the elaboration of cosmological, astrophysical and cosmogonic theories diametrically opposed in their content.

In cosmology, the first of these approaches consists in constructing various uniform and isotropic "models of the Universe" corresponding to various partial solutions of the equations of the general theory of relativity and in the study of their behaviour in time. These models are then compared with observation data and modified on the basis of new factual data.

The view is sometimes expressed that relativistic cosmological models originally appeared as the product of pure "play of the intellect", completely independent of any empirical data, and that empirical justification was found for them only later. This opinion, is, at best, imprecise. The application of the mathematical hypothesis method in cosmology–as in physical knowledge in general–does not deliver us from the need to use empirical data, and not just "in the final analysis" or as a final check on the correctness of the theory. Einstein himself on more than one occasion emphasised that relativistic cosmology emerged as an attempt to correlate the general theory of relativity with a number of facts and hypotheses resulting from observation.

His work was largely stimulated by the fact that Newton's theory of the Universe had run into some unpleasant paradoxes that it could not overcome. Hence, the application of relativistic theory in cosmology was not only justified, but inevitable. Einstein further pointed out that the mean density of matter in space does not equal zero, which raises the question: can this hypothesis prompted by experience be correlated with the general theory of relativity? Einstein believed that stars were uniformly distributed in space. Proceeding from this assumption, he regarded the structure of the Universe as uniform and isotropic (matter is uniformly distributed in space, with a constant mean density, its properties and behaviour at any given moment are identical at all points and in all directions). This hypothesis, later called the cosmological principle or cosmological postulate, permits a considerable simplification, since the indivisible spatio-temporal continuum is split into ordinary three-dimensional space and universal cosmic time.

Finally, it was the empirical fact that the velocities of stars are insignificant compared with the velocity of light that made Einstein modify cosmological equations by introducing a special constant (the so-called Λ-member) that did not follow from the theory; originally its only purpose was to make the Universe static. Einstein was, apparently, not acquainted at first with the work of V. Slipher concerning the "red-shift" in the spectra of nebulae which later were proved to be other galaxies. Through these investigations, conducted in 1912-1914, it was discovered that the spectral lines of many nebulae, whose nature was at the time the subject of acute debate, were shifted towards the red end as compared with their normal position. In the early 1920s the "red-shift" was detected for dozens of nebulae.

The most natural explanation of this phenomenon was by the Doppler effect. It followed that the nebulae were receding from us at fairly high velocities: the greatest velocities reach values in the neighbourhood of 1,000 *km/sec.* In 1924-1926 E. Hubble proved that these nebulae were stellar systems, similar to our galaxy, pertaining to a system of a higher order–the metagalaxy. In 1929 E. Hubble and M. Humason established that the "red-shift" is approximately proportional to the distance of galaxies from us. Later the presence of the "red-shift" and its approximate proportionality to the distance were confirmed for many hundreds of galaxies and other extragalactic objects. The greatest of all recession velocities discovered by now is greater than 240,000 *km/sec,* i.e. 0.8 of the velocity of light!

When relativist cosmology was created (1917), Slipher's work was only known to a few specialists. However, even before the theory of "expanding Universe" was constructed, Einstein more than once discussed papers containing references to V. Slipher's results. One can only assume that he knew of the "red-shift" effect in the spectra of nebulae, but

did not attach to it any special significance: if that were not the case, his desire to construct a model of a static Universe would have little empirical motivation.

A. A. Friedman,[1] who in 1922-1924 showed that the solutions of the general theory of relativity are, generally speaking, non-stationary (or rather that the theoretical Universes corresponding to these solutions are non-stationary), proceeded primarily from the inner logic of the development of relativist cosmology itself. But his work cannot be regarded as purely speculative as he makes use of the same factual data that were analysed by Einstein and that were in essence quite sufficient to warrant the conclusion as to the non-stationary nature of the Universe. The behaviour of the "model of the Universe" at $\Lambda = 0$ is determined, according to A. A. Friedman, by a certain critical value of the mean density of matter: if the density at a given moment is greater than the critical value, the model is alternately expanded and condensed (oscillating, or pulsating models), but if the density equals the critical value or is less than that value, the model is expanded without limit (monotonously expanding models).

A. A. Friedman's conclusion regarding the non-stationary nature of the theoretically possible Universes (worlds) which he had considered did not attract the scholars' attention at once. And that was not only because A. A. Friedman's work was not sufficiently well known; this result seemed too strange or at any rate requiring serious confirmation even to those who knew Friedman's work. It seemed "suspicious" to Einstein, too, but he later admitted his error. In 1927 the Belgian mathematician G. Lemaître developed A. A. Friedman's theory in detail; he came to the conclusion that matter from which the metagalaxy emerged must have been in a superdense state and represented a kind of "primitive atom", the beginning of the expansion being of an explosive nature.[2]

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[1] See A. A. Friedman, "On the Curvature of Space"; "On the Possibility of a Universe with a Constant Negative Curvature of Space"; "The World as Space and Time"; *Selected Works,* Moscow, 1966.

[2] *G. Lemaître, L'hypothèse de l'atome primitif,* Neuchâtel, 1946.

A. A. Friedman's theory was, undoubtedly, a major step forward as compared to Newton's cosmology. Observation confirmed the theoretically deduced conclusion as to the non-stationary nature of the metagalaxy and its apparent explosive origin. But the empirical confirmation of *some* of the inferences from A. A. Friedman's theory does not mean at all that the *whole* of the theory with all its assumptions and idealisations is reliably substantiated. The "models of the Universe" built on the basis of A. A. Friedman's theory are only the first attempts at a mathematical description of an expanding metagalaxy, oversimplified and as yet not fruitful enough.

The development of a general theory of the metagalaxy until recently was hindered by the lack of factual material. For example, the empirical estimates of mean mass density in the metagalaxy are as yet extremely imprecise. Some of them are higher than the "critical" density (2×10^{-29} g/cm^3) by an order or two, others, somewhat better substantiated, yield values less than the "critical" density, still others, values close to the "critical" density. The proponents of the theory of a uniform isotropic Universe, therefore, disagree not only about the choice of the "model of the Universe" to be preferred, but also about the type of models (monotonously expanding or oscillating) which better corresponds to reality.

Although, on the one hand, many uniform isotropic "models of the Universe" are formally unimpeachable and, on the other hand, the empirical data now available are limited, it is already clear that the basic assumption on which these models are built–the cosmological postulate–is very remote from the actual conditions in the metagalaxy. The research of the recent decades has shown the justifiability and the urgency of considering not only the simplest solutions of the equations of the general theory of relativity involving the assumptions of uniformity and isotropy, but also less trivial solutions realising more interesting and in some cases more "extravagant" possibilities allowed by these equations. It became clear as the result that many inferences of the theory of the "expanding Universe" are not absolutely reliable. In particular, taking into account the possible deviations from isotropy and uniformity, it may be shown that the velocity of metagalactic expansion may be different in different regions and the expansion of some spatial volume in one region may be accompanied by its compression in the neighbouring region. Hence the uniform expansion of the metagalaxy "from a point" must be regarded as an idealisation that is too strong and unjustified. The volume of the metagalaxy at the starting point was, probably, comparatively small, but greater than zero, and the initial density of matter very high, but by no means infinite.

The discovery of the "relict radiation" predicted on the basis of A. A. Friedman's theory, if the current interpretation of it is confirmed, may mean that in the past the density of matter in the metagalaxy was a milliard times greater than it is now. But we cannot say as yet whether it was even much greater than that. Further observations must reveal that.

Furthermore, the concept of one-valued (uniform) world time introduced in the theory of the uniform isotropic Universe proves to be applicable only within fairly limited bounds in the theory of the anisotropic non-uniform Universe (e.g. in the version developed by A. L. Zelmanov). That means that the concept of a state at a given instant of time is strictly speaking inapplicable to the metagalaxy as a whole; accordingly, the evolution of the metagalaxy cannot be viewed as a succession of changes of states. Finally, one may adduce the fairly well substantiated empirical data indicating extreme non-uniformity of the distribution of matter in the metagalaxy. This is a particularly convincing proof of the need to reject the cosmological postulate as an oversimplification.

Further development of the theory of structure and evolution of the metagalaxy must follow the path of establishing ever closer links between this theory and observation data now rapidly increasing in volume. When observation provides sufficiently ample factual data on the distribution and motion of masses in the metagalaxy, we shall be able to introduce real and not arbitrary conditions in the cosmological equations as well as look for other, more exact equations.

These two approaches to the study of the Universe can be brought into even greater relief in astrophysics and cosmogony.

In astrophysics numerous models of the inner structure of stars of various types have been evolved on the basis of the first of these approaches. Founded on simplified but, nevertheless, apparently reasonable assumptions, these models may in a number of cases be more or less successfully correlated with some of the known factual data on the various characteristics of stars. But despite the enormous amount of work done in this direction, the modern theory of the inner structure of stars has not yielded any predictions of fundamentally novel phenomena that would later be discovered by observation, although astrophysics literally overflows with unexpected discoveries. On the other hand, after the new facts had been discovered, it was usually possible to correlate them with the theory by the addition of more or less arbitrary hypotheses. All of this significantly decreases the value of the models of the inner structure of stars that have been evolved until now and proves their inadequacy. Even more serious were the difficulties involved in the development of various cosmogonic theories and hypotheses within this approach (of which the most popular was the theory mostly based on the work of F. Hoyle, J. Oort and M. Schwarzschild).[1]

This proved that the method of constructing astrophysical and cosmogonic theories had to be changed. The study of the structure and evolution of cosmic objects had to be conducted on the basis of *consistent generalisation* of observation data (the more so that the results of the research very often prove to be qualitatively new and "unexpected"). Only later should we set ourselves the task of constructing a theory explaining them.

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[1] F. Hoyle, *Frontiers of Astronomy*, Melbourne, 1956; *Galaxies, Nuclei and Quasars*, New York, 1965; J. Oort, "The Structure and Evolution of the Galactic System", *Zemlya i vselennaya*, Nos. 2, 3, 1965; M. Schwarzschild, *Structure and Evolution of the Stars*, Princeton, 1958.

It is necessary first to establish with a sufficient measure of confidence just *what* happens in the process of cosmic evolution; this task is in itself very complicated, difficult and often time-consuming. Attention should be focused on empirical data in which traces of cosmogonic processes are revealed with greatest clarity.

Firstly, these are non-stationary objects; their great role in cosmic evolution was prompted by the dialectical materialist concept of development. As is well known, Lenin paid special attention to the source of development in characterising the dialectical materialist conception of development. He emphasised that all phenomena in the world represent a unity (identity) of opposites. That means "recognition (discovery) of the contradictory, *mutually exclusive*, opposite tendencies in *all* phenomena and processes of nature...".[1] Each of the opposite sides of the single whole is capable of becoming its own opposite, the opposites are transmutable; the interaction or "struggle" of the opposites is the source of development.

The dialectical materialist proposition concerning inner contradictions as the source of development helped to comprehend the significance of non-stationary objects in the Universe as *law-governed stages* in cosmic evolution playing a decisive role in it. They are the *turning points* in the history of cosmic bodies and systems linked with their transition from one state to another or, as was found out later, with the emergence of new bodies; here we can observe directly the processes of changes of their states. Further research in this direction permitted predictions about many non-stationary phenomena in stellar systems, including those that were regarded by many as a complete surprise. They opened the way for a more complete understanding of various cosmogonic processes.

Secondly, valuable information about the nature of cosmogonic processes is provided by facts about non-uniformities in the spatial distribution of cosmic objects, e.g. stars and galaxies, as evolutionary changes in stellar groups and

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[1] V. I. Lenin, "On the Question of Dialectics", *Collected Works*, Vol. 38, pp. 359-60.

conglomerations, and in groups and conglomerations of galaxies may be traced with great reliability by the methods of the statistical mechanics of stellar systems. Of course, these (just as any other) factual data do not contain in themselves a one-valued physical theoretical interpretation. A generalisation of these data is impossible without the introduction, when required, of various physical hypotheses, construction of models, etc. And yet, generalisation of these data permits the study of change in various cosmic bodies and their systems that does not proceed from too arbitrary or doubtful assumptions.

Thirdly, factual data concerning objects of one and the same type at various stages of their development also merit special attention. For example, evolutionary interpretation of the Hertzsprung-Russell diagram of stellar states is of considerable value for comprehending the processes of stellar evolution. But the various stellar states on the Hertzsprung-Russell diagram may be arranged in an evolution series (or a number of evolution series) on the basis of different and even mutually exclusive hypotheses; to choose between them, we have to use data that are not contained in the diagram (e.g. the results of stellar statistics). Thus, empirical evidence about stellar evolution contained in the Hertzsprung-Russell diagram is of a circumstantial nature; a reliable "breaking of the code" involved is far from a simple affair.

Analysis of empirical data on the changes observed in cosmic bodies and their systems permits the formulation of substantiated hypotheses concerning the mechanism and physical essence of processes causing changes observed. These hypotheses about separate changes, prompted by empirical data—as distinct from all sorts of speculative schemes—are a most important part of theoretical interpretation of various phases of cosmogonic processes. They may help to construct their sufficiently adequate models and in the final analysis construct a substantiated theory of these processes. The guideline at all stages of constructing such a theory should be the results of generalisation of factual data. In constructing theories of various cosmogonic processes through

generalisation of factual data we should not neglect the difficulties arising from attempts to explain the studied phenomena on the basis of old conceptions. On the contrary, by concentrating on these difficulties and assessing them, we must analyse the possibility of having encountered qualitatively new phenomena and try to determine the direction in which familiar notions must be changed accordingly.

Thus, the study of the structure and evolution of cosmic systems must as a rule begin with the solution of separate particular problems which do not require the introduction of arbitrary hypotheses, i.e. with the study of elementary cosmogonic processes; after sufficiently numerous and reliable conclusions about the laws governing such processes have been accumulated, it will be possible to proceed to the study of the evolution of cosmic systems as a whole.

Investigations based on a systematic application of this approach to stellar cosmogony began originally at Leningrad University in the 1930s and continue now at the Byurakan Astrophysical Observatory.

Analysis of factual data on the stationary or non-stationary nature of stars and stellar groups of the galaxy has shown that our galaxy, in contrast to the generally accepted views, is a system where turbulent and at times swift changes occur.

Application of stellar dynamics principles to open stellar conglomerations resulted in the conclusion that, even if such conglomerations are in a "stationary" state, they should evaporate, as it were, as a result of stellar interaction. In the course of time individual stars leave the conglomeration just as molecules on liquid surface do. As a result of this process, many conglomerations will disappear within just a few hundreds of millions of years, and some of them, within dozens of millions of years.[1]

The same analysis was applied to the totality of double stars of the galaxy. It transpired that the decay of wide stellar couples resulting from their encounters with the stars of the surrounding field prevails over the appearances of

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[1] See V. A. Ambartsumyan, "Cosmogony and Modern Astrophysics", *Scientific Papers*, Vol. 2, Yerevan, 1960 (in Russian).

new couples through stars coming together accidentally. The number of solitary stars in the total stellar field of the galaxy grows steadily owing to the decay of conglomerations and of double stars, the process developing in one direction only. Thus, decay and diffusion, in complete accordance with the second principle of thermodynamics, characterise the *general direction* of processes in our galaxy and, as later turned out, in other galaxies as well.

The establishment of these facts also permitted the formulation of the "short scale" concept in determining the age of the galaxy and of constituent stars. According to the "long scale" accepted in the early 1930s, the age of the stars of the galaxy was assumed to be 10^{12}-10^{13} years. But the discovery of the inevitable decay of stellar groups and conglomerations within relatively short periods proved that the age of the galaxy in its present state cannot exceed (in the order of magnitude) 10^{9}-10^{10} years.

As for the idea of stellar systems and stars being formed from rarefied gas, it became ever more definitely clear, in the 1940s-1950s, that it lacked the necessary observational basis, was essentially arbitrary and to an extent had even become a prejudice. We may point out three groups of indirect, but very distinct proofs indicating that the initial state of matter out of which cosmic objects developed was a dense or superdense and not rarefied state, and that they were formed through disintegration, decay, explosion and not through gradual and slow condensation.

The first group of facts pertains to stellar associations—recently emerged groups of stars decaying immediately after their birth.[1] These systems mostly proved to be nonstationary in the true sense of the word, since the constituent stars rapidly move away from each other. They could not have been formed directly from the diffuse matter as a result of gravitational instability, since the stellar group originating in this way would be stationary in any case. An explanation of the observed features of the associations that would not be too far-fetched or contradictory is only possible if we assume that the protostars are bodies of quite a different nature than nebulae or ordinary stars. These bodies must have great masses and comparatively small radii, which testifies to their high density. Protostars must contain enormous amounts of potential energy. When they break down, "fragments" appear whose mass is of the order of the mass of a star. These "fragments" are not stable and quickly become stars. The remaining mass of the former protostar forms a nebula. Part of the potential energy contained in the protostar turns into the kinetic energy of the expansion of stellar groups and associated diffuse nebulae.

This hypothesis does not involve the construction of any theoretical models of the protostars, neither does it consider the concrete mechanism of their transformation into stellar groups and conglomerations. The properties of prestellar matter are, probably, so peculiar that it will be difficult to explain them on the basis of contemporary knowledge of elementary particles. First, we must find various external manifestations of properties of prestellar matter, accumulate as much factual data about them as possible and study their laws. Only then will it be possible to make well-founded conclusions about the nature of protostars.

There are grounds to believe that the description of star formation will require a generalisation of some fundamental laws of physics in their contemporary form, e.g. the torque conservation law and, perhaps, even the law of conservation of energy. As the history of the law of conservation of energy shows, physics has on more than one occasion encountered violations of this law *in its concrete form* restricted to types of energy known at the given time. The need thus arose for a generalisation of the law of conservation of energy, for extending it to ever new, previously unknown kinds of energy, which resulted, accordingly, in the development of the very concept of energy in physics. Suffice it to remember, for instance, the formation of the concept of the mechanical equivalent of heat, the introduction of the concept of the rest energy of a body in the special theory of relativity, etc. With each such generalisation the idea of conser-

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[1] See V. A. Ambartsumyan, "Evolution of Stars and Astrophysics", *Scientific Papers*, Vol. 2.

vation of energy was extended to a wider than hitherto known class of magnitudes.

Apparently, the same should be expected of the further study of the formation of galaxies and stellar conglomerations. At first, there were some grounds to believe that the unusual properties of protostars and possible violations of the familiar laws of physics were due to the superdensity of protostars. At present it seems more probable that the cause is not so much the superdensity of protostars as their giant mass.

The second group of facts conducive to the belief in the existence of massive and dense protostars is associated with stellar evolution. It was found in 1954 that considerable quantities of energy are emitted in the atmospheres of some types of stars (e.g. "flaring-up" variable stars), the process being discrete in nature: the energy is emitted all at once, as in an explosion, and not gradually. Analysis of this phenomenon, which cannot be explained in the generally accepted view of thermonuclear reactions within stars, induces the conclusion: thermonuclear reactions are not the main source of energy for all types of stars and at any rate are not the only source of stellar energy.[1] The observed phenomena can be explained if one assumes that the inner regions of stars contain remnants of "prestellar" matter; in some way or other it may reach the superficial layers of the star or the regions outside it (the transference of energy occurs in discrete portions), where it is released causing a flare-up.

Finally, the third and the most convincing group of facts revealing traces of the dense or superdense initial state refers to unstable groups and conglomerations of galaxies and also to non-stationary phenomena in the nuclei of galaxies, where we observe various forms of activity. It was established in particular that radiogalaxies are distinctly non-stationary objects which can emit radio waves only within short spaces of time insignificant in comparison with the age of galaxies. They are not colliding systems, as almost all astrophysicists

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[1] See V. A. Ambartsumyan, "The Phenomenon of Continuous Emission and the Sources of Stellar Energy", *Scientific Papers*, Vol. 2.

at one time believed. On the contrary, we are dealing here with the division of the galactic nucleus into parts or with powerful explosions in dense nuclei.[1]

Radiogalaxies are only one form of manifestation of the activity of galactic nuclei. Other forms of activity have been discovered in the nuclei of some supergiant galaxies. The facts bear evidence that nuclei actively participate in the formation of their own galaxies.

What are the nuclei of galaxies? What is the mechanism of the enormously powerful processes that occur in them from time to time?

All of the described phenomena involving the activity of galactic nuclei would be impossible if the nuclei consisted only of stars and diffuse matter. The view was, therefore, formed in 1955-1957 at the Byurakan Observatory to the effect that galactic nuclei contain small-sized bodies that exceed the mass of ordinary stars by many orders and are different in their physical nature from stars and diffuse matter. These very dense and probably superdense bodies are a new form of matter perhaps completely unknown to modern physics. They are capable of division into parts moving away from each other at great velocities, and of emitting massive clusters of matter. To do that, they must contain vast quantities of energy in potential state. An explosion of the nucleus results in the formation of new galaxies or, in other cases, of various stellar subsystems in the galaxies. Part of the energy released in the explosion of the nucleus is transformed into the kinetic energy of the objects that are formed. It is as yet difficult to suggest a concrete physical mechanism for these processes.

Further development of this theory led to the conclusion that whole groups and conglomerations of galaxies, not just couples of galaxies, could emerge as a result of explosions in the nuclei. When groups emerged, only dense "embryos" of galaxies appeared first, which had been formed through simultaneous or successive division of a massive dense body.

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[1] See V. A. Ambartsumyan, "On the Evolution of Galaxies", *Scientific Papers*, Vol. 2.

In the division the embryos received great velocities. Moving away from each other, each of them formed a galaxy of its own, becoming its nucleus.

Observation directly indicates the ability of the dense or superdense matter of the nucleus to contain great supplies of energy till the next explosion. Can this property of the nucleus be explained by the known laws of theoretical physics? Although we do not yet know how to do it, the possibility of constructing a model for the galactic nucleus with observable properties on the basis of known laws of theoretical physics is not entirely ruled out. If this proves to be impossible, the conclusion will follow inevitably that the laws of theoretical physics in their present form are inapplicable here. This possibility seems not only very probable, but even not at all surprising, as the form of basic physical laws accepted at present is undoubtedly not final. For example, under conditions prevailing in galactic nuclei or in the centre of quasistellar radio sources these laws may prove to be inapplicable and will have to be subjected to further specification and generalisation, which will only increase their significance and widen the sphere of their applicability.

Indeed, the laws of physics are essentially a generalisation of a definite set of factual data expressed in the most simple and short form possible. But we must not think that the system of laws of theoretical physics obtained at some definite stage in the development of science is absolutely precise, final and not subject to further generalisation. These laws constitute only an incomplete and approximate reflection of objective reality, therefore they may, nay, must be subjected to specification and generalisation. (Specification and generalisation of laws of nature is usually an indivisible process. For instance, the transition from classical mechanics to the special theory of relativity was a specification of classical mechanics and at the same time a generalisation of it for great velocities.)

This view rests on the analysis of the development of modern natural science, which in the course of time discovers an ever increasing variety of new, hitherto unknown phenomena fundamentally different from anything which it

had previously dealt with. On many occasions we have had to generalise physical laws and theories to explain factual data characterising phenomena sharply differing in the qualitative aspect from phenomena that served as the basis for the formulation of the system of physical laws available at the given moment. Just such a need arises in the study of non-stationary processes in galactic nuclei and quasistellar objects. Never in the past did physics and astronomy have to deal with concentrations of such great masses in relatively small volumes. We are dealing here with masses of the order of 10^{10} (and sometimes more) of sun masses concentrated in volumes many times smaller than the volume of any stellar conglomeration. We are dealing here with transformations of matter in which density changes by a factor of milliards and the gravitational field strength may reach unheard-of values. There can be no guarantee that the physical laws we know will hold for these conditions, too. And it will not be at all surprising if it turns out that the data now available on non-stationary processes in the Universe, which present considerable difficulties for theoretical explanation, may in the course of time lead to direct contradiction with the known laws of theoretical physics.

An attempt at a mathematical description of some of such processes was undertaken by the West German physicist P. Jordan.[1] He believed that his theory describes the origin of stars. In actual fact it is, probably, more applicable to the problem of the origin of galaxies. (This shows that Jordan's work is of a fairly formal nature and not all of the physical ideas developed in it are clear. Besides, we cannot agree with some philosophical propositions put forth by Jordan in discussing these problems.)

Non-stationary phenomena in the Universe are revealed with increasing sharpness in the transition from stellar associations to galaxies, their groups and conglomerations and, finally, to the metagalaxy accompanied by the appropriate release of increasingly greater quantities of energy. In other words, a whole hierarchy of explosions, disintegrations and breakdowns exists. The expansion of the metagalaxy may

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[1] P. Jordan, *Schwerkraft und Weltall*, Braunschweig, 1955.

also be considered as the result of conjoint formation of a great number of galactic conglomerations (to be more precise, of "nuclei" or "embryos" whose fragmentation resulted in galactic conglomerations) through an explosive process. These phenomena should be completely incomprehensible within the conceptions postulating the formation of stars and stellar systems from rarefied gas.

Indeed, the existence of non-stationary groupings appeared to be so extraordinary from the "orthodox" point of view that doubts were frequently expressed concerning first the reality of stellar associations and later their non-stationary character. And only after the expansion effect was fully confirmed for at least some stellar associations and the idea of stellar associations as sources of star formation in the galaxy was generally accepted, attempts were made to explain the disintegration of stellar associations on the basis of classical ideas. All of them, however, proved to be of little effect.

A distinctly non-stationary character of many groups and conglomerations of galaxies is also incomprehensible within the hypothesis of their formation from rarefied gas: if galactic conglomerations had been formed in this way, they would be stationary. Numerous attempts to save the hypothesis by rejecting the non-stationary nature of groups and conglomerations of galaxies proved of no avail.

Even greater difficulties were caused by the problem of cosmogonic interpretation of radiogalaxies and quasars. When the interpretation of radiogalaxies as colliding stellar systems proved to be erroneous and factual data were obtained that made scholars accept the hypothesis about the presence in galactic nuclei of non-stellar bodies which sometimes explode, and when quasars were discovered, the proponents of classical conceptions explained explosions in galactic nuclei not as the result of release of energy contained in the nucleus (i.e. in terms of a new, hitherto unknown property of matter), but in terms of gravitational collapse–a catastrophic compression of originally rarefied matter effected by gravitational force accompanied by the release of enormous quantities of gravitational energy .

During several years literally hundreds of theoretically possible variants were considered in an attempt to explain just how gravitational energy released during collapse could be transformed into a most powerful optical and radio radiation of quasars. A satisfactory solution of this problem was not found, however. Each of the solutions suggested ran into some theoretical difficulties and its untenability became clear fairly soon. The basic idea of these hypotheses–the idea of gravitational collapse–lacks any empirical confirmation and proves to be inadequate in explaining fantastic quantities of energy released in quasar explosions.

It may be added that all attempts to explain the transition from the superdense initial stage of the metagalaxy to rarefied gas and the appearance of density fluctuations in it, which could result in the formation of galaxies, stars, etc. proved fruitless.

In the light of the views developed at the Byurakan Observatory the difficulties of revealing the mechanism of transition from the superdense initial stage of the metagalaxy to rarefied gas are not at all surprising, because the very presentation of the problem is unjustified. It is much more natural to regard the evolution of the metagalaxy as the process of fragmentation of dense or superdense matter accompanied by the formation and subsequent scattering of diffuse matter. It is difficult to give a theory of the initial stages of this process for the same reasons which make it as yet impossible to develop a theory of star formation or a consistent theory of cosmogonic activity of galactic nuclei. The difficulty lies here not only in the lack of factual data, but also in the fact that an adequate description of the state of matter at very high densities and of the mechanism of transformation of this matter into observable cosmic objects may require a generalisation of contemporary physical theories for the case when quantum, relativist and gravitational phenomena are equally essential.

Thus, as distinct from the astronomy of the 18th-19th centuries, in which the ideas of the unity of the world and its development were often applied, first, unconsciously, and second, independently of each other, these ideas in modern astronomy, applied together, have become the most important methodological principles of investigation. All this proved the extreme fruitfulness of Lenin's idea that "the universal principle of development must be combined, linked, made to correspond with the universal principle of the *unity of the world*, nature, motion, matter, etc."[1] This idea lies at the base of any of the modern approaches to the study of the Universe.

Revolution in Modern Astronomy

The current transition from one level of knowledge about the Universe to another and a deeper one, with its attendant radical breakdown of many familiar concepts and their replacement by unexpected and unusual ones, and a painful and contradictory search for a new theoretical language more adequately reflecting objective reality, may with complete justification be viewed as a revolution in astronomy.

The starting point of the present-day revolution in astronomy was a deep crisis of former conceptions: their profound inner contradictions and contradiction to the empirical data. The new ideas were first put forth on the basis of an extremely limited number of facts pertaining to the non-stationary processes in the Universe, some of which had been known earlier as well, but were now interpreted in a radically new manner. These conceptions are as yet schematic and simplified. They permit an explanation, and a qualitative one at that, of only a small part of amazing phenomena discovered by modern astronomy. This is usually the case at a stage when new conceptions have not yet formed a consistent theory, while the swift tide of new facts and observations does not permit a return to old theories.

New conceptions in astronomy are partially formed in the language of old concepts and ideas; it will not be possible to get rid of them at once, and new conceptions in astrophysics, cosmogony and cosmology will be more fully substantiated only in the future.

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[1] V. I. Lenin, "Conspectus of Hegel's Book *Lectures on the History of Philosophy*", *Collected Works*, Vol. 38, p. 256.

The development of modern astronomy shows that it would be unjustified to consider it as just another "applied" sphere for physical theories that holds no promise of anything fundamentally new for physics. On the contrary, now, no less than in the age of the Renaissance and the Enlightenment, astronomy offers us countless surprises increasingly strange not only from the point of view of common sense, but also of the theoreticians of modern physical science who, it would seem, have seen everything and have lost the ability to be surprised by anything. The "curiosity chamber" of physical knowledge is almost every year enriched with ever more surprising objects posing before theoreticians ever more difficult and complicated enigmas.

The facts already known warrant the view that the basic problems of modern astronomy may prove to be fundamental and their solution will involve, in one way or another, a radical revision of a number of important concepts of modern physics. The "surprises" of modern astronomy may turn out to be the source of new and most profound ideas and even the source of a new revolution in the entire system of physical knowledge.

Thus, despite the fairly popular view that there is only one extreme sphere of research in the entire domain of physical sciences which may be a real source of revolutionary changes in our basic physical concepts (the physics of elementary particles), it is becoming ever more apparent that there are two such spheres—the physics of elementary particles and astrophysics which may be just as useful for theoretical physics as the study of the microcosm.

Further development of the revolution in modern astronomy will doubtless entail a great number of discoveries even more unusual and striking than the ones made hitherto. "Human reason has discovered many amazing things in nature and will discover still more, and will thereby increase its power over nature."[1]

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, pp. 281-82.

Part III

PHILOSOPHICAL AND METHODOLOGICAL PROBLEMS OF THE BIOLOGICAL SCIENCES

V. A. Engelgardt

THE PROBLEM OF LIFE IN MODERN NATURAL SCIENCE

GENERAL APPROACHES TO THE DEFINITION OF THE ESSENCE OF LIFE

Of all the problems that have always seemed most tantalising to those attracted to the mysteries of nature, the problem of the essence of life–one of the most difficult problems in the cognition of the world–has, since antiquity, appeared as attractive and awesome as it was unapproachable. Socrates' "Know thyself" refers to the cognition of the highest level attained by the animate world in its development–the sphere of human thinking and behaviour. But this knowledge clearly presupposes sufficient information about the very fundamentals of the existence of living beings. In the final analysis, it must start with the question: What is life?

The mystery of life has for millennia been the haunting ground of metaphysics, the domain of belief and not of knowledge. The concept of life was inseparably linked with the concept of the soul, with vitalism in its diverse aspects, with the conceptions of the "vital force", Driesch's "entelechy", Bergson's "élan vital", etc., which were regarded as unknowable, thus preparing the ground for agnosticism and various forms of idealism.

All of these conceptions, different as they were in detail, were based on the proposition that living beings and life processes could not be explained within ordinary conceptions of determinate dependences. This was stated with particular clarity by a major natural scientist of the latter half of the 19th century, the President of the Berlin Academy of Sciences, Du Bois-Reymond, in a speech on the "seven mysteries of the world"–the greatest problems of the natural sciences. He regarded four of them as being transcendental, outside the reach of cognition, and these include problems relating to living matter. It was these enigmas that Du Bois-Reymond had in mind when he proclaimed his "Ignorabimus" ("We shall never know"), which later became famous as the motto of agnosticism.

It is interesting to compare this motto with the words of an outstanding scientist and a consistent materialist, J. D. Bernal, the founder of a leading trend in molecular biology: "Life is beginning to cease to be a mystery and becoming practically a cryptogram, a puzzle, a code that can be broken, a working model that sooner or later can be made."[1] These words contain an extremely clear exposition of the methodological principles of modern natural science with regard to the problem of life. Although the proposition cited above stresses the solubility of the problem in principle, it does not indicate just how far we have succeeded in solving the "puzzle" and whether there is already an approximate answer to the most cardinal question: what is life?

We have to admit that it is as yet impossible to give such an answer conforming to modern requirements. It would have to reveal the essence of life, its nature, and to permit of an unambiguous differentiation of life and non-life; it would serve as the basis for the definition of the concept of "life".

A review of the numerous attempts to define the concept of "life" would require an inordinate amount of space (and the result would not justify expenditure). The range of such attempts is extraordinarily wide, and it will suffice here to cite a few widely differing examples to show their diversity.

In the 1930s, the prominent English biochemist N. W. Pirie, famous for his penchant for paradoxical formulations, entitled his contribution to a special collection of papers "The Meaninglessness of the Terms 'Life' and 'Living' ".[2] Bernal described the paper as an "iconoclastic essay".

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[1] J. D. Bernal, "Definitions of Life", *New Scientist*, Vol. 33, No. 528, 1967.

[2] N. W. Pirie, *Perspectives in Biochemistry*, Cambridge, 1937, p. 11.

The reasoning is based on the idea that a sharp line could not be drawn between living and non-living objects. We shall return to this point later on.

This definition may be contrasted with the definition of life given by Bernal himself in the paper cited above. Having presented certain ideas, Bernal says: "All these considerations lead us to what may now be accepted as a provisional, though I hope, improved definition of life: life is a partial, continuous, progressive, multiform and conditionally interactive, self-realisation of the potentialities of atomic electron states."

We shall comment on the Bernal definition later. Let us now consider a work that appeared exactly in the middle of the span of time separating the two statements on the concept of life cited above—E. Schrödinger's book *What Is Life? The Physical Aspect of the Living Cell* (Cambridge, 1945), small in size but rich in content.

Owing to obscurantism displayed in the evaluation of the book, it was in some circles undeservedly condemned. In fact, it was like a stone rolling from the top of a mountain, starting the avalanche of the present-day "biological revolution", and its appearance was in this respect a momentous event.

However, taking as the title the question that has attracted natural scientists (and not only natural scientists, of course) for a long time, Schrödinger does not return to it in the whole of the book and does not answer it. He restricts himself to defending the thesis that the realisation of life requires "nutrition by negative entropy". This explains the emergence of higher degrees of ordering instead of the trend towards entropy increase required by the second principle of thermodynamics. But the proposition postulated by Schrödinger leaves unspecified the factor lying at the root of this amazing property. There are undoubted grounds for considering this property a *necessary* condition for the appearance and continuation of life, but we certainly cannot view it as *sufficient* for producing the phenomenon of life; Schrödinger himself does not make this inference. According to his conception, the structural features of living organisms, and in particular such important components as chromosomes, should be regarded as aperiodic crystals. This profound and fruitful idea again concerns only the specific feature of living objects, but leaves the question of the nature of life itself unanswered.

Going back to Bernal's proposition, we have to admit that, while many definitions of life have the fault that their criteria are exceedingly narrow (for instance, Bernal himself says elsewhere that life is not a metaphysical conception–it is a strictly ordered structure that may be traced even to the atomic level), in the given case we are dealing with an exceedingly broad definition. States of electrons in the atoms are just as varied in inanimate nature as in living objects, and the properties enumerated in the definition do not permit the construction of a clear picture of even the simplest living object.

The difficulty of solving the problem of the essence of life is, to a considerable extent, due to the absence of an exact and indisputable answer to a seemingly much simpler question which, in the natural course of events, should have been solved before the problem of life was discussed: where is the borderline between life and non-life? What criterion may help to determine whether an object is living or non-living? A few examples, some of which may seem a little naive, will at least reflect the existing difficulties.

If a criminal is guillotined, it is quite obvious that he is dead. But, if blood is pumped through his heart artificially, it may go on beating for hours, just as it used to beat while the man was alive. Moreover, as we now know, a heart may be transplanted into another man (thus lengthening his life). Thus, the organism as a whole may die, but its parts may, under certain circumstances, retain the ability to live for some time. Suppose we go down the hierarchy of biological organisation into the world of microbes and take the cell of an optional anaerobe, i.e. an organism that breathes in ordinary circumstances, but, in the absence of oxygen, it does not die but starts drawing the energy it needs from fermentation processes. The cell has stopped breathing, but–is it alive or not? The answer is clear: it is alive, but its mode of living is different.

We may destroy the cell entirely, e.g. squeeze out of it what the experimenter calls the cell juice under high pressure, but this juice will break down sugar, and form spirit and carbonic acid, i.e. ferment, in other words, cause the same phenomena as the living cell. The question arises: is the juice obtained alive? Here too the answer seems entirely clear: it is not alive; but it is much less clear why not and at what particular time the living object ceased to be living. Or let us take another case: the cell may be broken down, divided into parts–the so-called organelles, e.g. mitochondria, ribosomes, etc. If the required temperature, nutritive medium and other conditions are provided, these particles may perform the same functions as in the live cell over long periods of time–carrying out protein synthesis and ensuring the transformation of energy. Should organelles be considered alive, and if not, why?

If we go one step further down, the difficulty of giving a definite answer to the question of what is life and non-life increases still more. Everyone has heard of viruses. They are biological formations possessing the ability to cause infection. After penetrating a cell, the virus particle multiplies, the cell is in most cases destroyed and the virus particles issuing from it may infect a new cell. Outside the cell a virus particle does not manifest any of the properties which we consider to be the obligatory features of life: no processes of metabolism take place in it, it does not breathe or ferment, it cannot move or multiply, and it does not react to any external stimuli. W. M. Stanley, a major biologist, summed up the paradoxical properties of viruses thus: within the cell the virus behaves like a living creature, and it is stone dead outside the cell.

Essentially the same idea was much earlier expressed by the Russian microbiologist G. A. Nadson, who said that the virus was either matter having the properties of a creature, or a creature having the properties of matter. It must be added that, from the viewpoint of their chemical nature, many simple viruses could be regarded as matter, since they consist of two components only–protein and nucleic acid. Formally, they could be assigned to a category of chemical compounds well known to chemists–the nucleoproteids. But that is the chemist's view of the matter; on the biological plane everything appears quite different: viruses are nothing but intracellular parasites, and the concept of "parasite" is firmly linked with the concept of a living object existing at the expense of another (also living) object. Parasites are unknown in inanimate nature.

Thus, at all levels of biological organisation–from the nucleoproteid level, represented by a virus, to the level of the human organism–we face the impossibility of drawing a rigid boundary between life and non-life. Instead of using an immutable qualitative category, we have a series of gradations imperceptibly approaching a certain boundary that cannot be truly fixed. Hence the possibility of giving a faultless answer to the question "what is life?" still eludes us.

This concrete case brings into full relief the correctness of the principle, emphasised by Lenin, that "dialectical materialism insists on the approximate, relative character of every scientific theory of the structure of matter and its properties; it insists on the absence of absolute boundaries in nature, on the transformation of moving matter from one state into another, that from our point of view is apparently irreconcilable with it, and so forth".[1]

We arrive at the conclusion that science has no definition of the concept "life" covering all its aspects and explaining its essence through concepts that are already known. According to formal logic, to give a definition of a concept is to include it within a broader concept. But at the given level of knowledge it is impossible to find a broader definition that would reflect life in all its fullness and would not be reduced to a simple enumeration of individual characteristics but would reveal its essence behind the external features and manifestations, an essence that is amenable to specification. Thus we are inevitably left with the definition that life is the highest of all the known forms of the existence of matter attained in the process of evolution. The last definition does not contain the epistemological element; it is not the problem of the essence of life that is considered, but rather a classificatory task. But this definition actually entails fundamental consequences, since it decidedly eliminates everything that might have a metaphysical colouring, and rules out all the varieties of vitalist and idealistic views mentioned earlier.

In considering the definition given above, the question immediately arises: what does the higher quality of this form of the existence of matter consist in? In what is this form superior to states of matter in the inanimate world? This superiority is revealed in different aspects. As far as static criteria are concerned, such as the composition and structure of living objects, the diversity of the chemical components and the complexity of chemical structure of the vast majority of the chemical compounds found in living organisms far exceed everything known in the inanimate world. The same is true of the dynamics involved, i.e. the diversity and speed of transformations of kinds of matter. The levels characterising living systems are many orders higher than the levels observed in the inanimate world.

Even the properties listed here suffice to show that matter in the living world is at a higher level of development than in the inanimate world. The most important property of everything living, however, is ordering. Living systems are first of all characterised by a high level of ordering that cannot be compared with that of any known systems of the inanimate world. The principle of ordering embraces all the most important aspects of the material foundation of life. On the molecular and the immediately adjoining supermolecular level, it is revealed in the conformation of macromolecules, in their regular associations in multimolecular complexes, and in successive structures of an increasing degree of complexity leading to morphological organisation. Spatial ordering is accompanied by temporal ordering, which takes the form of ensuring a rigid succession of highly complex transformations of matter in the processes of metabolism underlying all manifestations of life activity. It is the ability of living objects to create order out of the chaotic thermal motion of molecules that constitutes the most profound and radical distinction of life from non-life.

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 261.

The uniqueness of chemical composition and specificity of conditions for the transformations to which substances are subjected in life processes–typical features of life–do not conflict with the peculiar features of phenomena of the inanimate world. These are differences, but not contradictions. The tendency towards ordering, however, has a special status. The living object in this respect is antagonistic, as it were, to the laws governing all nature, although it conforms to them. We may say that, instead of passively submitting to the law of nature, life ensures the possibility of actively counteracting this law, just as in lifting a heavy object we do not violate the law of gravitation, but counteract it.

The tendency towards ordering, towards creating order out of chaos, is simply contradictory to the principle of entropy increase, i.e. the second principle of thermodynamics, discussed by Schrödinger, as was mentioned earlier. It is exactly "nutrition by negative entropy", which he put forward as the most specific property of life. The ability of living objects to counteract the second principle entails a consequence of the utmost importance. Living objects must represent open systems, i.e. they must be able to interact with the surrounding medium and exchange energy with it. Because of this, the contradiction arising from the seeming violation of the second principle is eliminated: local decrease of entropy arising in an isolated living object is accompanied by its increase in the real "living object-environment" system so that in actual fact no violation of the second principle takes place.

If we accept that the present level of the development of natural science does not yet permit of an answer to the basic question of the essence of life, it may be that the question itself is meaningless. A situation might arise here that would in some degree parallel the conceptions of "weightless" liquids and the hypothetical substances that used to dominate physics, when the concept of ether was created to account for the properties of light, the concept of phlogiston to explain thermal phenomena, and the concept of fluids to deal with magnetism and electricity. The need for these hypothetical elements disappeared with increased knowledge

of these phenomena. It is naturally hard to say in advance if a system of concepts similar, for example, to the Maxwell electromagnetic theory explaining the nature of light will ever be found to interpret the nature of life. In any case, we must admit that such a possibility is definitely lacking at the present stage of the study of life.

INVESTIGATING THE ATTRIBUTES OF LIFE

The new feature introduced by modern science into the investigation of life is the vast increase in the amount of information on the elementary foundations of those basic mechanisms which ensure the realisation of the most important manifestations of life activity. We mean here those properties of life that have always been counted among the prime attributes of life, such as the ability to reproduce, the phenomenon of heredity, metabolism, motion, transformation of energy, etc. For many of these attributes it is now possible to go beyond the purely phenomenological characteristics that were the only ones formerly studied. It has now become possible to interpret their fundamental mechanisms in terms of the exact sciences and to reveal causal relationships. This should not be regarded as one of the usual successive steps in the gradual development of our knowledge, but as a series of significant qualitative advances.

This qualitative change took on an even more definite shape with the discovery of previously unknown phenomena which indubitably possess all the typical attributes of life. They lie at the very foundation of a number of important biological functions, are peculiar only to living systems and have never been (and apparently will never be) discovered in the inanimate world. These new phenomena and laws thus make an enormous contribution to the conceptions of the specificity of life. Here, however, as in the case of all the other attributes of life considered separately, we are not dealing with features which, taken by themselves, would permit us to draw a sharp, hard and fast line between life and non-life or to formulate a definition of the essence of life. Life is still perceived as a set of a greater or lesser number of properties and manifestations. One of the primary tasks facing the science of life should be the establishment of the extremely simple sets of attributes that justify the classification of given objects as living systems.

The types of these newly emerging specific features of life differ profoundly in their nature. They comprise such characteristics as certain features of chemical composition, new principles of the biosynthesis of macromolecules, molecular mechanisms for regulating processes in living systems, and the foundations of biological information. It is quite clear that the cognition of an increasing number of the attributes of life, in particular those of a more general nature, is opening up new possibilities for the cognition of life phenomena. Below we shall concentrate on the new qualitative features of life revealed by modern science.

Molecular Biology: A New Stage in the Study of Life

In discussing the new attributes of life, we must emphasise that, unlike the "classical" features, they are not immediately observable. Knowledge of new features of life has become possible through the decisive intrusion of the exact sciences–physics, chemistry, crystallography and others–into the domain of biological study. This was accompanied by the introduction into experimental biological research of extremely simple objects situated on the very borderline between life and non-life such as viruses or systems belonging to the genuinely molecular level.

The cumulative effect of new approaches and new forms of thinking was not a simple increase in the number of new factors, but vast mutual reinforcement of closely interweaving lines of research. The sphere of analytical study of the basic phenomena of life has grown enormously and, hand in hand with this process, synthetic, integrative concepts have developed. Thus, a new science appeared within the very short term of about two decades–molecular biology, which caused

a real revolution in many most important fields of biology. This was noted by the outstanding physicist P.M.S. Blackett, according to whom molecular biology has revolutionised the science of life in the same measure as the quantum theory revolutionised nuclear physics forty years ago.[1]

The very name of this new branch of natural science shows that it aims to reach into the most elementary and deep foundations of the existence of the animate world–the level of the atoms and molecules responsible for the phenomenon of life. As a result, there is now the possibility of characterising the specificity of life processes in a new light, of revealing completely the material bases of the biological mechanisms ensuring the existence of numerous functions of living objects, and of cognising the laws of the integrative principles that help to form that inner unity and integrality that is a most important attribute of life.

The situation in biology early in the latter half of this century resembles to a degree the situation in physics at the turn of the century–the time when Lenin wrote his classical philosophical works. Physics was then going through a period of total reappraisal of values. Lenin showed profound insight in recognising evidence for the irrepressible progressive movement of knowledge in the newly emerging concepts. The radical changes that have taken place in biological science within recent decades are viewed as a revolution in the theory of the animate world. This is true not in the sense that some of the former views have been discarded, but in something different. The revolution in biology is mainly expressed in the fact that researchers are now equipped with completely new instruments, methods and conceptions, and major tasks are accomplished through entirely new objects. This has resulted in enormous achievements, and some of these seemed even quite recently, before the revolution came, infinitely remote, if not in principle beyond the reach of experiment. Among these we may count the chemical synthesis of the protein molecule, the breaking of the genetic

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[1] See *European Conference on Molecular Biology*, Geneva, 22-25 January 1968. CEMB 68/45E, p. 15.

code and the elucidation of the material essence of hereditary phenomena, cognition of the most important biological regulatory mechanisms, the interpretation of the nature of some manifestations of life activity as the result of structural changes in molecules of biological polymers–proteins and nucleic acids, and so on.

Before we proceed to consider some special results of molecular biology, we shall present a generalised concept providing a broad outline of the specific phenomena of life.

Life has long presented itself to the scholar's mind as a process. Leonardo da Vinci embodied this conception in an artistic image. "The body of anything whatsoever that receives nourishment continually dies and is continually renewed.... Unless therefore you supply nourishment equivalent to that which has departed, the life fails in its vigour; and if you deprive it of this nourishment, the life is completely destroyed. But if you supply it with just so much as is destroyed day by day, then it renews its life just as much as it is consumed; like the light of this candle formed by the nourishment given to it by the fat of this candle, which light is also continually renewed by swiftest succour from beneath, in proportion as the upper part is consumed and dies, and in dying becomes changed from radiant light to murky smoke. And this death extends for so long as the smoke continues; and the period of duration of the smoke is the same as that of what feeds it, and in an instant the whole light dies and is entirely regenerated by the movement of that which nourishes it...."[1]

We may say that life is a set of certain principles, each of which taken singly does not define life, but the absence of even one of them makes life impossible. One of these principles is structural organisation. We cannot imagine a structureless object endowed with life but containing no elements of a definite and to a certain degree fixed order. Other principles are represented by a combination of three flows lying at the basis of life–the flows of matter, energy, and information. We shall consider them first, relegating problems of structural organisation to the concluding part of the paper. We shall consider these qualitatively very different flows separately, although they are intimately interwoven, forming an intrinsically connected triad which might be characterised as a "biotic triunity" forming the dynamic basis of life.

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[1] *The Notebooks of Leonardo da Vinci. Arranged, Rendered into English and Introduced by Edward MacCurdy*, New York, 1954, p. 141.

The Flow of Matter

In discussing the flow of matter as the principle forming the material basis of life, it is natural to ask the question: where is the lowest level of material formations at which it is reasonable to expect the first manifestations of life? Are such terms as "the living protein" and "the living molecule" justified? In the last case the answer will undoubtedly be negative. It is inconceivable that the set of principles of different qualities which, as we said earlier, characterises life phenomena should be inherent in individual molecules or types of chemical substances. The realisation of the phenomena of life requires a certain ordered set of material components, i.e. a definite material system. We shall avoid the term "living matter", since it carries a certain amount of vagueness, and shall use instead the expression "the living system".

The lower limit of the complexity of such a system appears to be the two-component system which may be observed on the borderline between life and non-life–in the simplest viruses. The most important classes of biopolymers–proteins and nucleic acids–supply these components; there are no known systems that might be classed as living which do not contain both components. Moreover, we reject in principle the possibility of living systems that do not contain both of these components. This statement may be said to have the status of a postulate. It is not axiomatic, but is rather based on a firm experimental basis and follows from the fact that these two types of macromolecular substances divide between themselves the task of ensuring the flows which together form the basis of life. Nucleic acids play the leading role in effecting the flow of information, while the flow of matter and the flow of energy are conditioned by the properties of proteins, especially the most important of these properties–catalytic activity. Proteins are also crucial to the structural organisation of a living system.

The flow of matter as such in some respects would appear to require less comment than the other flows. It is the carrier of the immediately observable form of the connection between the living system and the environment; it forms the basis of such aspects of life activity as nutrition and metabolism. No changes have taken place over the period in question that entail essentially new viewpoints or introduce fundamental modifications in the well-established system of concepts. But the situation is changed radically, firstly, when we consider the relationships between the flow of matter and the other two flows–energy and information; secondly, when we examine the separate links that make up the flow of matter. Several aspects become apparent here that may definitely be viewed as specific to living systems.

The main part of the flow of matter in living objects is constituted by a vast number of chemical transformations which the components of living systems undergo, be it elements of their own structure, subject to biological wear and renovation, or substances arriving with nutrition, carrying structural of energetic material. All these transformations covered by the concept of the chemical dynamics of life are initiated by biological catalysts, or enzymes, which are protein-like in nature. The vast majority of these chemical reactions do not differ in essence from those occurring in inanimate nature, although enzymes are much more perfect than the usual catalysts employed in chemical production or laboratories as regards such properties as high selectivity and their powerful effect.

At the same time, living systems perform chemical reactions that have never occurred in the inanimate world; these may be considered as a new specific attribute of life. Their significance is due not only to their specificity, but also to the fact that they determine the most important property of

life–the capacity for self-reproduction–i.e. the "matrix synthesis" reaction.

The discovery of the matrix synthesis principle should be regarded as a major breakthrough in modern natural science, since it served as the basis for a concrete interpretation of one of the fundamental attributes of life, and one that operates at the level of molecular structure. Matrix synthesis mechanisms are extremely intricate. As for the essence of the principle, it is simple and clear: the new molecules are synthesised in precise agreement with the programme embodied in the structure of a previously existing molecule. Our everyday life and technology provide many analogues for that: the hardened metal reproduces all the details of the mould used for casting; the negative film in photography is used to obtain prints fully retaining the outline of the object, although in reverse relationship of light and shade; the invention that ensured unlimited possibilities for the flow of information born of the mind–the Gutenberg printing press–permitted the typographical reproduction of a text, however large it may have been, without distortion. This latter example is the closest analogy to the principle of matrix synthesis, which was used by nature thousands of millions of years ago, when life first appeared.

The matrix synthesis principle is important in that the construction of both nucleic acids and proteins is based on it. Some details of the matrix synthesis principle are not identical in the two cases, but the guiding principle is the same–the principle of the complementary interaction of certain molecular structures.

To give even the barest outline of the essence of the matrix synthesis mechanism, we shall have to use what would seem to be purely chemical data. We shall attempt to keep them to a minimum; we believe that this deviation from the general trend of the exposition is justified by the extreme importance of this problem.

The leading role in the matrix synthesis is played by nucleic acids, which form the material basis of the matrix. Four types of nitrogen-containing base form parts of nucleic acids: adenine, guanine, cytosine and either thymine or uracil, abbreviated to *A, G, C, T* and *U*. By means of the residues of phosphoric acid and carbohydrates, i.e. in the form of the so-called nucleotides, these form chains of immense length containing dozens to hundreds of thousands of links alternating in a strict succession specific to each case. Individual bases may interact with each other, forming a special type of chemical bond–hydrogen bonds. The combinations are strictly selective, so that only complementary couples are formed, in which the molecular structures complement each other. *A* can only combine with *U* (or *T*), and *G* with *C*.

Let us begin by considering the matrix synthesis of nucleic acids themselves, which proceeds in the following manner. The previously existing molecule of nucleic acid (which plays the role of the matrix) specifies the order (determined by the complementarity rule) in which the individual nucleotides are arranged on it. Drawn nearer to each other in space, the nucleotides are combined with each other by firm chemical bonds by the action of a special enzyme–polymerase. A kind of replica of the matrix molecule is obtained–a new molecule of the nucleic acid having a structure strictly determined by the structure of the matrix molecule. This is the mechanism responsible for the doubling of the genetic material (DNA) during cell division, and in the same manner the matrix DNA serves as the basis for synthesising a special kind of the nucleic acid (the so-called messenger RNA), which in its turn plays the role of a matrix (of the second order, so to speak) in the matrix synthesis of protein. The mechanism of the phenomenon is in this case complicated by additional links, but the general principle holds.

In protein molecule synthesis, the strict order of the mutual combination of amino acids is ensured by a specific reaction, where the first stage is the formation of a nucleotide "mark" through the addition of amino acids to nucleic acids of a special type called transport acids (having a low molecular weight and denoted by the symbol *t*-RNA). These transport acids contain a grouping of three nucleotides (a triplet) characterising a particular amino acid. Through this triplet. the tRNA molecule with the added amino acid finds the complementary triplet in the structure of the messenger (matrix)

RNA and is combined with it, thereby fixing the position of the appropriate amino acid determined by the matrix.

Then amino acids in immediate proximity to each other form the so-called peptide bond, on which the structure of proteins is based, and a polypeptide chain is formed which, when the necessary length is reached, becomes a protein molecule. The individuality of a protein molecule is determined by the order of arrangement of amino acids in a polypeptide chain, and this order and the very possibility of their joining are due to the matrix nucleic acid and its molecular structure–the order in which nucleotides alternate. The successive order of nucleotides in DNA predetermines the result of the appropriate matrix syntheses, and we may say that coded in the chemical structure of the DNA is the information which determines a particular structure for the synthesised proteins and, in the final analysis, ensures their synthesis.

The flow of matter and the flow of information thus merge in matrix synthesis, the former as a synthesis of the most important component parts of the substances of living systems, proteins and nucleic acids, and the latter as definite indications fixed in the chemical structure of macromolecules of nucleic acids. We shall deal with the latter aspect somewhat later; at present what must be emphasised once again is the profound significance of the matrix synthesis principle as a specific attribute of life. The matrix synthesis principle is the ability of life to reproduce itself interpreted at the genuinely molecular level in chemical terms. Nature has here solved a task of infinite complexity which is of key significance for the entire problem of life–the reproduction of giant molecules without which life is impossible, molecules containing thousands and even hundreds of thousands of separate links, and the mechanism of reproduction is such that it guarantees the extremely precise conservation of the order of mutual arrangement and alternation of these links.

It would be going too far to insist that the matrix synthesis embodies the essence of life. But it is quite certain that life as we know it on our planet would be impossible without matrix synthesis.

When dealing with the matrix synthesis principle, we must be quite clear that the synthesis involves two partners–the matrix and the enzyme. Therefore the description of DNA, for example, as a "self-replicating" molecule is erroneous despite the regrettable popularity of such statements. In actual fact, the DNA by itself, without the appropriate enzyme, has no capacity for "self-replication" at all. The replication reaction takes place due to the catalytic effect of the polymerase enzyme.

Leaving aside many other, less essential characteristics of the flow of matter in living systems, we must once again emphasise the prime significance of proteins. This prime significance was reflected even in the earliest studies, in which they were named "proteins" (from the Greek πρῶτος, "the very first"). The essential role of protein was stressed by Engels,[1] who postulated the inseparable link between life phenomena and the presence and transformation of proteins, thus displaying acute insight and going far beyond his contemporaries' level of conceptions of the chemistry of living objects. Proteins constitute the quantitatively dominant share of the material substance of living objects. A significant and also predominant part consists of proteins with catalytic properties, i.e. enzyme proteins. And it is the action of enzyme proteins that sets in motion the whole host of chemical transformations making up what is known as metabolism, which underlies all biological functions. Thus, proteins are both a material basis and motive force for the whole of the flow of matter. Owing to the multiformity of their chemical and physical properties and, in particular, thanks to their macromolecular nature and ability to form three-dimensional combinations, proteins play a decisive role in the structural organisation of living systems. Finally, they play a most important part in effecting the flow of information and in accomplishing the vital integrative regulatory tasks determining the integral character of any living object.

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[1] See F. Engels, *Anti-Dühring*, Moscow, 1975, p. 96.

The Flow of Energy

As far as the flow of matter is concerned, present-day research has revealed some fundamental features that had been unknown and even unsuspected until recently; this is less true of the flow of energy. The foundation of bioenergetics is the energy of chemical transformations. Radiant energy is involved in two cases only–in photosynthesis and in light perception (photoreception)–but it is restricted to the initial stage, where photon energy is transformed into chemical energy as a result of changes in the electronic structure of the appropriate light-sensitive substances–chlorophyll and visual purple. This is followed by a chain of chemical reactions, as in all other life processes.

One of the characteristic features of life energetics is the multiformity of energy transformations in the carrying out of various biological functions, the other peculiarity consists in combining this multiformity with the unification of some basic links of the flow of energy. This unification results from the fact that the immediate source of energy for the most diverse manifestations of life are compounds containing bonds rich in energy (which have been called macroergic). These are primarily compounds of phosphoric acid, the most important of which is adenosinetriphosphoric acid (denoted by the symbol ATP). The energy of macroergic compounds acts as a sort of "energetic small change" which is used to cover energy expenditures required in the realisation of many chemical processes of metabolism, in particular of almost all synthesis reactions and practically all biological functions.

It is no exaggeration to say that the entire flow of energy entering the living system from the outside world in the form of the chemical energy of nutritive substances and released in the exothermal metabolic reactions, such as cellular breathing, i.e. oxidation of organic compounds, or in anaerobic decay, i.e. fermentation, goes through the stage of macroergic ATP bonds in the cycle of life transformations. This is also the form into which radiant energy is transformed in photosynthesis. The unification of energy exchange, the passage of the entire energy flow at a particular location through the narrow channel of a single type of molecular bond makes this aspect of the existence of living systems a specific one. In some measure, it deserves to be included among the attributes of life.

Apart from the feature of unification, the energetics of living systems is also characterised, as was noted earlier, by a multiformity of energy transformations; illustrations of this feature are well known, and we can restrict ourselves to a mere listing of some of them. They include the conversion of chemical energy into mechanical work occurring in all types of motion (e.g. the motion of cilia in lower organisms), or, in particularly large quantities, in the work of a muscle. The transfer of water and changes in the concentration of dissolved substances, as well as all types of active transport of substances through membranes accompanied by overcoming concentration gradients, require the performance of osmotic work. The functioning of elements of the nervous system in the transfer of nervous impulses involves electric phenomena which may reach very high values, e.g. in the discharge of the electric organ in some fish. Conservation of the metastable state characteristic of living systems would be unthinkable for any length of time if it were not supported by a flow of energy.

Of all forms of energy capable of performing work, only the transition to thermal energy may proceed directly without any specialised mechanisms. In all other cases, the conversion of one kind of energy into another requires a physical apparatus of the most varied complexity. As for living systems, our knowledge of the essence of the basal mechanisms involved in energy transformations is extremely scanty. Since energy flows in living systems are among the fundamental features of life, gaps in our knowledge of these laws are felt very acutely.

In dealing with the transition of molecules into an excited state through electron shifts to higher energy levels in quantum absorption or through the return of electrons to stable orbits, we have, in fact, sufficiently concrete conceptions only of quantum transitions in the electronic structure of the atom. When we speak of such transitions in molecules,

we have in mind the above-mentioned processes involving photons, e.g. in photosynthesis, luminescence and the perception of light. As for the other forms of energy transformation in living systems, also mentioned earlier, our data are restricted to registering external effects and comparing initial and final states; adequate knowledge of the mechanisms of the intermediate stages in energy transformations is lacking.

The immense and incomparable successes attained by modern natural science in recent decades in the study of the laws of life, which involve flows of matter and information and give us every right to speak of the dawning of a new era in the cognition of the animate world, bring out very forcibly the incompleteness and fragmentary nature of conceptions pertaining to the flow of energy. The efforts of researchers in the near future will undoubtedly be directed towards these goals. If the future achievements here are as great as in the other intensely developing fields, it will be a new step towards a deeper cognition of the still unexplored domains of life.

The Flow of Information

In considering the concepts of matter and energy flows, we observed a combination of classical, firmly established views with novel conceptions introducing a revolutionising element. The concept of information flow is different from these fields in that it is entirely the result of breakthroughs in the natural science of recent years, the result of the introduction of cybernetic views into the field of biology, since information theory, though it appeared on the scene before cybernetics, is one of its fundamental elements.

In considering the flow of information together with matter and energy flows, we must make a reservation. We will not be treating the mathematical aspects as they are discussed, for instance, in Claude Shannon's classic works on the mathematical theory of communication aimed at solving certain problems of a technical nature. Applications of the mathematical aspects of information theory to the analysis of the elementary bases of life phenomena are not yet clear, although there are grounds for believing that, owing to the universal nature of the principles of this theory, its further development will open up possibilities for such applications, which will be further extended and deepened. But, for our purposes, we would do well to limit ourselves to the qualitative features characterising, according to A. N. Kolmogorov's definition, systems capable of receiving, storing and processing information and of using it for control and regulation.

The methodological significance of the conception of information flow is immense. In particular, it presents in a concentrated and in many respects extremely detailed form (the details being taken from living systems—the highest level of the development of matter) the philosophical proposition whose importance was emphasised by Lenin—the thesis that the linking together of events is "merely links in the chain of the development of matter".[1]

Information is always associated with a definite carrier—an object or an event, and, of course, the information flow in living systems is no exception to this rule. On the contrary, it may serve as a graphic example of the combination of the information flow with the flow of matter. Information is found in living systems in diverse forms. Among the most significant forms is the one functioning in control processes. Norbert Wiener, the founder of modern cybernetics, said that any control both in the living organism and in the machine depends on communication, which involves the transfer of measurable quantities of information.

The activity of any living system and, consequently, its whole being are permeated with the principles of order and self-regulation. Their realisation is only possible in the presence of a definite set of connections which endows a complex diversity with the features of unity and integrality, the formation of the system entailing new properties lacking in the component elements of the given system. This is expressed in the well-known principle that the whole is greater than the sum of its parts. Information flow is basically a manifestation of a set of connections, which unifies the separate components of such a system and serves to transmit signals between these components. Of prime importance are relationships presupposing feedback or, to be more precise, the reciprocal two-way effect that forms the basis of all control mechanisms.

The nature of the channels along which information travels is diversified, and the types of its functioning are varied. An important contribution of modern natural science to the cognition of the specificity of life is, undoubtedly, the establishment of the omnipresent role of information flow as a component of living phenomena and the discovery of entirely new forms of its realisation that function mainly on the molecular level.

Two types of information communication in living objects (higher organisms) have been known since antiquity—the nervous and the humoral system of signal communication. We shall not touch upon them, since this is a domain of extremely high levels of biological organisation lying beyond the scope of our review. We shall concentrate on phenomena that are closest to the primary manifestations of life and occur largely on the molecular level. It must be emphasised that the very fact of discovering information communication at the level of molecular structure should be viewed as one of the major events ushering in a new era in modern biology. Of all the types of information communicated through molecular interactions, the genetic one is of the greatest interest, since it exceeds the limits of the individual biological object and extends through an infinite sequence of generations.

The essence of genetic code functioning is that the whole of the genetic information transmitted during cell division from the maternal cell to the filial one, determining all the properties of the developing organism, is contained in the DNA of the cell's nucleus. The principle of coding, storing and transmitting information solely by means of molecular

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[1] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works*, Vol. 38, p. 159.

structure becomes quite obvious here. If we take into account that the DNA molecules of one spermatozoon and one ovum contain all the information determining the development of a higher organism, man included, we come to appreciate the degree of miniaturisation attained by nature in the solution of a most important task–conservation of typal individuality simultaneously with the reproduction of life on the earth. This has been achieved through chemical coding performed at the very extreme of material divisibility where the individuality of a chemical substance is still retained–at the molecular level.

Earlier we described the matrix synthesis principle as one of the recently discovered attributes of life. Now we may say that the matrix principle in its very essence is an information flow in a molecular-structural form manifested in the self-reproduction of living organisms, on the one hand, and in the realisation of hereditary information in the synthesis of specific proteins, on the other hand.

Matrix synthesis reveals the main biological purpose of nucleic acids: they are, to the exclusion of all else, the material, molecular-structural foundation of one of the basic channels of information flow. We are dealing here with a distinct example of molecular-functional specialisation that is widespread in animate nature.

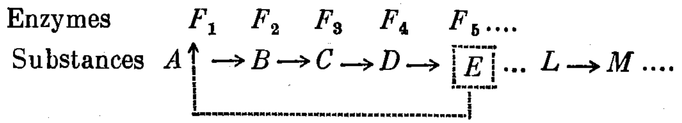
All this makes it clear why nucleic acids are inalienable components of living systems: life is impossible without the flow of information, and the motion of this flow is impossible without nucleic acids at a key site. However, the biological role of nucleic acids, in its fundamental features at any rate, is restricted to servicing a particular site in the information flow, and however important that site may be, it does not cover the flow of information as a whole. On the contrary, its mechanisms are not restricted to matrix synthesis.

Conservation of the property of ordering life processes is ensured by the intricate regulation of the functioning of all enzymes involved in the flow of matter, which is manifested in the ability to react to various changes both in external conditions and inner requirements determined by the varied functions of the living organism. Regulation and control of all sections of the material dynamics of a living system are based on information mechanisms–the signalling communication channels receiving and processing information. At present, the principles behind the performance of this regulation and control have been understood only in a few cases, and detailed data on their separate links are even less available. We expect that further research will reveal new laws pertaining to the regulation of the flow of matter and the energy flow inseparably connected with it.

Quite recently a new major step was made in the cognition of regulation mechanisms. An event of prime importance was the discovery of an entirely new category of phenomena constituting one of the key sites in the flow of biological information. We are referring to the regulatory mechanisms based on the principle of "allosteric" interactions. They were discovered in the study of information flows occurring in some enzyme processes and basically possessing typical features of negative feedback systems.

Molecular Mechanisms Regulating Biological Processes

The study of a great number of various enzyme reactions where each successive stage is stimulated by a special enzyme revealed a peculiar phenomenon which does not occur in non-biological chemical reactions initiated by certain catalysts. It turned out that very often the product of a particular stage, frequently quite remote from the first link in the chain, produces a strong and strictly specific inhibiting effect upon the enzyme at the beginning of the reaction chain. This may be represented diagrammatically as follows:



Product B in this scheme, formed from the initial substance A by the action of the first enzyme F_1, serves as the substratum of the effect of the next enzyme F_2, etc. The process might go on indefinitely if one of the intermediate products (in this case, E) did not inhibit the initial ferment F_1. If a product does not undergo further transformations fast enough, it inhibits the process, i.e. exerts a regulatory effect of the feedback type.

Cases of specific inhibition of enzymes by low-molecular chemical combinations, mostly kindred in their structure to the normal substrata on which the given enzyme acts, were not entirely new to science. The inhibitive effect of the so-called antimetabolites is based on the affinity between their chemical structure and that of the substratum and, consequently, on their affinity with the catalytic enzyme group which they bind, thereby obstructing the interaction of the enzyme with the substratum. This phenomenon, called competitive inhibition, is typical not only of catalytic enzyme processes, but may be displayed in ordinary reactions.

As for the type of inhibition described above, which is radically different from the competitive inhibition phenomenon, the chemical nature of the inhibitor differs completely from the substratum of the enzyme subjected to the inhibition; that is why its effect is not directed at the catalytic grouping of this enzyme. By joining the macromolecule of a protein enzyme, the inhibitor causes a change in the spatial configuration of the enzyme molecule and thereby strongly interferes with its catalytic function. This effect has been called allosteric regulation, i.e. regulation conditioned by the molecule changing its configuration.

We must emphasise the extremely great heuristic significance of the concept of allosteric effect. Just as with the principle of matrix synthesis, we are dealing in the case of allosteric effect with aspects of life completely unknown hitherto.

The allosteric effect specifies the nature of relations between the macromolecular compounds, particularly proteins, which make up the long-term basis of living systems, and the low-molecular components of the swift flow of matter formed during multiform metabolic processes. Allosteric interaction opens up ways for the numerous bonds between the low-molecular intermediate products of metabolism (metabolites), without which direct chemical interaction between them is impossible. It may prove to be especially important that allosteric concepts make it possible to interpret the mechanism of the effect of the most important factors of humoral information, namely, hormones, the products of internal secretion. Until recently, the main difficulty in explaining the ways and means of the mechanism causing their effect on many processes of metabolism was that hormones could not be included in any chemical equations expressing, for example, the essence of the basic carbohydrate exchange reactions in the case of insulin and adrenalin, or reactions of energy exchange, e.g. oxidative phosphorylation, in the case of the thyroid gland hormone.

The other, and no less significant, factor determining the importance of the theory of allosteric mechanisms is that they reveal the essence of the specific form of protein functioning that affects the flow of information, and one of its major channels, at that. The integration of the three flows which we have stressed repeatedly is expressed here most clearly.

Molecular Structures and Biological Organisation

The establishment of the decisive role of the spatial configuration of protein macromolecules has made it necessary to consider a new category of factors which we have not yet touched upon and which determine one of the basic attributes of living systems–their three-dimensional spatial structural organisation. Here we are dealing with an almost boundless gradation of levels of increasing complexity–beginning with the structure of individual molecules and ending with the integral structure of higher organisms. The extreme importance of this aspect of life is in sharp contrast to our extraordinarily limited knowledge of its real basis. That knowledge is almost entirely restricted to descriptive characteristics of certain forms of structural organisation and barely touches on the laws of their origin. We are undoubtedly dealing here not with a simple succession of independently formed levels, but with a process of development from lower forms to higher ones, i.e. with a hierarchy of structures.

Among the fundamental factors stimulating the origin of levels in the organisation of life, some authors include a hypothetical "biological field". This concept was born of an external analogy with the physical conceptions of electric and magnetic fields, the gravitational field, etc. But the actual content of the field concept as applied to biology did not increase our knowledge of the essence of the forces at work in living organisms, but rather concealed our ignorance. These views were in the nature of arbitrary postulates and remained sterile, since they did not stimulate experiment or theoretical justification. Their metaphysical colouring was revealed in the fact, among others, that they were compatible with such concepts as entelechy.

Recognising the material continuity of the gradations of biological structures, we must emphasise that the above-mentioned hierarchy has a peculiar order, actually opposite to the one that usually occurs in a hierarchical series: it is not the higher form that issues orders to the lower one, but, on the contrary, lower-order structures contain elements determining the features of a higher organisation. So far, this has been clearly revealed only at the very elementary stages corresponding to the molecular level or the ones immediately adjoining it; but laws discovered here are indubitably a partial reflection of a universal principle.

The starting point for the gradation of structures of increasing complexity is the so-called primary chemical structure of molecules of the two main classes of biopolymers–proteins and nucleic acids. The term denotes the order of arrangement of primary structural elements, amino acids or nucleotides in the polymer chain of the appropriate macromolecules. The formula of the chemical structure

of a molecule of protein or nucleic acid is usually represented as a unidimensional structure. In actual fact, however, the macromolecule has a rigidly determined three-dimensional structure: a linear chain is spiralised or folded according to a regular pattern into the so-called secondary structure. The next stage, designated as tertiary structure, emerges when the linear basis of a macromolecule having a secondary structure takes on an even more complicated three-dimensional configuration characterised, in turn, by a specific spatial arrangement. Quaternary structure is the result of a patterned association of individual molecules retaining their tertiary structure in strictly determined multimolecular complexes.

The question naturally arises: what determines the acquisition of ordered structures of increasing complexity by a substance, in this case a biopolymer? Present-day research provides a clear-cut answer to that question. The decisive factor here is the principle of ensuring the minimum of free energy. The primary structure of a polymer molecule is created by the chief valency bonds of chemical affinity, which are extremely strong. Conversely, all subsequent levels of structural organisation are based on weak interaction forces. On the one hand, there are hydrogen bonds, and on the other hand, mainly electrostatic forces–the van der Waals forces, dipole and hydrophobic interaction forces. The formation of these types of bonds requires the presence of molecules with certain structural features: hydrophobic bonds arise between apolar molecules, hydrogen bonds require electronic structures, etc. Accordingly, the conditions for the origin of such bonds are grounded in the primary chemical structure. This structure, i.e. the lowest and at the same time the most solid and strictly determined level, contains information controlling the origin of subsequent stages of structural organisation. The formation of the above-mentioned weak connections is accompanied by a decrease in the free energy of the system, and so the process of the formation of higher-order structures requires a reduction of free energy to the minimum permitted by the primary structure. This physical requirement appears as a leading factor in the structure of living systems, at any rate at the most basic levels approaching the molecular one.

We should like to emphasise the dialectical specificity of the situation emerging here: a contradiction arises between two oppositely directed trends. On the one hand, in the series of increasingly complicated biological structures we have a clear-cut manifestation of the principle of order in seeming opposition to the second principle of thermodynamics. But on the other hand, as we have seen, the motive force bringing about the increase in structural order is the tendency towards attaining the minimum of free energy, i.e. towards the entropy increase required by the second principle. This contradiction must apparently be resolved by the quantitative correlation of the factors involved in either tendency. We do not yet have the necessary measurements, but it must be assumed that, in the final analysis, the gain in entropy in the formation of structural connections is greater than the decrease in entropy conditioned by structural order.

If we do not take into account the possibilities of modern research determined by the level of knowledge attained, it is permissible to draw the following conclusion. Knowing all the energetic parameters characterising the macromolecule in accordance with its primary structure, it is possible in principle to predict *a priori* the spatial configuration it will assume when left to itself. There is evidence to show that this bold statement is justified. Ordinary instruments cannot make the required calculations, but powerful computers make it possible to obtain, from the knowledge of the primary chemical structure, a graphical picture of the three-dimensional structure for some types of macromolecules. Comparison of these results with the data of X-ray crystal analysis available for these molecules showed great similarity.

The fundamentally important fact that the primary components of biological structures carry elements of information determining higher-level ordering is borne out by the possibility of "self-assembly". Its essence is this: if the molecular aggregates of complex structure are decomposed by appropriate stimuli, i.e. if the quaternary structure is destroyed, the phenomenon of "self-assembly" occurs when favourable conditions are restored, that is, the original, often a very complicated and highly ordered piece of molecular architecture reappears. It is possible to extend this method to such structural formations as bacterial viruses (bacteriophages), plant and animal viruses, and even subcellular particles like ribosomes. All these objects display the phenomenon of self-assembly, and the high efficiency of the process is proved by the resumption of the original biological activity. The flow of information beginning at the level of molecular structures permeates the subsequent stages of the structural hierarchy and introduces a strict determinedness into the entire domain of the spatial organisation of living systems.

CONCLUSION

The outstanding achievements of modern science studying the specificity of living objects include breakthroughs in the synthesis of the most important components of living systems. Modern chemical experimentation has opened up possibilities which until quite recently seemed almost impracticable. Several years ago J. B. S. Haldane, the prominent biochemist and geneticist, said that if the same kind of investment were made in the study of the first enzymes as in the development of a new make of military aircraft, the goal would be reached very quickly, since the difficulties here are not fundamental, but technical.

Great advances have been made in the chemical synthesis of nucleic acids, and it may be assumed that chemists will soon produce a synthetic matrix which will serve as the basis for obtaining a protein, unknown in nature, with a stipulated primary structure by using the biological assembly mechanisms of the ribosome. Something of this kind has already been done: nucleic acids forming a bacterial virus (bacteriophage) have been synthesised in the test tube with an appropriate enzyme and without the use of a living cell. The preparations obtained possessed the most important property of the natural virus–they were infectious. Penetrating the bacterial cell, they form their second constituent–the specific protein—and, by combining with it, they form a full-fledged virus.

These experiments, to a certain extent, provide the answer to the question as to the possibility of artificially producing a living organism, albeit primitive, in a chemical and physical experiment; in other words, it is the answer to the question: is the synthesis of life possible? Quite recently even the posing of this question seemed completely fanciful. The situation is radically different now.

At the very beginning of this paper we pointed to the paradoxical nature of the situation now existing in the search for the answer to the question: what is life? No comprehensive answer even to the question of the difference between life and non-life exists at the moment. Now we face a paradox of quite a different kind: we can obtain something living without knowing in detail, perhaps, what life *is*. But this need not disarm us in our quest. There is little doubt that precisely in this way, in an apparent contradiction to the logical order of stages, a decisive step will be made, bringing us closer to the ultimate goal—cognition of the essence of life. Can one possibly doubt that this will be the greatest triumph of natural science this century?

N. P. Dubinin

MODERN GENETICS IN THE LIGHT OF MARXIST-LENINIST PHILOSOPHY

The Leading Natural Sciences in This Century

The revolution in natural science and technology in the latter half of the 20th century is again focusing attention on the problem of philosophical interpretation of the immense body of facts accumulated by science. Mankind has entered an era of extremely rapid scientific development. The current revolution has confronted natural science with the task of solving the greatest enigmas in the world. The future of socialism is linked with the development of science as a force directly affecting production in society. All this lends the utmost importance to the fundamental problems of the philosophy of science.

Problems concerning the philosophical interpretation of the complexities of modern science and its laws, the new status of science in the life of mankind and its role in the transformation of the world arise mainly in the rapidly progressing modern disciplines which emerged in the 20th century within the domains of physics, mathematics, chemistry and biology. These disciplines also include genetics, which, together with other biological disciplines, has accomplished gigantic breakthroughs and is now approaching knowledge of the essence of life, creating the possibility of the artificial reproduction of life.

For many centuries, natural science with its spontaneously materialistic view of the world and equally spontaneous reliance on dialectical principles has been fighting its way through the maze of idealism, metaphysics and agnosticism.

In the 19th century, Marx and Engels created dialectical materialism, which opened up possibilities for conscious treatment of the philosophical problems of natural sciences.

At the beginning of this century, the development of natural science was powerfully stimulated by the ideas in Lenin's brilliant work *Materialism and Empirio-Criticism.* Lenin applied a Marxist analysis to the principles of physics which replaced the 19th-century mechanist conceptions; he showed that the radical changes in natural scientific concepts may be given an adequate interpretation only in terms of dialectical materialism, and revealed the complete inadequacy of idealistic treatment of the revolution in natural science. Proceeding from the unity of the dialectics of things and the dialectics of cognition, Lenin stressed that the objective basis of cognition is the infinite Universe, the infinite number of properties of things, specific features of phenomena and, consequently, aspects of their study. He wrote: "The electron is as *inexhaustible* as the atom, nature is infinite. . . ."[1]

Lenin showed that materialist dialectics is the basis for the cognition of the deep essence of the things studied by any science. It cannot be introduced into the science from without and cannot be replaced by the empirical achievements of the science, however great they may be. It is one of the tenets of dialectical materialism that man's cognition of nature begins with immediately given phenomena and proceeds to their essence, to a knowledge of their laws. In this process, every step in the cognition of nature is tested by praxis and the testing leads to truth. Lenin wrote: "From living perception to abstract thought, *and from this to practice*—such is the dialectical path of the cognition of *truth,* of the cognition of objective reality."[2]

The science of life is one of the sciences that have undergone a radical transformation in their ideas. Genetics holds the key positions in modern biology. The development of genetics has reached a point where it has become virtually possible to study the deep essence of genetic laws and, as a result, to find new ways of controlling heredity, affecting the formation of organisms, solving many problems of combating disease, and drastically increasing the nutritive resources of mankind. Elucidation of the essence of life in the light of modern genetics will exert a profound influence on the life of humanity. Consequently, biology is joining mathematics and physics, as a frontier science, and is becoming a leader among the natural sciences.

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[1] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works,* Vol. 14, p. 262.

[2] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works,* Vol. 38, p. 171.

The Material Foundation of Heredity.
The Concept of the Gene. Life as a Special Form of the Existence of Open Material Systems

Modern genetics is founded on the theory of genes. This theory was developed on the basis of the new principles of 20th-century biology; the elaboration of these principles has been of the greatest significance for the materialistic cognition of nature. They have been tested by experiment and production practice. They have revolutionised the old biology and led to dialectical materialism in the study of the essence of life. The establishment of such an essential property of life as the phenomenon of heredity was of the greatest significance in creating the new biology.

To determine the nature of any life phenomena, we must reveal their physico-chemical foundations. This was pointed out by the founders of Marxism. Thus, Engels wrote in the *Dialectics of Nature*: "Only after these different branches of the knowledge of the forms of motion governing non-living nature had attained a high degree of development could the explanation of the processes of motion representing the life process be successfully tackled. This advanced in proportion with the progress of mechanics, physics, and chemistry. Consequently, while mechanics has for a fairly long time already been able adequately to refer the effects in the animal body of the bony levers set into motion by muscular contraction ... the physico-chemical substantiation of the other phenomena of life is still pretty much at the beginning of its course."[1]

Lenin remarked that life does not contain anything over and above the very same atoms which constitute the basis of non-life. It is only a matter of their special organisation, a specific form of motion. In his book *Materialism and Empirio-Criticism* he wrote: "...in its well-defined form sensation is associated only with the higher forms of matter (organic matter) ... there still remains to be investigated and reinvestigated how matter, apparently entirely devoid of sensation, is related to matter which, though composed of the same atoms (or electrons), is yet endowed with a well-defined faculty of sensation. Materialism clearly formulates the as yet unsolved problem and thereby stimulates the attempt to solve it, to undertake further experimental investigation. Machism, which is a species of muddled idealism, befogs the issue and side-tracks it. . . ."[2]

The development of the theory of the material foundations of heredity, i.e. the essence of the reproduction of life forms in successive generations, has resulted in the construction of the chromosome theory of heredity. The prime unit of life is the cell, which has a nucleus and cytoplasm. The nucleus contains thread-like structures in the form of polymers made up of proteins and nucleic acids; these structures are called chromosomes. It is primarily the chromosome substances that contain the material structures involved in the phenomenon of heredity in organisms.

Chromosomes proved to be deeply differentiated into qualitatively different structures that were named genes. Genes lie in the chromosomes in linear order and each of them has a molecular structure of its own. The theory of genes quickly became the centre of theoretical biology. Papers appeared in great numbers devoted to the study of the arrangement of genes inside chromosomes, their structure, the genes' interaction with each other in the development of the individual, etc. Genes displayed an ability for multiform changes (called mutations), and the study of these changes resulted in the theory of mutations. The new data of genetics changed the methods of plant and animal selection.

Materialist dialectics is the general theory of the development of both matter itself (nature and society) and the reflection of this development in man's consciousness. For two thousand years, the history of biology has been the scene of controversy between idealism and materialism. Idealism latched on to the phenomenon of heredity, presenting it as a non-material property of life.

From the philosophical viewpoint, the history of genetics has been full of contradictions. After the discovery of the laws of heredity, substantiation of the gene theory, the theory of mutations and the chromosome theory of heredity, metaphysics and idealism were very much in evidence for a long time, dressed up as theories such as Machism, neovitalism, etc., which were alien to materialism, but fashionable at the time.

The achievements of molecular genetics in the last fifteen or twenty years have been of great significance in substantiating the principles of dialectical materialism in biology. These achievements revealed the chemical nature of the gene. The gene proved to be part of a molecule of desoxyribonucleic acid (DNA). A DNA chain consists of nucleotides, which are a combination of the residuum of sugar, phosphoric acid and nitrogen-containing base. The first two components are the same in all DNA molecules. The specific properties of genes are determined by the different combinations of four nitrogen-containing bases–adenine, thymine, cytosine and guanine, which form parts of individual genes in several hundred nucleotides. The order of the nitrogen-containing bases within the gene is its code, i.e. the language of the control system through which the gene, passing on its information to the cell, determines a certain aspect of the development and life of the cell and the organism as a whole.

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[1] F. Engels, *Dialectics of Nature*, Moscow, 1976, p. 69.

[2] V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 46.

The gene concept acquired physiological and biochemical characteristics; it was demonstrated that the gene code, i.e. its molecular structure, programmes protein synthesis in the cell. This programming has a complex character. First, the gene molecule serves as the matrix on which a molecule of a specific informational ribonucleic acid (*i*-RNA) is synthesised. As *i*-RNA molecules are synthesised, they receive the information coded in the gene. Later they enter the cytoplasmic structures called ribosomes and ensure the specific arrangement, in accordance with the gene code, of amino acids in the synthesis of a protein molecule.

The genes themselves in each generation of cells undergo self-replication; proteins in the shape of special enzymes play an important role in the process. Through this autoreproduction, genes are formed once again for each new cell out of the nitrogen-containing bases and other substances synthesised in the cytoplasm. Thus genes are drawn into metabolism and affected by environmental factors. As a result, these chunks of genetic information, the genes, undergo infinite mutations through transformations of their molecular structure. The discovery of the chemical nature of genetic material caused radical changes in the classical conceptions of the gene as an indivisible corpuscle and the unit of functioning, mutations and recombinations. In actual fact, the gene proved to be a structurally and biochemically complex system.

These latest studies have discovered in the cell, within the gene and in the complex of genes (the genotype) a new microcosm of immense complexity, in which the features of integrality and infinite divisibility form a unity. On the whole, the genotype is a kind of "programming device" containing information which determines the life of a cell, the development of the individual and its life activity. The hereditary information is the sum total of the historical development of the given species of organism and the material basis for subsequent evolution. The theory of the genetic code has opened up great opportunities for the introduction of the methods of cybernetics and modelling into biology.

The main methodological weaknesses of the old theory of the gene were mechanism and autogenesis. Mechanism tried to establish itself by exploiting the idea of gene indivisibility, the conception of the genotype as a mosaic of genes and the conception of the organism (phenotype) as a mosaic of features. Metaphysics and autogenesis in the old theory of genes were expressed most clearly in the fact that genes were divorced from metabolic processes in the organism and from the effect of environmental factors, which paved the way for autogenesis and for ignoring the dialectical relations between the internal and the external. According to the old conceptions, each gene is an element eternally identical to itself and unchangeable. These mistakes of the past have been rectified. Now we are facing the problems of the unity of the external and the internal, determinism in gene mutation, and the elaboration of general dialectical materialist principles of the theory of development aimed at cognising hereditary phenomena.

The history of the gene theory gives a mirror-like reflection of the role of philosophy in the development of science. At the beginning of the century, genetics was dominated, thanks to idealistic philosophy, by autogenesis, according to which genes do not undergo any development and do not change under the effect of external factors. This caused both theory and practice to deviate from the correct path. From the dialectical materialist viewpoint, this position has always been regarded as erroneous. G. A. Nadson, G. S. Filippov and H. J. Muller established experimentally that radiation causes enormous mutability in genes. I. A. Rappoport and Ch. Auerbach demonstrated the existence of chemical mutagens. As a result, the modern theory of mutations is based on the possibility of infinite change and unlimited development in any gene.

This theory blazed new trails for practical work. A. A. Sapegin and L. N. Delone were the first to obtain radiomutants in wheat. Today mutagenic plant selection is increasingly becoming part and parcel of practical work contributing to the solution of such important problems as the creation of immune strains of wheat, fall-resistant kinds of plants, etc. Modern genetics played a particularly great role in the development of the industrial production of antibiotics, vitamins, amino acids and other substances.

Quite clearly, microorganism selection, which forms the basis of the microbiological industry, has been fathered by molecular genetics and gene theory. The biological problems of distant space flights will also be solved through the use of modern advances in genetics. The same is true of the problems of protecting the heredity of future human generations from the increase in background radiation on the earth and from the harmful effects of chemical and other mutagenic factors.

Overcoming idealistic and metaphysical errors, genetics has found a new path in the gene theory, a path illuminated by dialectical materialism; on this basis, its profound ties with practical work have come to light.

An important feature of the new studies of the gene is the discovery of the universal material basis of heredity. Revealing unity in the qualitative multiformity of nature is one of the major tasks of science. Lenin wrote in the *Philosophical Notebooks*: "...the universal principle of development must be combined, linked, made to correspond with the universal principle of the *unity of the world*, nature, motion, matter, etc."[1]

The discovery that the material nature of the gene is represented by a section of the DNA molecule is yet another confirmation of the unity of the organic world. DNA molecules proved to be the material substratum in which the genetic information of almost all living beings on the earth is coded. One can hardly imagine a more convincing proof of the unity of life, the common source of its origin and the mutual conditionality of its history. The historical method is of immense epistemological significance. Lenin wrote: "... the most important thing if one is to approach this question scientifically is not to forget the underlying historical connection, to examine every question from the standpoint of how the given phenomenon arose in history and what were the principal stages in its development, and, from the standpoint of its development, to examine what it has become today."[1]

The evolution of life forms is founded on cellular systems, and their specific features change the specificity of the communication channels between generations. Most important for the higher forms is the complex phenomenon of individual development, without which the phenomenon of heredity cannot be realised either. The problem arises of the principles and forms of programming, through genetic information, the development of the individual. The difficulty here is to understand the manner in which integrality in individual development is programmed.

The gene problem is far from being solved. The most important question of the role of genes in protein synthesis has been studied deeply, but many of the innermost aspects of their structure and function are not yet clear. We have a long way yet to go to reach the discrete foundations of life. At the same time it is already obvious that only the interpretation of life as a system will ensure the greatest success in cognising the essence of life and the bases of individual development. Methodological analysis of the problem of life holds out great promise. It should develop and extend the changes in the philosophical view of life that were ushered in by the breakthroughs in molecular genetics.

Proceeding from facts, we may say that life on the earth is the integral existence of DNA, RNA and proteins in the form of open systems (individualised individual, and species, integral, structural-biochemical, self-regulating) which have the property of reproducing the historically developed forms of genetic information. The time has come to study the most important methodological principles of the unity of discreteness and integrality in the systems-structural foundations of life as the highest form of the development of matter.

The discovery of the systems nature of life will show the way to the cognition of the essence of life and to mastering

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[1] V. I. Lenin, "Conspectus of Hegel's Book *Lectures on the History of Philosophy*", *Collected Works*, Vol. 38, p. 256.

[1] V. I. Lenin, "The State" *Collected Works*, Vol. 29, p. 473.

this phenomenon in all its historical complexity. But the gap between life and non-life must first be bridged by experimental reproduction and, later, by the creation of "live molecules" of DNA and RNA.

In 1967 and 1968 two tasks of fundamental significance for the gene problem were accomplished. A. Koran's group developed methods for synthesising DNA molecules with a given order of nucleotides at the gene level. In this way the gene of the alanine yeast transport RNA was synthesised consisting of 71 nucleotides. A. Kornberg's group created artificial conditions in which a virus matrix was autoreplicated. Thus, approaches to the construction of "live molecules" have now been found. Artificial construction of a living cell–the only self-organising system that we know–is a task of the future.

All hereditary diseases and defects in man stem from defective genes in the organism's cells. Now that it has been proved that genes can be reproduced artificially, prospects have opened up, in principle, for devising genotherapeutic methods and applying them in medicine. They may eliminate ailments that have plagued humanity throughout its history, such as cardiovascular diseases, cancer, mental disorders, dwarfishness, haemophilia and many others, as well as bacterial and virus diseases.

Man will overcome the defects of his biological nature. Future researchers will have to tackle many fundamentally new tasks, relying on the application of the gene theory to the genetics of man.

The Problem of Purpose. The Factors of the Historical Development of Organisms. Control over the Evolution of Species

Purpose in the organic world is the most important property determining the organisation, functions and behaviour of living organisms. Everything is permeated with purpose–from the structure of genes in viruses to man's higher nervous activity. Purpose is not a primordial, but a historically

acquired property of every species which comes into being as its adaptive reaction to environmental stimuli. Like all evolutionary properties, purpose is programmed in the genetic material. It is through genetically programmed purpose at all levels of life, from molecule to organism, that objectives are attained in the development of each individual; without this, life is impossible. Man's individual development begins with a single fertilised ovum containing the programme of the development of the individual as a whole. Under certain conditions, the cell goes through giant stages of historically conditioned development in short periods of time, realising the goal set by the genetic programme.

For thousands of years the quality of purpose in organisms was used by teleology to consolidate religious dogmas. Purpose was also given a false interpretation in an idealistic biological conception named vitalism. The vitalist idea of the presence of primordial non-material factors in organisms is centuries old, having originated in Plato's conception of the soul and Aristotle's doctrine of entelechy. At the turn of the century, vitalism was spread through the work of J. J. von Uexküll, H. Driesch, A. Wenzl and others.

Charles Darwin's work was primarily important because proceeding from materialistic positions, he discovered the factors that gave rise to purpose in organic forms. Darwin showed that purpose emerges as the effect of natural selection, heredity and mutability. He revealed the unity of randomness and necessity in the formation of purpose. In modern genetics these views of Darwin's culminated in a great triumph for dialectical materialism, which in actual fact formed the philosophical basis for the solution of the fundamental problem of the evolutionary doctrine–the establishment of the role of mutation in evolution and selection.

The classics of Marxism acclaimed Darwin's theory. Engels believed that the solution of the problem of the relationship between objective randomness and necessity was the core of Darwin's theory; he wrote in the *Dialectics of Nature*: "Darwin in his epoch-making work, set out from the widest existing basis of chance. Precisely the infinite, accidental differences between individuals within a single species, differences which become accentuated until they break through the character of the species, and whose immediate causes even can be demonstrated only in extremely few cases, compelled him to question the previous basis of all regularity in biology, viz., the concept of species in its previous metaphysical rigidity and unchangeability."[1]

The goal of science is the search for the intrinsically necessary conditions that are concealed behind the various random events. But randomness is a form of manifestation of necessity. It is clear in the light of this thesis that the analysis of random events may be, and in fact very often is, a way towards revealing necessity.

The research that laid the foundation of genetics–G. Mendel's discovery of the basic laws of heredity–proved to be a triumph for the scientific significance of the categories of randomness and necessity. Analysing the consequences of the random combination of gametes with different alleles, Mendel discovered the laws of splitting thereby revealing the deepest biological processes of heredity.

At the end of the 1920s Mendel's discovery became the basis for genetic interpretations of evolutionary problems. As for the geneticists of the early 20th century, they misinterpreted the relationship between Mendelism and Darwinism and deviated from Darwin's dialectical and materialist positions. Some geneticists of that period held vulgar mechanist views, actively preached agnosticism, and spread idealistic views on the nature of the gene and mutations. De Vries attempted to substantiate the doctrine of the catastrophic appearance of species by postulating leaps which, in his view, were caused entirely by internal factors. He believed that hereditary mutability causes adaptation instantaneously, without a previous historical evolution. W. Bateson put forward the presence-absence hypothesis, in which the appearance of hereditary changes and all evolutionary processes were presented as different stages in the internally conditioned degradation of heredity, the decay of some original genotype which contained the potential possibility of the entire

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[1] F. Engels, *Dialectics of Nature*, Moscow, 1976, pp. 220-21.

evolution of organisms. In 1912-1916, J. P. Lotsy suggested the idea that hybridisation was the only basis of evolution. He believed that both the inorganic and organic worlds were based on the permutations of a definite number of invariable elements. In the first case, chemical elements function as bricks of matter; in the second, life appears to consist of a definite number of immutable genes.

Darwin's great service to science was that he freed biology from the old metaphysical conception of absolute predetermined necessity that was foisted on nature by divine law. According to Darwin's theory, the factors of historical development are natural selection, objectively random, indeterminate mutability, and heredity. This discovery of Darwin's showed that evolution is not the attainment of any predetermined objectives and is not determined by any purposive stimuli in the organisms themselves. Purposiveness is a historical acquisition of organisms which is necessarily conditioned by the environment, but is created through selection from objectively random deviations. Pointing to the fact that the theory of natural selection gave the only correct explanation of the origin of organic purpose, Marx wrote in his letter to F. Lassalle dated January 16, 1861: "...it not only deals the death-blow to 'teleology' in the natural sciences for the first time but also sets forth the rational meaning in an empirical way...."[1]

The significance of purpose was given a new and fundamental interpretation by the appearance of a profound synthesis of Darwinism and genetics. Modern population genetics, whose origins can be traced back to a paper by S. S. Chetverikov, published in 1926, showed that the emergence of new species is based on the law of the unity and struggle of opposites. The appearance of mutations under natural conditions, the emergence of complexes of mutations, the behaviour of populations as indivisible hereditary systems (Mendelian populations), and the effect of selection–all these factors of evolution in their integral unity were investigated

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[1] K. Marx, F. Engels, *Selected Correspondence*, Moscow, 1975, p. 115.

in a large number of experimental and theoretical studies. It was demonstrated that mutations are causally conditioned, but, since they are not purposive, they are objectively random as far as the adaptive properties of species are concerned. Some of them prove to be useful and are spread in populations through selection. They cause polymorphism within the species, then become the property of all individuals of the population, of the subspecies and, finally, transform the properties of the whole species. Negative mutations are not simply discarded: they may, in large numbers, "infect" the species genotype, causing the appearance of "genetic burden" in populations. All these evolutionary processes in populations involve increasing quantitative changes, which culminate in qualitative leaps when species appear. The study of these quantitative changes resulted in the wide use of mathematics in population genetics.

Experimental and theoretical analysis of genetic processes in evolution has consolidated the positions of Darwinism in genetics and has shown the significance of the historical method and the theory of development for the understanding of the essence of mutability and heredity itself. The evolutionary ideas in genetics fought their way through along different routes. Their unification has now resulted in a synthetic many-sided genetic morphological approach to the problems of evolution and selection. Population genetics has now acquired great significance in medical genetics. Some problems involved in the origin, spread and treatment of man's hereditary diseases are being solved through the wide application of data from population genetics.

Population genetics is one of the most rapidly developing fields of general genetics. The knowledge accumulated in this new domain is growing yearly. Population genetics data are badly needed by the evolutionist, the plant and animal breeder, the taxonomist, the ecologist, the general biologist and the philosopher. In the past, analysis of evolutionary laws was based entirely on the analysis of changes in the form of organisms. Population genetics went to the heart of the evolutionary process and discovered the real mechanism of heredity, mutations and selection.

The outstanding Soviet scientist N. I. Vavilov defined selection as evolution controlled by man's volition. At present, the evolution of many forms of natural life is beginning to be affected by man's activities. The rapid growth of science and technology makes the problem of relations between man and nature particularly urgent. Accelerating world industrialisation, the use of chemicals in agriculture and industry, the increased level of radioactivity and many other factors of industrial development are affecting the biosphere and making a substantial impact on the natural evolution of living organisms.

The problem of rational control of the evolution of life is now being pushed into the foreground. Conservation of nature and increasing its riches are inseparable from the transformation of nature. The sources of disease and other harmful factors must be eliminated.

The genetic theory of evolution faces immense tasks. It is necessary to reveal the activity of selection, heredity and mutability in populations in concrete detail, and to determine the essence of transformations of genetic systems based on integrated genotype complexes, the laws of historical development in different groups of organisms, the role of genotype determination of macroevolution, etc. Moreover, in order to control the evolution of species, it will be necessary in the future to transform in many respects the objectively random basis of natural mutation and create a method for eliciting flows of controlled mutability of organic forms. This negation of the laws of natural mutagenesis contains great possibilities for the goal-directed selection and control of the evolution of life on earth.

The Problem of Mutations. The Essence and the Phenomenon in the Origin of the Hereditary Mutability of Organisms

The phenomenon of mutations is the basis of evolution, selection and hereditary mutability in the entire organic world. It is the unavoidable motion of organic matter in the genetic material which conditions the eternal process of the emergence of new phenomena. The theory of mutations is closely linked with the gene theory, the theory of chromosomes, and the philosophical category of causality.

The history of the problem is a particularly apt illustration of the role of methodology in cognition. A long struggle had to be waged against mechanist and idealistic conceptions before geneticists came to realise that mutations occur according to the laws of dialectical materialist determinism.

In further treatment of the problem, researchers face the task of developing the philosophical foundations of the scientific cognition of nature. Lenin wrote: "...natural science is progressing so fast and is undergoing such a profound revolutionary upheaval in all spheres that it cannot possibly dispense with philosophical deductions."[1]

The facts about mutation are now known in great detail. The deep dialectical nature of events taking place here has been revealed. It has become clear that there are no mutations without causes. The factors affecting mutations lie in the dialectical connections between the external and the internal, which are implemented, in their activity, through the specificity of genes and living systems as a whole.

The problem of causality is one of the main lines of division in the struggle between idealism and materialism. Materialism considers causal connections to be inherent in things existing outside consciousness and independently of it. Causality is objective and universal.

Proceeding from the achievements of science and practice, dialectical materialism asserts the existence of universal interaction between the objects and phenomena of the world, their universal law-governed connection in which causal relation is only one aspect. As Lenin pointed out, causality is only part of the world connection; cause and effect are only links in the chain of the development of matter. Lenin said that in solving a problem one must find the particular, main link in the chain of events; by pulling on this link, one may pull out the whole chain.

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[1] V. I. Lenin, "On the Significance of Militant Materialism", *Collected Works*, Vol. 33, p. 234.

When considering an individual act of mutation, we observe a clear picture of determined events, distinctly brought out in artificial mutagenesis. Thus, by subjecting cells to the effect of alkylating compounds, we mainly produce alkylation of guanine through nitrogen in the seventh position. In the case of the effect of nitric acid or acridin on phages we see clearly the definite changes which they cause in DNA molecules. There are mutagens which, by affecting definite types of genes, produce a picture of specific mutation. All this warrants the conclusion that the quality of mutations is determined by the quality of the active factor. Does this mean, then, that the study of natural mutations and the analysis of the totality of experiments in artificial mutagenesis yields a complete knowledge of cause? This is regrettably not the case. The forms of connections between the genetic material and the factors of the internal and the external medium are exceedingly complex. These connections are based on the relations of necessity and randomness, of the essential versus the non-essential, and the internal versus the external. The result is that the causal relations in the organism turn out to be dependent on a large number of factors, which determines the statistical character of the integral process of mutations. It is this circumstance which conditions the fact that, from the point of view of organisms' degree of adaptation to the environment, mutations are objectively random changes. But objective randomness is not absolute randomness.

Some scientists believe that the individual changes of genes are in principle not determined. But a more profound analysis shows that within each species mutations, however chaotic they may seem, reflect an internal law which is implemented through random events. This specific feature is expressed in certain limitations on the variations in mutations, and in the similarity of hereditary changes in cognate species.

According to one conception, internal necessity in mutations is based on the tendency towards adaptive orientation of mutations owing to genotype programming. It is insisted that the result is a general correlation between the quality of adaptive changes in heredity and the quality of the active factors in the environment. But this presentation of the problem is incorrect in the light of organic determination of mutations. If we ignore this circumstance, the mutation process loses its basic feature, which is connected with the manifestation of the category of objective randomness in the formation of adaptive properties of species.

In population genetics, the concept of evolutionary homeostasis has been introduced, which denotes evolutionary stability of populations and species in response to changes in the environment. We know how quickly plants, animals and microorganisms change their heredity, adapting themselves to changes in the environment caused by man's activity. Changes in the chemical conditions often follow the introduction of substances into the environment which have never affected organisms before, yet populations quickly acquire adaptive properties. In this case, there can be no question of a correlation between the useful properties of mutations and the quality of the active factor.

All these evolutionary processes are based on the use of new objectively random mutations as well as the genotypic reserves of populations; by utilising them, selection quickly integrates new adaptive genotypes. Generally speaking, evolutionary homeostasis is only conceivable if the law of the objective randomness of mutations is strictly observed. There are many facts to prove that peculiarities of mutations are determined by genotypic factors. This shows that the ability of genes to change in many ways and in many directions in response to the same mutagenic factors is programmed into the genotype. It took nature millions of years to create the foundations of evolutionary homeostasis, thereby programming the genetic basis for the emergence of objectively random mutations. The dialectics of events here is such that the original non-adaptedness of mutations appears as a deeply ingrained evolutionary adaptive property. The objective randomness of mutations, transformed through selections, creates necessity in the form of the adaptation of features.

This concerns not only higher organisms, but also bacteria and viruses. The objective randomness of mutations is one of the most profound laws of the historical existence of organisms. It reflects a most important evolutionary adaptation, without which the infinite evolution of life in response to the ever changing environmental conditions would be impossible. Of course, every species and every population has definite limitations on the "degrees of freedom" determined by a certain historically common gene complex. We owe this discovery to N. I. Vavilov, who formulated the law of homological series in hereditary mutability. But within these limitations, the law of the objective randomness of mutations is of the greatest significance. The solution of the problem of the nature of mutations does not make the randomness of genetic changes an absolute. The interaction between the genetic system and the environment proceeds through organic determination and not through mechanical connections. Environmental factors are refracted through the specificity of the living system which actively transforms them itself through metabolic processes. Lastly, genes are capable of different changes under similar stimuli. The result is a flow of genotypic diversity consisting of mutations objectively random in relation to the original environmental factors. As for the determined nature of the mutation phenomenon itself, it is apparent from the fact that we are now able to produce diverse mutation forms in great numbers by means of radiation, various chemical factors and other effects. Work on chemical mutagenesis has shown specific mutations. The laws of objective randomness, however, still dominate events in the artificial elicitation of mutations too.

The attempts to present natural mutations as the adequate adaptive response to the effect of external factors are merely an unjustified reduction of the complex dependences of a living organism to the level of cause-and-effect relations. This is a typically mechanist approach, which does not take into account the transition from one type of connection to another. Natural mutagenesis is affected by numerous random factors; as a result, the phenomenon of natural mutations is not determined by direct and unambiguous connections, but requires statistical analysis.

Drawing conclusions from the laws of natural mutation, we may say that they are based on an internal ineradicable motion within the genetic material, since genes are involved, through the unity of the internal and the external, in the metabolic processes within the cell, without which life is impossible. The forms of this motion are determined, on the one hand, by the historical peculiarities of genotypes, as is registered in the Vavilov law, and on the other hand, by the programme for the solution of a purposive task, requiring a manifestation of the objective randomness of mutations. The former is evidence for historical connections between species, i.e. for the past in evolution. The latter is the seed of all the infinite possibilities of the current and future evolutionary changes in response to any variations in the environmental conditions through the realisation of the unity of randomness and necessity.

In the light of the fact that natural mutation is controlled by a system of organic determination, the negative attitude towards the possibility of inheriting the so-called acquired features is quite understandable. Dialectical relations of the external and the internal in integral living systems preclude cause-and-effect relations between changes in the properties of an integral organism and the adequate changes of the molecular gene structures. A change in the organism may alter the course of the mutation process, but it will not violate its objectively random nature.

The mechanist idea of the adequate inheritance of acquired properties, stemming from failure to distinguish between essence and phenomenon, has shown an amazing tenacity during the thousands of years that the history of biology spans. Organisms acquire new properties in two ways. Firstly, they may do so through changes in heredity. These properties are acquired by organisms through mutations produced by the internal and external medium factors. These features are genotypic; they are strictly inherited in the form of dominant, superdominant, co-dominant, semidominant and recessive alleles or chromosome changes. Secondly, organisms may change as integral morphophysiological systems in the process of individual development, which does not entail adequate changes in their molecular hereditary structures. In these cases, variations appear on the basis of retained genotypic systems within the norms of reactions that are characteristic of them. All these individual acquired properties are phenotypic and are not inherited.

The phenotype is a phenomenon, and genotype is the essence that is immanent to an organism; their variations are not indifferent to each other. Changes in the essence (the genotype), transformed in the process of integral development, lead to certain variations of the phenomenon–the phenotype. Changes of the phenotype, transformed by the system of organic determination, are a factor of mutations.

For a long time these truths, quite obvious now in the light of modern genetics, were not fully realised by researchers; only precisely established facts and strict theoretical analysis showed that the interaction of phenomenon and essence in the problem of heredity goes far beyond the usual conceptions of cause-and-effect relations between the external and the internal. Science has known many "obvious" truths that were later refuted. Thus, it seemed self-evident at one time that the sun rotates around the earth. It took a long time for astronomy to arrive at a generally accepted conception in which the sun and the earth occupied their proper positions.

The correlation of the genotype and the phenotype in the evolution of organisms appears as an interaction between form and content. The source of evolution is the struggle of contradictions of content and form, where form (the phenotype) functions as the conservative factor. The passing of quantity into quality eliminates the negative aspects of the old in such a way that the new content ensures an adequate new form. Form (the phenotype) in the process of evolution is not passive; by regulating the directions of selection, it radically affects the processes determining content (the genotype). Evolution goes through certain critical periods, when changes in the environment produce radical transformations in the properties of species. These periods may be compared with epochs of social revolution which come after long periods of so-called peaceful development. In these periods the species mobilises immense reserves of hereditary mutability, deviations of phenotypes develop in response to environmental stimuli, and changes in the hereditary content of the species and the forms of its struggle for life become impulsively swift and varied.

Here we encounter the "wonder" of critical moments in the formation of species. This applies particularly to the biological basis of the emergence of man. Discussing similar processes in the domain of social events, Lenin wrote: "There are no miracles in nature or history, but every abrupt turn in history, and this applies to every revolution, presents such a wealth of content, unfolds such unexpected and specific combinations of forms of struggle and alignment of forces of the contestants, that to the lay mind there is much that must appear miraculous."[1]

Turning to the most important problem of the entire theory of life, namely, the problem of the direction of mutations, we should see clearly that, according to the dialectical materialist view of nature, causal relations are multiform. The specific causes of mutations have been discovered, but, in order to solve the problem of directed mutations, we have to know the whole cause, i.e. the circumstances which necessarily imply a consequence.

It is difficult to say how this immense task of the natural sciences will be accomplished. It is clear, anyway, that the current approaches are inadequate to the task. The modern molecular theory of mutations is of great consequence, as it brings to light the nature of the interaction between chemical and physical mutagens and the DNA molecular structure. It has been shown that these reactions may be quite specific. This specificity, however, is displayed at the level of individual nucleotides and small groups of them, irrespective of their connection with any gene. The objective is purposive variations of certain genes, each of which serves as the focus of specific biochemical processes in the cell. To attain this, we must reveal those properties of genes which characterise them as integral systems. So far, we have not discovered these properties. At the same time, the concrete variations of genes have to be implemented in certain molecular changes. In order to deliberately change a particular nucleotide in a gene, we have to bring about its specific chemical interaction with the mutagen and, what is more, to ensure the recognition of the given individual nucleotide by the mutagen in the gene system. Taking into account the uniqueness of the system of each gene, this will guarantee the selectivity of the attack and its repetition for each of the genes. If these effects operate comprehensively, this may serve as the basis for changes of any degree of complexity in genes.

Judging from the advances made in artificial gene synthesis, it will be possible in the future to synthesise mutant genes of any structure and introduce them into the genotype system of the cell.

Lastly, it should be pointed out that we do not yet know all aspects of mutation. It has become clear that the gene-mutagen interaction produces only primary chemical changes in the chromosome.

From this point onwards, a long time may elapse before the true mutation appears. All this time parcels of metastable-affected chromosomes exist as potential changes which have a whole number of properties. It is as yet impossible to understand their essence from the viewpoint of the modern molecular theory of mutations. At the same time, potential changes throughout their life are affected by various modifying influences.

A new period in the study of mutation was ushered in when it was discovered that the cell possesses special enzyme systems which protect the DNA molecules carrying genetic information. These enzymes cut out the initial injuries inflicted on DNA strands by mutagens. The complex processes developing here control the appearance of mutations. The elaboration of problems of mutation formation requires control of all the conditions within cells in which the formation of gene and chromosome mutations proceeds. The problem is to direct mutation processes. It has been shown that, by controlling mutations, one may produce identical disorders in both DNA strands, which results in complete mutations, or preserve disorders in one strand, thereby creating conditions for obtaining mosaic mutations.

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[1] V. I. Lenin, "Letters from Afar", *Collected Works*, Vol. 23, p. 297.

To master directed gene mutation, a radical change will be required in the processes within the cell which determine the statistical laws of mutation formation. It is well known that man, according to his needs, turns possibilities into reality through his activity; some of the possibilities, very rarely realised in nature, may become the basis of new branches of science and technology through artificially created favourable conditions.

Control of Heredity. The Unity of Theory and Practice in Genetics

The influence of biology on practice is determined by the fact that it constitutes the theoretical foundation of the agricultural and medical sciences. Practice is not only the objective of science–it is also an instrument of cognition.

Modern science plays an extremely important part in the life of a society. Science originally grew out of man's productive activity. The unity of production and science is obvious, but one must bear in mind that, apart from the practice of production, there exist the logic of cognition and experimental practice. Whole new domains of experimental and theoretical disciplines have appeared which at times merge with production and at other times go far ahead, blazing the trail into the future. We see that in some cases what seems to be a totally abstract study of nature may lead to discoveries which, like flashes of lightning, illumine the future development of civilisation. The 25th Congress of the Communist Party of the Soviet Union had good reason to point out the need to raise the efficiency of social production on the basis of scientific and technological progress. The Party Programme says: "Application of science in production becomes a decisive factor of rapid growth of the productive forces of society."[1]

The principle of the unity of theory and praxis ensures the high status of fundamental studies of nature. Lenin wrote: "Truth is a process. From the subjective idea, man advances towards objective truth *through* 'practice' (and technique)."[1] Fundamental studies open up new possibilities for the transition from potentiality to reality.

Through fundamental studies prepared by the development of science and practice, in the course of which theories are constructed reflecting the basic laws of nature, science achieves breakthroughs of major practical significance. This is the way of all the revolutionary transformations which science introduces into practice, developing, in its turn, on the basis of social productive forces. Before our very eyes, theoretical and experimental sciences generated by the development of productive forces, having passed through the stage of contemplation and later abstract thinking, i.e. after major theoretical generalisations have been attained, become the material force of the transformation of production. The theory of nuclear physics and new experimental methods have resulted in the use of atomic energy; the development of mathematics–in the appearance of cybernetics, the science of controlled systems; the development of chemistry–in the appearance of synthetic polymer production; the development of theoretical and experimental genetics–in such methods of heredity transformation as polyploidy, heterosis, radiational and chemical mutagenesis. The combination of new sciences and new production technology formed the basis of spacecraft design. The more significant a theoretical task accomplished by science, the greater its influence upon life and production. The future of our country is linked with science.

The prime task of natural science is to discover the possibilities available in nature and, through practical activity, to transform the world. The formulation of theoretical possibilities is the basis for devising a science development programme; it widens its horizon. The time is approaching for an all-out offensive on the greatest mysteries of nature. Science today is attempting to solve the problems of the origin, existence and development of the Universe, and to reveal the mysteries of the microcosm and the laws of the development of nature at all stages in the evolution of matter. Just as much

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[1] *The Road to Communism,* Moscow, 1962, p. 572.

[1] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works,* Vol. 38, p. 201.

attention is being given to the problem of the essence, origin and development of life. The point is that the fundamental possibilities involved in the accomplishment of these great tasks should be realised maximally and used for purposes of peace, for the benefit of man.

The development of genetics has already exerted considerable influence on the level of agriculture and medicine in the USSR. Soviet plant and animal breeders have achieved great results. N. I. Vavilov and I. V. Michurin played an exceptional part in creating the scientific basis of Soviet research in selection. The various plant types developed by P. I. Lisitsyn, P. N. Konstantinov, A. A. Sapegin, A. P. Shekhurdin, P. P. Lukyanenko, V. S. Pustovoit, N. V. Tsitsin, V. N. Mamontova, F. G. Kirichenko, V. N. Remeslo, M. M. Khadjinov, V. Y. Pisarev, A. G. Lorkh and others have raised the level of Soviet agriculture and changed the quality of raw materials.

The work of S. N. Davidenkov, S. G. Levit and others in the USSR has laid the basis for medical genetics, which seeks to describe the aetiology of and provide methods for treating man's hereditary diseases.

Within the last twenty years genetics has made it possible to experiment directly with molecular structures in which the genetic information of organisms is coded. This was brought about by the development of physics, mathematics and chemistry which have introduced into experimental genetics the use of gigantic technical facilities and new procedures.

The extraordinary achievements of the physical and chemical study of molecular structures and processes in the living cell are not directed towards a mechanistic reduction of higher forms of the motion of matter to lower ones. All these methods reveal the deep phenomena lying at the base of the biological form of the motion of matter. They deal a final blow to all kinds of idealistic approaches to life phenomena as a mystical essence.

The development of the new genetics was marked by continuity; it proceeded on the basis of the connection between the old and the new in the development of methods and ideas. Its spiral-like nature is a characteristic feature of dialectical

development occurring through a negation of the negation. Pointing out this important feature of dialectics, Lenin wrote: "A development that repeats, as it were, stages that have already been passed, but repeats them in a different way, on a higher basis ('the negation of negation'), a development, so to speak, that proceeds in spirals, not in a straight line. . . ."[1]

The modern effective methods of the study of genetic material have been developed on the principles of the chromosome theory of heredity, the gene theory, and the theory of mutation. Nowadays, dialectical materialist philosophy serves as the basis for synthesising the methods of genetics, physics, chemistry and mathematics and for investigating the main aspects of life, its origin and the possibility of creating methods for controlling life. The focus of these events is the new theory of the gene, involving contemporary methods of research. The problem of interaction between the cell, the cytoplasm and the environment conceals the main mystery of the systems-structural basic properties of life as an organic integral open system.

The future of genetics will depend on the development of fundamental research, on the methodology of this research and on the connection between genetics and practice. The principal fundamental achievements will apparently be attained in (1) the gene problem; (2) the systems principles of the organisation, functioning and development of life on and outside the earth; (3) the genetics of man; and (4) the development of revolutionising methods in the practical application of genetics to agriculture and medicine.

The problem of the gene conceals the mysteries of the material basis of heredity.

The scientists studying the gene problem are treading the thorny paths of research; they will make many unexpected discoveries, breaking through old conceptions. They have entered the domain of genetic molecular structures and their functions, whose complexity supersedes everything we have to deal with in nuclear physics. Indeed, what we are facing here is the real possibility of synthesising the initial forms of life.

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[1] V. I. Lenin, "Karl Marx", *Collected Works*, Vol. 21, p. 54.

The complexity of the problem calls for a synthesis of the thinking of the physicist, the chemist, the cyberneticist, the biochemist and the geneticist. The influence of the latest achievements on agriculture and medicine will be felt increasingly every year.

On the basis of the gene theory, modern genetics as a whole has achieved great successes in the study of plants, animals, microorganisms, viruses and man. The latest profoundly materialistic developments in genetics secure its status among the leading sciences forming part of the productive forces of communism. Man has entered the age of the atom, the gene and space.

The discovery of the principles of integrality in the organisation of living matter is the condition for solving the mystery of life as one of the stages in the development of matter in the Universe. The triumvirate of DNA, RNA and proteins, which interact in the concrete circumstances of the organisation and biochemical phenomena of living structures under certain external conditions, creates the qualitative specificity of life. This, together with the gene problem, conceals the mystery of the origin of life, of the realisation of genetic programmes in individual development, of life activity, the mystery of the historical development of the cell and all organisms. All this determines the ways towards a new, systems-structural approach to the study of the cell in all its organic integrality which endows a living system with its unity of form and function.

Since 1958, when F. H. C. Crick published his work,[1] his views on the central dogma of molecular biology had been dominant. According to these views, the flow of genetic information is unidirectional: DNA →RNA→protein. In 1970, the work of H. Temin and others[2] proved that RNA molecules may function as matrices for copying DNA molecules. Thus, a revision of the central dogma of molecular biology began, indicating the development of a new conception of the living cell system. Genetic information, having reached protein, also affects the forms of the existence of the DNA genetic molecules themselves in a mediated manner, through the effect of enzyme proteins. This presents a picture of universal interaction in the cell system, the presence of specific connections, determinism and integrality. While the formulation of the central dogma of molecular biology resulted from one-sided enthusiasm for the informational cybernetic approach, the new concept of the interaction of DNA, RNA and proteins in life phenomena clearly displays a profound dialectical materialist approach to the understanding of the essence of life.

Human genetics calls for close attention, since its problems are of enormous significance for general biology, anthropology and medicine. The significance of human genetics in the future will steadily increase. Understanding of the foundations of the biology of man, his biological future, the fight against hereditary defects, man's travel in the boundless depths of space will all be affected by the development of human genetics.

The most important fact that has a bearing on human genetics is that man in his development has excluded himself from the evolution of the animal world. This eliminates the mistakes made in eugenics and scientifically refutes racialism. After the unified processes of anthropogenesis and sociogenesis had resulted in the appearance of man, an extraordinarily complicated interlacing of primary (social) and secondary (biological) factors came into being in the life of man. This qualitative leap occurred in the evolution of man alone.

The development of genetic methods, which have a revolutionising effect on practice, also requires serious methodological analysis. Apart from the general scientific foundations of selection, genetics has also created a number of fundamentally new approaches to plant, animal and microorganism selection. These include the application of methods for genetic control of heterosis, experimental polyploidy, radiational and chemical selection, etc. The role of these new methods in the light of the task of decisively increasing the world's food resources, and their correlation with the old

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[1] See F. H. Crick, "The Biological Replication of Macromolecules", *Symposia of the Society for Experimental Biology*, XII, 138, 1958.

[2] See H. M. Temin and S. Mizutani, *Nature*, 226, 1211, 1970.

classical methods of selection both require deep methodological analysis. The same is true of the new trends in medical genetics, such as the cytogenetics of man, the genetics of human populations, the treatment of hereditary diseases, the struggle against their spreading in populations, the assessment of the influence of radiation and chemical mutagens on man's heredity, the problem of malignant tumours, and the immunogenetic incompatibility of tissues. The more distant fundamental problems include those of producing controlled mutations and revealing the nature of genetic programming in individual development.

The problem of life, which is, in the final analysis, man's main interest, is becoming the focal point of natural science. The genetic reconstruction of the cell arises as a practical task; its solution will permit the control of molecular-genetics processes that are the basis of life phenomena.

The practical impact of new branches of biology on the world's food resources and raw materials and on the struggle of medicine for man's health and life is already being felt. This impact will increase enormously in the near future.

The control of life based on cognition of its essence is the central problem of modern biology. The main goal of biology is the accomplishment of the practical tasks of agriculture and medicine, and the control of world evolution as a whole.

Conditions must be created for a sharp increase in the productivity of plants, animals and microorganisms; new methods in the struggle for man's health, youth and longevity must be mastered; methods must be worked out for controlling the genetic processes on which the evolution of species is based.

A guarantee of this new stage is the fact that the achievements of the last twenty-odd years have won the central position for genetics in biology and placed it among the leading sciences of today. Carrying with it the whole of biology, genetics has become the main sphere of application of physics, chemistry and mathematics in the study of the problem of the essence of life and in working out qualitatively new ways of controlling the heredity of organisms.

The time has come for a firm union between genetics and selection; genetics and medicine; genetics and the science of education; genetics and the biological problems arising in the study of space; and, finally, genetics and the biological problems involved in the widespread use of atomic energy. Genetics as the pivotal science of life is becoming not only a vital theoretical discipline, but also a practical science which has deep practical ramifications and makes a great impact on the level of the present-day development of the social productive forces connected with agriculture and medicine.

The future of genetics holds out the prospect of countless benefits for humanity. Genetics will be fully used in the struggle for the health and wealth of the Soviet people.

The achievements of genetics in revealing the material essence of heredity, the chemical nature of the gene, the biological essence of integrality in life and in the development of the cell, as well as the development of powerful methods for controlling life which facilitate new approaches to overcoming various problems in agriculture and medicine, are an important stage in the present-day development of the dialectical materialist foundations of natural science and an instrument in the active transformation of nature.

Part IV

THE PHILOSOPHICAL PROBLEMS OF THE EARTH SCIENCES

Y. K. Fyodorov

DEVELOPMENT TENDENCIES AND SOCIAL SIGNIFICANCE OF THE EARTH SCIENCES

On several occasions Lenin criticised the views of Malthus' followers, revealing their anti-scientific nature. For example, in his long article "The Agrarian Question and the 'Critics of Marx'" he analysed the current attempts of the Malthusians of the time (the early 20th century) to blame the misfortunes and shortages caused by purely social factors on supposedly universal natural laws, and commented: "Thus, the 'law of diminishing returns' does not at all apply to cases in which technology is progressing and methods of production are changing; it has only an extremely relative and restricted application to conditions in which technology remains unchanged."[1]

The decades that have elapsed since that time have completely confirmed this brief and clearly formulated proposition, as well as the need for a careful analysis of the entire problem of interaction between society and the environment.

The rapid increase in the volume of natural resources used by man, the increased impact of man on the natural environment, the swift growth of the earth's population time and again have raised the problem of the sufficiency of the planet's resources for the needs of its population, their proper use, the protection of nature against society's harmful influence both in the scientific and sociological aspects. We

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[1] V. I. Lenin, "The Agrarian Question and the 'Critics of Marx'", *Collected Works*, Vol. 5, p. 110.

shall consider in this connection some very general features of the development tendencies and social problems of the earth sciences: geology, geography, meteorology, oceanography, geochemistry and others.

The earth sciences study phenomena and processes evolving in the very body of the earth, on its surface, in the oceans, in the atmosphere and in the space near earth, as well as the interaction of these processes. As a rule, they deal with complex processes that are the scene of extremely complicated interaction and interlacing of numerous physical, chemical, and, in the planet's outer layers, biological phenomena too.

For a long time observation under natural conditions and analysis of the results of that observation were practically the only possible methods for studying natural phenomena. In fact, they still provide the bulk of the information required by the earth sciences. In this they differ essentially from other sciences like chemistry, physics and the principal branches of biology, where the main instrument of research has always been experiment, i.e. reproduction of the investigated phenomenon under controlled conditions.

Apart from the subject matter of the earth sciences and their method of research, we should take into account the goals they set themselves. I believe that the principal objective of these sciences is obtaining information needed by society for the effective organisation of its interaction with the natural environment. In the final analysis, of course, all sciences provide society with the means of interacting with the surrounding world. In this case, however, we are dealing with knowledge that is directly employed in man's interaction with the elements, with the objects of the natural environment.

In studying concrete natural objects, the earth sciences attempt to describe, comprehend and ultimately construct a quantitative theory of the natural processes intrinsic to these objects in order to increase the efficiency with which the resources and properties of the natural environment are used, to ward off any harmful effects, and to create a scientific basis for developing a technique for transforming nature.

The principal factor determining the present-day state of the earth sciences is, in our view, the level, nature and efficiency of the interaction between society and nature.

The Modern Stage in the Interaction Between Society and Nature

There was a time when primitive man and the boundless and incomprehensible world confronted each other, face to face. Nature and resources were inexhaustible as far as the needs of the planet's small human population were concerned, and the power of natural phenomena seemed infinite in comparison with man's potential. Natural environmental conditions set narrow, insurmountable boundaries within which man's existence was possible. But gradually the situation changed, slowly at first and then faster and faster. Let us draw a brief outline of the current stage reached in mastering the earth, the degree to which its resources are used and the measure of our potential.

For many hundreds of millennia, human tribes inhabited very limited areas and each of them had some idea only of a very small part of the earth's surface. Only the last few thousands of years have witnessed the development of commodity exchange, military campaigns in distant countries and other forms of human contact, largely within one continent. In fact, it was only in the 16th and 17th centuries that the first more or less correct conceptions were formed of the surface of the globe as a whole, its oceans and continents, and of the peoples inhabiting it. Within the last fifty years the study and description of the earth's surface has been largely completed. The elimination of the few blank spots left on the map of the world, mainly in the broad expanses of the oceans, will certainly be of considerable scientific interest, but will hardly affect the development of society to any considerable degree.

Even three or four hundred years ago, the earth's surface appeared as a vast space with a few separate and weakly interconnected centres of human activity. The development of production and the rapid growth of population have increased the size of these centres and are now merging them with each other. The isolated and largely independent development of human societies and separate civilisations in the various regions of the globe has come to an end. Colonial plunder and usurpation set off the formation of a world economy and international relations. The appearance and consolidation of the world socialist system begun by the formation of the Soviet state entailed new forms of relations between countries and peoples, and gave rise to a major new trend in the development of human society at the present historical stage.

The social connections and the movements of men, raw materials and commodities, throughout the earth, which once presented serious difficulties, now require only insignificant portions of the general expenditure of human labour. World economic ties have transformed the economies of individual countries in such a way that only the largest of them could maintain their present level of existence if they were to be locked within their own borders. Any country, any part of humanity is linked by increasingly close ties with many other parts, even those in the remotest regions of the globe. These ties are developing in the fields of economics, politics, science and culture, the world is becoming more and more unified and integral, and it is not just a matter of chance that in this period man took his first steps beyond the limits of the planet.

The launching of the first artificial earth satellite inaugurated the space era. Considerable information has now been obtained about the moon, Mars and Venus, and reliable information is being relayed from space across hundreds of millions of kilometres. Man has learned to exist and work in the part of space closest to the earth, and has landed on the moon. Science has now formed a conception of the structure of the Universe up to distances of the order of around 10^{22} *km*, albeit on the basis of indirect data.

The attitude towards natural resources has undergone a substantial change. Once, many of them had no significance for man at all, whereas now almost all substances making up the earth's crust and almost all kinds of natural energy are used in one way or other in the economy. The range of practically utilised natural resources (renewable and non-renewable) has particularly increased within the last two or three decades.

The renewable natural resources are characterised by balance, a definite correlation between credit and debit. At present, a considerable proportion of the credit component of the balance of renewable natural resources is used in the economy. Thus, about 70 per cent of soil suitable for agricultural production as it is now practised is cultivated. The entire area covered by forests has decreased noticeably within the last 200 years, and in some countries more trees are now being felled than are being planted. However, in the world as a whole some 40 per cent of the yearly net increase in the number of trees is being utilised. Ten to fifteen per cent of fresh water is being used (for irrigation in agriculture, for industry and for everyday use), 10 per cent of which evaporates or is chemically bound to industrial products, and the rest is returned to the rivers more or less polluted. The number of wild animals that were once hunted and formed the main source of man's nutrition is now insignificant on the land, and they do not play a sizeable role in the balance of biological raw materials. The biological resources of the ocean considered as a whole are used to a quite insignificant degree, although some species of marine animals have been destroyed and others are close to annihilation. About 5 per cent of the rivers' energy resources is being used, i.e. about half of their entire potential (assessing it from the viewpoint of current methods of hydroelectric plant construction). The energy of direct solar radiation, the wind, the sea tides and the heat of the earth is used to an insignificant extent.

It should be borne in mind that in many countries virtually full use is being made of some of the renewable resources—soil, forest, hydropower or fresh water. Of the renewable natural resources on the earth as a whole, there appears to be a shortage of fresh water, some species of fish, and whales.

An indication of the non-renewable natural resources is given by their known, prospected deposits. Numerous computations by many economists within the last few decades support the conclusion that the deposits of the most important resources will last for periods of time from one or two hundred years to several thousand years, taking into account present mining methods and the established rate of consumption growth. Of the fuel deposits oil is, perhaps, in the shortest supply. It should be pointed out, however, that throughout history the increase in world deposits of resources resulting from the discovery of new deposits, increased efficiency in treating ores, etc. has always significantly exceeded their consumption both in absolute terms and in terms of the proportion consumed by each inhabitant of the planet, the growth of population notwithstanding. Thus, within the last thirty-odd years the prospected world deposits of coal and oil have increased by several times, and the resources of other raw materials have also increased considerably.

Let us now consider the effect of the environment on society and vice versa.

Primitive man could only exist within a very narrow range of natural conditions. Since means of protection against the harmful effects of the environment have been created, there are now no places on the earth's surface, in the ocean and even in the zone of space closest to the earth where man cannot exist and function. As the population grows and production develops, man himself is beginning to make an ever greater impact on the environment. Among the factors and indicators of this impact is the energy obtained or transformed by man in his activity.

At the primitive stage, each of the tribes, which could not have counted more than a few hundred people, was able to develop a power of a few kilowatts by working in common (the entire population of the earth at the time could hardly have exceeded one hundred thousand), whereas now power of the order of around 10^9 *kw* is available to mankind from permanent sources of energy.

10^9 *kw* is still a negligible quantity as compared with the energy radiated by the sun (10^{23} *kw*) or the energy of the earth's motion and rotation. But it is already becoming noticeable in comparison with the energy of the processes evolving on the surface of our planet, in the atmosphere and in

the ocean. These processes, which determine the diversity of climate and weather on earth, are set in motion by the flow of solar energy falling on the lighted part of the earth. Its power is some 10^{13} *kw*. Assuming that the growth rate of energy production is the same as it has been these last fifty years (and it will most likely increase), in a hundred or two hundred years' time 10^{13} *kw* will be available to mankind from permanent sources. Although man's energy resources now are much less than a thousandth fraction of this quantity, we must not take this ratio to be the measure of our present ability to affect the elements. In actual fact it is much greater.

The fact is that the natural environment does not have a rigid structure. The permanent natural processes in the atmosphere and the oceans–the motions of masses of air and water, the natural water cycle, etc.–are closely linked with each other. Changes arising in some process are passed on to a second, a third one and so on and sometimes reach the original point through the feedback circle. Not infrequently spontaneous reactions and unstable conditions emerge here. In such cases a small impulse is sufficient to switch a large-scale natural process into a different channel. Precisely these specific features of atmospheric processes form the basis of recently discovered methods of active interference in some meteorological phenomena.

The interdependence and occasional instability of natural phenomena have another very important consequence–the great sensitiveness of the natural environment to any interference with its natural regime. The spontaneous reaction which we are trying to produce in developing our methods of affecting the weather may in some cases proceed independently of our intention. Thus, the felling of trees significantly affects conditions in rivers–spring floods increase and the underground water supply in low-water periods decreases. Ploughing the steppe without taking appropriate measures considerably increases soil erosion. The heat produced in various production processes, as well as the emission of combustion products into the atmosphere, making it less permeable to thermal rays, entail higher equilibrium temperature of the earth's surface, and so on. The extent of man's interference in the course of natural processes and the resultant changes in the natural environment are the cause of justified anxiety throughout the world.

While becoming more and more independent of the state of the environment in our practical activity, we do, nevertheless, need increasingly varied, precise and quick information about natural processes. Although modern ships and aircraft can travel in almost any weather, they need much more detailed and varied information about the state of the atmosphere and the sea than their predecessors a few decades ago. This information is needed not so much for deciding whether or not to sail or take off, as for computing the most expedient and economically optimal route, choosing the itinerary of the voyage or flight conditions, the amount of load, etc.

Fifty years ago, the structure of the upper layers of the atmosphere or of the ocean depths was of purely cognitive interest for the few scholars engaged in these problems. Nowadays systematic information about the state of these media is of great practical significance for the uninterrupted functioning of long-distance radio communication and for computing the movements of space apparatus and the activities of submarines.

Increased need for information about the state of the environment–the atmosphere, the ocean, near space, the earth's crust–calls into being the organisation and rapid development of the necessary global services–meteorological, ionospheric, seismic, etc.

Thus, at present we know the whole surface of the globe, and we make practical use of all of it. The conquest of space has begun. We have extended the possibility of our existence by learning to protect ourselves effectively from harmful conditions at any point on the surface of the earth, in near space and in the ocean.

Man uses practically all the known renewable and non-renewable resources near the surface of the globe: some of them in large measure or almost completely, others only to an insignificant degree.

Our activities are already introducing noticeable changes

in the natural course of phenomena on the earth's surface, and we are beginning to master methods for controlling some of them. Our need for information about the state of the natural environment is growing.

The State and Development Tendencies of the Earth Sciences

The state of the earth sciences and the tendencies of their development are determined by the present stage in the interaction between nature and society, as described above. These sciences are, on the one hand, the product of human experience, generalised in the process of interaction with nature, and, on the other hand, they are our weapon in further extending the sphere of interaction and increasing the efficiency with which we use natural resources. What specific features of the present state of the earth sciences should be pointed out?

One feature, in our view, is the development of studies pertaining to global problems as well as to subjects outside our planet–in space. The earth sciences have always dealt with phenomena and processes developing on the whole of the planet or large parts of it. But, depending on practical needs and their course of development, each of these sciences may concentrate on certain concrete problems that may be global, regional or local.

Cognitive interests mainly called for the solution of global problems: by analysing phenomena occurring on the whole of the earth, in the whole of the atmosphere, in the ocean or in the solid body of the earth, it is possible to understand the nature of certain processes. As for practical interests, they have posed until recently only regional or local tasks. Thus, the development of weather-forecasting methods, describing the climate, geological prospecting or assessing seismic danger are primarily necessary for work in individual countries.

Recently not only cognitive, but practical interests as well have more and more frequently directed the attention of researchers in this field towards global phenomena. This is apparently explained by the increase of the share of global elements in practical activity. Air communications are becoming increasingly distant, and the exploited regions of the oceans are now much farther removed from the nearest shore. Finally, flights and man's entire activity in near space are naturally of a global character. Because of this, information about the state of the environment on the whole of the earth, and comprehension of the processes unfolding on a planetary scale are acquiring greater practical significance, and the earth sciences are becoming truly global in nature.

Great significance is now attached to space. We believe that this is, on the one hand, a consequence of newly discovered possibilities of obtaining information about objects in space, and, on the other hand, a response to the practical needs arising in the conquest of space. Thus, the geochemist, studying the natural cycle of substances on earth, now, naturally, sets himself the task of studying the general laws of the cycle of substances on different planets under their specific conditions. The meteorologist's object of research is no longer the earth's atmosphere, but also the atmospheres of other planets. The assessment of the possible structure and properties of planetary atmospheres is now acquiring essential practical significance for the computation of flights to the planets and landing on their surfaces. Similar requirements and possibilities arise in the study of other geophysical phenomena. This important aspect of the development of the earth sciences is an instance of what may be called the "cosmicisation" of modern science.

The increased role of global and space problems in the earth sciences is generating a considerable growth in international co-operation, which is, apparently, of the greatest significance in just these problems. Over the last two decades a large number of new international scientific organisations have appeared in addition to those already functioning with success. There has been a noticeable increase in the number of international scientific conferences, symposia and congresses.

We pointed out above that until recently the only research method used by the earth sciences was the method of observation. This made a specific imprint on their development. In the past each of the sciences began with the accumulation of

factual material. Obtaining information, the development of various methods and instruments for observation and conducting observations in different regions of the earth required immense labour and attention. This work is far from accomplished, but it is now seen as the means rather than the end.

All earth sciences are now passing, in one way or another, from description and the simplest, mostly qualitative analysis of observation data to the development of quantitative theories built on a physico-mathematical basis. This is brought about, in our view, not only by the general logic of the development of any field of knowledge (it is a well-known fact that mathematisation is spreading to all scientific disciplines, including the humanities), but also by a sharp increase in the practical requirement for a greater volume and, more importantly, greater precision of data about the state of the natural environment. Precise knowledge of meteorological or hydrological conditions, deposits of natural resources, the probability of earthquakes of varying force, etc. is necessary in designing various structures or planning economic measures. It is easy to see that erroneous or imprecise assessments of environmental parameters in construction always result either in the destruction of what is built or in superfluous durability and unjustified expenditure. As the scale of construction grows, this waste caused by ignorance becomes colossal.

Only physico-mathematical analysis provides objective methods for the computation of future states of the environment, first and foremost for the numerically expressed weather forecasts. The transition to the physico-mathematical basis proceeds in different ways in the various earth sciences. Moreover, it is not being effected without argument and controversy. Some scholars believe that the earth sciences are descriptive in their very essence. We believe this viewpoint to be quite erroneous. Description characterises only the initial stage in the development of the sciences in question. Their further development inevitably leads to the construction of physico-mathematical quantitative theories, which is the most characteristic feature of the present-day state in each of the earth sciences. This transition is proceeding, perhaps, under the most favourable conditions in meteorology: nowadays meteorology is almost indistinguishable from atmospheric physics. However, in such sciences as geography and geology, the transition is accompanied by much greater difficulties.

The physico-mathematical restructuring of the earth sciences increases the role of experiment. Nowadays artificial reproduction under laboratory conditions of the various elementary processes is widely practised, such as the behaviour of substances under the extreme pressures characteristic of the deep layers of the earth's crust, and the specific features of phase transitions of water in clouds. Experiments in the natural location have begun too, particularly in developing methods for affecting natural meteorological phenomena, e.g. the stimulation or inhibition of cloud development, precipitation, etc.

A more or less profound introduction of the ideas and methods of physics and mathematics into the earth sciences caused the rapid change now taking place in the technical apparatus used. This is of particular significance, since it is an invariable feature of the earth sciences that they process enormous amounts of factual data characterising the state of the natural environment at different points in space and moments in time. The volume of information required grows as practical needs make us deal with increasingly fine distinctions in the state of the environment. This, in turn, conditions the development of observation means and methods of analysing the data obtained. As for observation techniques, the most important aspects of their development are the application of telemetric devices, movable platforms and remote control methods.

Even several decades ago, just as in the previous one or two centuries, the measurements of the state of the environment–air temperature, magnetic field strength, the velocity of river flow, etc.–were mostly taken by an observer on the spot.

Apparently, the sonde that went up in the Soviet Union in 1930 was the first radiotelemetric system in the world. A small balloon carried devices to indicate temperature, humidity and atmospheric pressure together with a miniature radio transmitter to communicate information about the structure of the atmosphere up to a height of several kilometres. Later, again in the USSR, the first automatic weather stations appeared in remote places on land and on the drifting icefields of the Arctic, which transmitted regular information about the weather, and, finally, meteorological rockets. Telemetric systems are now used in many meteorological, oceanographic and various other geophysical investigations and services. Such systems are of special significance in outer space research where extremely complex measuring and control devices mounted on spaceships are sent from the earth to other heavenly bodies hundreds of millions of kilometres away from it to obtain information.

Measurements in the ocean have for quite a long time been taken with the help of mobile units (ships). Recent decades have seen wide use of specially equipped planes for determining quickly the state of geophysical fields and various characteristics of the earth's surface on a large scale, e.g. for magnetic survey work, mapping sea ice, surveying sea temperature, assessing crops, etc. The earth's artificial satellites have proved to be extremely suitable movable platforms for determining rapidly the characteristics of geophysical elements on the entire surface of the globe. In recent years the USSR and the USA have created special space-borne weather-monitoring systems which provide a review of the state of the atmosphere around the whole earth once or twice a day.

Of great importance for advances in observation techniques is the development of remote-control instruments for probing planetary environments. Geophysicists have long used the passage of natural seismic waves through the earth's body to discover its inner structure. Analysis of the propagation of acoustic waves arising in the air from large explosions permitted us to establish the specific structure of the atmosphere. This stimulated the use of artificially generated seismic, acoustic and hydroacoustic vibrations to reveal the structure of the earth's crust, the atmosphere and the ocean. Radiation in the radio frequency range proved very effective in discovering and measuring the characteristics of many atmospheric phenomena both in the ionised regions of the upper atmospheric layers and in precipitation, clouds and some other phenomena of the lower layers.

Application of telemetric, remote-control and movable measuring systems creates the conditions for, and at the same time requires automation of, the analysis and processing of data (because of the great speed at which information is obtained and the vast amount of the processed data). Automation of observation and the mechanisation of data processing are being introduced into meteorological research and meteorological services.[1] At present, automatic lines have already been realised for the entire cycle of obtaining and analysing meteorological and hydrological information–from measurements at stations to numerically expressed forecasts obtained through large computers. But the situation in other earth sciences is different. Automation is as yet insufficient in the time-consuming processing and analysis of geophysical measurements used in prospecting for natural deposits and in the study of the structure of the globe.

Finally, essential for the present state of the earth sciences is the development of problems involved in active interference in natural phenomena, and in the goal-directed transformation of the natural environment. Some of these sciences have dealt with problems of transformation of the natural medium they study throughout their history. Thus, hydrology of land-borne water, pedology and silviculture have grown and developed together with hydrotechnology, agronomy, forestry, etc., but the range of the transformation, the proportion of natural resources transformed through practical activity, and the effect on the natural processes have until now been insignificant. In recent decades the range of the transformation of the natural environment and interference with the natural conditions have grown sharply.

Power-generating, meliorative and transport hydroengineering installations change the structure of rivers within short periods of time in greater measure than natural processes in the riverbeds over thousands of years. River systems that have been reconstructed now constitute a considerable share of the entire river network of the globe. Even more considerable are changes introduced in the state of the soil, the forest and other elements of the biosphere. However, our understanding of the various processes in the natural environment after man's interference, and particularly of spontaneous reactions and control chains, does not correspond to the technical possibilities available. It is not difficult to calculate the time needed to fill a new water reservoir or its capacity, but it is much more difficult to assess its future biochemical conditions and, accordingly, the possibilities of fishing, the dynamics of the littoral or the effect of rising ground waters over large areas. It is easy to chemically exterminate the pests (and, incidentally, all other insects) over a considerable area, but it is difficult to guess what sort of new ecological equilibrium will be established in this area and when, and what its ultimate effect on the protected culture will be.

Research lasting many years was required to understand the complicated processes of the transfer and precipitation on to the earth's surface of the radioactive particles formed in nuclear explosions, although the basic laws of atmospheric motion were known. There is much that is not yet clear in the perturbations that a high altitude nuclear explosion produces in the extremely sensitive upper layers of the atmosphere.

True, the great sensitivity of this medium is fraught with the danger of unpredictable and frequently undesirable "secondary" effects of our interference in the environment, but at the same time it opens up the possibility of controlling some natural processes. For instance, meteorology makes wide use of the spontaneous reaction of the transition of a supercooled water cloud into crystalline state. To bring about this reaction, it is sufficient to introduce a few dozen grams of iodic silver or other substance suitable for the formation of crystallisation nuclei for each cubic kilometre of the cloud, by firing a shell or rocket into it, or by scattering the substance from a plane. Under certain conditions the further course of this reaction may result in dispersion of the cloud or fog, small precipitation or the inhibited development of a powerful hail cloud. It should be noted that a few dozen grams of the right reagent introduced into a cloud essentially affect processes involving tens of millions of kilowatts. Dispersion

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[1] **Y. K. Fyodorov, "Technical Reorganisation of the USSR Hydro-**meteorological Service", *WMO Bulletin,* October 1964, p. 182.

of low clouds and fogs at airports in winter and protection of crops against hail are actually practised in the USSR.

The achievements in the control of certain local meteorological phenomena are, naturally, an incentive towards considering interference in large-scale processes including the task of changing the climate. The main point in this problem is, we believe, the stability and uniqueness of the climate. Since it is the result of a relative and variable equilibrium of a complex conglomeration of processes developing in the atmosphere and in the ocean, the climate depends on the quantity and composition of the solar energy falling on the earth, the direction of the axis, the rotational and orbital velocity of the earth, and the size and distribution on the planetary surface of continents, oceans and mountain ranges.

There is reason to believe that, assuming identical basic features of the structure and peculiarities of rotation of our planet, not one, but several, different equilibrium states of all the climate-forming processes are possible, and that at times this equilibrium may be unstable. If correct, this assumption opens up the fundamental possibility of changing the climate by applying energy that is much smaller than that needed to maintain it. Naturally, in this case too we are thinking not of any climate whatsoever, but of one of the possible climates which may be more favourable in some regions, but will almost certainly be less in others.

The task of transforming the climate can hardly be regarded as an urgent one at present. However, the increased range of man's interference in the natural environment and the need for the precise evaluation of its consequences, the budding possibilities of controlling some natural processes and the realised danger of undesirable spontaneous reactions in the environment have all considerably heightened interest in active interference with natural processes.[1]

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[1] See Y. K. Fyodorov, "Active Interference in Meteorological Processes", *Meteorology and Hydrology in the Fifty Years of Soviet Power*, Leningrad, 1967 (in Russian); G. K. Sulakvelidze, N. Sh. Bibilashvili and V. F. Lapcheva, *Precipitation Formation and Interference in Hail Processes*, Leningrad, 1965 (in Russian); Y. K. Fyodorov, "Weather Modification", *WMO Bulletin*, July 1967, p. 122.

Some Social Problems

Let us consider a problem which is, we believe, the principal problem of a social nature that faces the earth sciences—that of the rational use of the earth's natural deposits.

The question of the sufficiency of natural resources for meeting the needs of the rapidly growing human society has, of course, since Malthus' time, become a social problem. Malthus attempted to explain and justify the inevitability of poverty in contemporary society by the imbalance between the increasing population and decreasing soil fertility, whereas his modern followers take a broader view of the question. Pointing to the finite nature of all the world's natural resources, they contend that this sets a limit for the development of society. They explain the difficult economic situation in many developing countries by the accelerating growth of their populations versus their still low rates of economic development; they believe a decrease in the population growth to be the only way out of the situation.

It should be noted that forecasting the earth's population on the basis of its present rate of growth seems an extremely dubious procedure. The organised community of the future will certainly be able to put definite limitations on its growth, if it finds this necessary.

Incidentally, humanity now faces the increasingly more serious problem of regulating not only its quantitative, but also its qualitative composition—the problem of education and training in the broadest sense. Of particular significance are the following aspects of the problem: harmonious combination of the personal interests of every individual and of the collective's social interests; timely and effective transfer of the most valuable possessions of the vast and rapidly growing treasury of world culture to each new generation and suitable professional training based on the present and future needs of society and the abilities and inclinations of every individual.

We can see that at present only countries following the socialist road are paying proper attention to this problem and that it is being handled on a principled and correct basis. A society which does not have a definite goal and a long-range perspective of its development is unable to solve this problem.

The problem of regulating the qualitative composition of society may reveal completely new aspects and unexpected difficulties. Advances in the study of the hereditary mechanism have, some biologists believe, brought us close to mastering certain of its functions, which will permit us to plan and create some of the characteristics of future generations. At present, perhaps, half the families in the world have the practical opportunity to have or not to have a child according to their wish; but the time is, probably, not too distant when parents will have the means at their disposal to impart to their future child a special ability for music or literature, or the features of aggressiveness or kind-heartedness. Will not the social and moral problems (as A. Buzzati-Traverso seems to think[1]) be more complicated than the problem of regulating the size of the population? We cannot go into these interesting questions here. What we want to find out is this: does the finite nature of natural resources create now or in the foreseeable future a fundamental threat to the well-being of a growing population? Does it set a limit to the development of human society?

The earth and all its resources certainly have finite limits. But the efficiency of their exploitation in the widest sense of the term, particularly in relation to the progress of technology and transformation of the means of production, of which Lenin wrote,[2] is increasing so fast that the potential for satisfying the basic needs of society throughout history has been growing faster than the needs themselves. Let us cite a few examples. If we assessed the quantity of energy that might be obtained by using all the resources and means known in the mid-19th century, the net result would be about 10,000 *kwh* per head. The present-day evaluation is about 200,000 *kwh* per head. It is easy to see that this growth in potential energy resources is explained by the progress attained within the last hundred years in obtaining energy. New natural deposits have been found, new sources of energy discovered, the efficiency of energy transformers has been increased, and so on. And we have not yet taken into account such sources, now known in principle and undoubtedly available in the future, as the direct transformation of solar energy, the earth's heat, tides and wind, not to mention the energy of nuclear synthesis. We can also expect the discovery of fundamentally new ways of obtaining energy. There is definitely no energy shortage threatening humanity.

There is no threat of a food shortage either. An indicator of the continual growth of the productivity of agriculture is the constant reduction of the proportion of the population engaged in it. The mere spread of the efficiency already attained in the advanced countries to the entire farming world would yield a huge increase in production. And this in spite of the extremely low efficiency (less than 1 per cent) of the photosynthesis reaction through which, in the final analysis, the whole of agricultural produce is obtained. Meanwhile, there is no reason whatever to consider this efficiency level to be the limit. It is a fact that only a very small part of the vast biological productivity of the ocean is used at present. There are already in existence various methods of producing synthetic foodstuffs. Thus, in this field, too, we observe a rapid growth in the possibilities of obtaining food per head.

We pointed out earlier the rapid growth in the prospected deposits of mineral raw materials. There is hardly any need to show that a similar situation exists as regards the problem of materials. We are witnessing the swift development of entire industries producing materials for satisfying man's extremely varied needs out of easily accessible and cheap kinds of natural raw materials. Thus, we see that society's needs, which are growing because of the increase in population and in each individual's requirements, should not be related to some constant limiting quantity, but to a variable and increasing possibility of satisfying them through

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[1] See A. Buzzati-Traverso, "Tendencies in Modern Biology and New Moral Responsibilities", *Scientific World*, No. 4, 1967, p. 13.

[2] See V. I. Lenin, "The Agrarian Question and the 'Critics of Marx' ", *Collected Works*, Vol. 5, p. 110.

discovery of new and more effective use of the existing natural resources of the planet.

So far fundamental possibility of satisfying society's needs, considering the resources of the whole planet in relation to the whole of humanity, has been growing faster than the needs. There are no grounds for believing that the situation will change in the hundreds of years to come. At the same time, we cannot, naturally, contend that this will always be so. The finite nature of the size and mass of the earth may in the distant future limit the size of its population to a definite optimal number.

But the door into space has already been opened, and it is not hundreds of years, but decades that separate us from communication with other planets. It is not a matter of the hypothetical "colonisation" of other planets, but of the coming of the space age in the development of human society—an era in which the sphere of its practical activity is no longer limited to the earth, but is extended, in the foreseeable future, to the nearest planets of the solar system and later, without any doubt, farther.

It is at present difficult to foresee the concrete forms of man's exploitation of the natural resources of the Universe outside the earth. But the very fact that the possibility of breaking out into space and of flights to other heavenly bodies has been attained much earlier—hundreds of years earlier—than mankind may approach the limit of exploiting the riches of the planet is, in our view, the most general and convincing indication of the fact that the growth of man's possibilities keeps ahead of his needs. It follows that neither the resources of nature nor its laws at any time in the past, present or future have set or could set limits on the growth and development of mankind.

From time to time, there happen in the biosphere peculiar catastrophes that are due to a rapid growth of the number of organisms in some region where the volume of resources used is invariable, or in cases where the population is invariable, but the resources are reduced or disappear. Here the destroyed equilibrium can only be restored by a reduction in population through starvation or mass migration to other regions, since the efficiency of the interaction between plants or animals and the environment is increased through slow changes in their biological nature, and through the formation of new species. But none of this can be applied to human society.

Malthusian impasses could have appeared at every stage in the development of mankind, at different levels of population, if technology had not advanced and the means of production had not been transformed. It is clear that not only the present, but even a much smaller world population could not live by hunting or by primitive forms of cattle-breeding, as our distant forefathers did—the natural resources would be insufficient for that. But one can only talk about a surplus world population in the future if one proceeds from the present possibilities of exploiting the resources of our planet, and assumes that technical progress will come to an end.

The development of human society in its interaction with the environment may, apparently, be regarded as a kind of chain reaction in which each stage creates all the necessary conditions for the considerable growth and expansion of the next. Human society constitutes a natural and supreme stage in the development of life in the Universe, a development that is unlimited in time and space. In this respect we support the profoundly optimistic and interesting conception put forward by G. F. Khilmi.[1]

It should be emphasised that in referring to the possibilities of human society we mean fundamental possibilities, determined by the appropriate level of scientific and technological progress. The practical possibilities in any given country differ substantially from the theoretical ones. But the reasons for that belong to the domain of social phenomena. Thus, prolonged colonial exploitation and the resulting technical backwardness, lack of qualified personnel, and other social causes led to a situation in which, over the last 25 or 30 years, the developing countries have increased agri-

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[1] See G. F. Khilmi, *Foundations of the Physics of the Biosphere*, Leningrad, 1966 (in Russian).

cultural productivity by 8 per cent, whereas the USA and Canada have increased their agricultural productivity, high as it was, by 25 per cent. If the rate of population growth in a developing country is 2 per cent, while the rate of economic growth is 2.5 per cent, one can hardly expect a rapid rise in standards of living. In a situation like this, some countries may, quite understandably, look for a temporary solution in a planned reduction of the birth rate. But the main solution lies in the rapid acceleration of the rate of economic growth. That this is feasible is proved by many examples from the development of socialist countries, for instance, the development of the Soviet republics of Central Asia. Only social reasons interfere with the effective exploitation of natural resources.

The divergences between countries with different social systems in their attitude to natural resources are noteworthy. The socialist countries have declared all their natural resources to be the property of the whole people, and so from the very outset take serious measures to study, conserve and develop them. It is not out of place to recall here that the extensive and immediate study and registering of the country's natural resources was listed as a prime task in Lenin's draft of the plan outlining the most urgent tasks of the Academy of Sciences.[1] In 1918-1920 large research institutes and surveying and prospecting expeditions were organised with this aim in view. The Soviet Government still follows this line, and so do other socialist countries. The result is that the prospected deposits of natural resources have grown dozens of times over and now completely cover the current and future needs of socialist countries. Vast hydroengineering construction became possible, the Northern Sea Route was opened, and so on.

The developing countries which recently freed themselves from colonial dependence face a very complicated situation as far as natural resources are concerned. As a rule, they are extremely rich in various natural resources. But the

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[1] See V. I. Lenin, "Draft Plan of Scientific and Technical Work", *Collected Works*, Vol. 27, pp. 320-21.

struggle for possession of their own mineral deposits, forests, arable land and waters proves in many cases to be more difficult and complicated than the struggle to gain formal political independence. It should also be noted that at the time of colonial domination the metropolitan countries had no interest in the comprehensive study and development of the natural resources of their colonies. They were only interested in whatever promised high profits within a short period. The main result of this policy is the abnormal monocultural system. The lack of trained national cadres, experience and equipment creates additional obstacles. But the great efforts made by the developing countries, as well as the aid from socialist countries, will, undoubtedly, enable these serious difficulties to be overcome. The young states will in the end wrest their natural riches from the hands of foreign monopolies and use them in their national interests.[1]

Recently, the developed capitalist countries also included the problem of natural resources among the most urgent national problems. After about two hundred years of predatory exploitation of their natural wealth a very grave situation has emerged in these countries as regards water, forests, soil and some mineral deposits. The threat of the complete destruction of, or considerable damage to, the natural resources induced the adoption of rational measures for their protection and planned exploitation: soil erosion is being checked, the felling of trees is strictly regulated, measures are taken against air and water pollution, and well-organised national parks have been opened up. But the industrial capitalist states take these measures only at home.

The monopolies of the USA and other Western countries continue the predatory exploitation of natural resources abroad, mainly in the developing countries, reaping enormous profits. They cling to their possessions and privileges acquired in the colonial times and attempt to consolidate and expand them economically. It is well known that the entire

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[1] See Y. K. Fyodorov, "Some Problems Relating to Developing Countries", *Impact of Science on Society*, Vol. XIII, No. 4, 1963, pp. 279-84.

state policy of the USA and other Western countries towards the developing countries is directed at the consolidation and extension of the possibilities for shameless exploitation of the natural resources and manpower of the developing countries.

Simultaneously the USA is now taking various measures to secure the most favourable conditions in the exploitation of the resources of our planet that are as yet "no man's"—the oceans, the continental shelves and the seabed. The USA is preparing for a possible carve-up or seizure of these riches.

Thus we see that a mere fraction of the enormous potential for the effective exploitation of natural resources is being realised owing to purely social reasons—the existence of the capitalist system, the economic subjugation of some countries by others, colonialism and neo-colonialism, disunity and the lack of comprehensive co-operation in human society as a whole. Both technically advanced and backward and ineffective forms of agricultural production coexist on our planet, which means that the sum total of all arable land and forests is, on the whole, exploited not only irrationally, but in a predatory manner as well. This signifies a decrease in the extent of these riches for man.

The ocean's riches are, on the whole, also exploited rapaciously. The existing international agreements on fishing including whaling solve only a very small part of the problem of effective control. Meanwhile, it is quite possible even now to pass over from fishing of the ordinary type to pisciculture or, on broader lines, to cultivating the assorted biological products of the ocean on a global scale.

The present level of knowledge and technology already permits not only of the planned and effective exploitation of all the renewable natural resources on the earth—it also makes it possible to begin work on changing the balance and total resources of the most important renewable resources (fresh water, forest, etc.) both in the various regions of the globe and on the earth as a whole.

But this will be impossible until a human society, unified in its organisation and functioning, appears on the earth.

Thus, it is not insufficient resources, but their uncontrolled and disorganised exploitation on a global scale that creates difficulties for the development of society now and threatens us with grave consequences. This is particularly true of the renewable natural resources at the not-so-remote time when the degree of their economic exploitation will increase and approach the upper limit.

The other danger lies in the rapid increase of man's effect upon the natural environment. We mentioned earlier that nature is quite a sensitive system in a kind of dynamic equilibrium. The fast growth in heat emission near the earth's surface due to the operation of industrial enterprises, the melioration of arable land, the felling of trees, the construction of hydroengineering installations, the introduction of new substances into the natural chain of reactions from the industrial waste emitted into the atmosphere and water, as well as the widely used chemical fertilisers, herbicides and insecticides—all this is already producing a direct effect, quite noticeable against the background of the natural processes, small though it is. If the present rate of growth of productive forces is maintained, it is to be expected that within the next few decades this effect will in some cases be comparable in scale with that of natural processes.

Taking into account the instability of the natural environment and the possibility of spontaneous reactions, one should reckon with the possibility of spontaneous violations of the environmental balance and the transition to other, perhaps undesirable, states. On the other hand, the instability of natural processes, as was pointed out earlier, opens up the possibility of deliberately influencing them by weak stimuli.

However, realisation of this possibility at a time when reactionary forces are dominant in the capitalist countries would be more likely to cause a "meteorological war", of which some politicians and military men in the USA dreamed in the 1950s,[1] than major planetary measures to rationally transform the climate.

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[1] See *Bulletin of the American Meteorological Society*, No. 6, 1953.

It should be noted that technological progress rapidly develops in any field of human activity a possibility for controlling large-scale processes in the broad sense of the term. Vast quantities of energy are governed at the control centres of integrated power systems, modern industry is capable of mass-producing enormous amounts of any type of commodity, activity on an insignificant scale may be sufficient to unleash a nuclear war, and so on. Naturally, increased ability for control must be accompanied by a growth in its reliability and a guarantee of its purposiveness, since the scale of the possible losses and disasters for humanity resulting from errors in control is growing just as fast. An increase in the reliability of control is actually taking place within individual enterprises and larger production units and, in a planned socialist economy, within whole countries, but this is, obviously, not the case as far as humanity as a whole is concerned.

There is a definite gap between the already existing and rapidly developing ability to produce effects of a global nature and the absence of a suitable social mechanism not only for controlling such effects, but also for assessing their expediency from the viewpoint of all mankind. When all or nearly all of the renewable natural resources are included in the practical activity of mankind, major long-term measures on a global scale to rationally transform the planet's natural environment will become an absolute necessity. It will be necessary to manage the integral "nature's" economy, including the cultivation of natural resources on a global scale, just as efficiently and rationally as is now required in agricultural production on a farm, plantation, collective or state farm in socialist countries. Because of this, the problem of deliberate transformation of the natural environment, and the tasks of cultivating the most important natural resources on a global scale will become the principal ones in the totality of the earth sciences, including those studying the biosphere.

In the next few decades the registration of the main nonrenewable natural resources and the assessment of the balance of renewable resources on the whole planet and in the various regions must be accomplished and methods must be found for exact calculation of the consequences of the various types of modification of the natural environment. Special significance attaches to the study of spontaneously developing reactions and to the search for methods of control. It is easy to see that these problems, common to all the earth sciences, are now becoming vitally important not only in the scientific, but also in the socio-political field.

The present state and development prospects of the earth sciences within the national framework, as well as the rapidly growing and strengthening co-operation between scientists of different countries in this respect, guarantee the successful and timely solution of these problems. But this is not enough. Harmonious interaction with the natural environment at the nearest stage of man's total exploitation of the planet's resources requires a positive goal and perspectives of the development of human society. Marx, Engels and Lenin discovered this goal and substantiated the laws and perspectives of development. They created the conviction that the unity of human society in general and in relation to nature in particular would be attained, through peace and socialism, before the predatory exploitation of the planet's resources or unco-ordinated interference in the natural environment resulted in irreparable consequences.

Part V

PHILOSOPHICAL AND METHODOLOGICAL PROBLEMS OF CYBERNETICS

A. I. Berg and B. V. Biryukov

CYBERNETICS AND THE PROGRESS OF SCIENCE AND TECHNOLOGY

The distance covered by science over the last fifty years is enormous. The discoveries made on this road are milestones in the enrichment and extension of the scientific picture of the world, and we owe them largely to the achievements of mathematics and technology. From the theoretical point of view, mathematics and the technical sciences are the most important elements in the modern scientific and technological revolution, which, in its turn, exerted a powerful influence on the economic life of society and on social structures, and stimulated the progress of science entailing qualitative changes in the whole sphere of fundamental and applied research.

The scientific and technological revolution is linked with the twofold process of the *differentiation and integration of sciences.* This article will deal with cybernetics, and we shall, therefore, emphasise that aspect of the dialectical phenomenon "differentiation versus integration" which is expressed in the *synthesis of knowledge.*

Early in this century many scientists viewed specialisation in scientific research as a natural and irresistible development: the volume of knowledge was rapidly growing, the sciences branched out. It was believed to be good form to stress the delimitation of "spheres of influence" between pure science and applied fields. But even at that time these tendencies–the tendency towards differentiation (specialisation) and towards opposing theory and application–were resisted by the trend towards integrating scientific ideas and strengthening the ties between scientific theories, on the one hand, and technical and social practice, on the other. Scientists attempted to control the "Babel of tongues" of the growing multitude of scientific disciplines by constructing if not a genuinely "unified" language, then at least a small number of languages of the basic, fundamental concepts. The systems, or "languages", of such concepts contributed to the ideological unification of different scientific trends. This synthesising role was, of course, played by philosophy, and later, at the turn of the century, by physics as well. Still later–and this is essential for the present paper–the role of a powerful synthesiser was played by the *mathematisation of the sciences* and the formation and development of a new interdisciplinary scientific trend, *cybernetics.* Although mathematisation and cybernetics themselves contributed to the ramification of knowledge, this was outweighed by their integrative function, which has been universally acknowledged by scientists and engineers.

The Problem of Control

Cybernetics is the answer of human knowledge and technical practice to the social need to control and organise by precise methods. In the USSR the need to control and organise became clear right at the outset of the new society. Soviet power was only months old when Lenin set the goal of the scientific organisation of labour and management. In his work *The Immediate Tasks of the Soviet Government,* written in 1918, he said that, since the task of suppressing exploiters had on the whole been completed, the next urgent task was the management of the state. The main goals were economic ones: victory in the economy and in production, universal accounting and control. Lenin criticised the negative nature of the American Taylor system, but at the same time he suggested that the positive features of the system for organising labour should be taken into account. This was to be used to increase productivity and to improve the organisation of production in a society based on social owenrship.

This work was delayed by the Civil War and its consequences. But after five years Lenin again turned to problems of organisation in his article "Better Fewer, But Better" and other works. He insisted on energetic measures to perfect the state mechanism of the Soviet Republic. A public movement for increasing the efficiency of labour and management gradually developed. The first centres appeared whose goal was to elaborate theoretical problems and to implement the scientific organisation of labour. Decades have elapsed since that time. The country's economy has grown hundreds of times. Vast experience has been gained in the field of management and organisation, and great successes have been achieved in the planning and management of the economy, and in regulating social relations.

Progress in the economy and in the methods of economic planning called insistently for better management. But the problem of management is closely linked with another important problem–that of *information.* To achieve good management, one must master information processes, theoretically and practically.

The situation as regards information in all the developed countries, including the USSR, has become quite complicated.

The normal functioning of developed countries is now impossible without processing enormous amounts of information in quite specific, and usually very short, periods of time. It should be recalled, for example, that tens of thousands of different *types* of intricately connected indices are used in the management of a modern enterprise, let alone larger economic, production or administrative units.[1]

The mastering of information and management processes is not necessary for its own sake, but for increasing labour productivity and for the further continuous growth of the efficiency of man's work in the spheres of material production, intellectual effort and education.

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[1] See Y. I. Chernyak, Y. Z. Maiminas and V. M. Zherebin, "Economic Cybernetics", *Cybernetics in the Service of Communism,* Moscow, 1967, p. 367 (in Russian).

Indeed, with the growth of productive forces, the range of production widens and its content becomes more complicated; with the growth in the scale of production, the complexity of economic management is growing even more rapidly, the flows of economic information are increasing and the methods of processing it are changing; the increased intensity of technological processes is making new demands on the speed and precision with which they are managed; with the growth of the national economy as a whole, management under optimal conditions comes to be of great economic significance; the complexity of the managerial apparatus of a giant state makes higher demands on the speed and reliability of collecting, processing, producing and using information at all levels.

The development of science also implies an increase in the volume of information processed. The lone scholar type is becoming a thing of the past–in fields involving the applied sciences, at any rate. The solution of major scientific problems is now usually achieved by large bodies of scientists. These bodies have powerful equipment available and great advantages as regards obtaining and processing scientific information. Descriptive sciences are being transformed into exact sciences using not only informal and qualitative, but also mathematical and logico-mathematical methods of research. The development of theoretical methods and the creation of technical means for processing information aimed at achieving effective (ideally, optimal) solutions is an urgent necessity in modern society.

Thus, cybernetics, like the scientific organisation of labour in the USSR in the 1920s and early 1930s, arose from, and is developing in accordance with, the objective demands for a better organisation of labour, and for increasing its productivity and efficiency. But, as distinct from the scientific organisation of labour in the period–a movement founded on very modest scientific and technical means–cybernetics is based on a new powerful branch of science and technical practice–on electronics and, in particular, radio electronics.

Cybernetics was formed as an *extremely comprehensive* trend. It was called into being, on the one hand, by the design

and application of complex automata, automation of production, electronics and computers. On the other hand, cybernetic ideas were prompted by branches of knowledge pertaining to control and information processing in *concrete* spheres, such as the science of life. Thirdly and lastly, the inner logic of the development of the most abstract sciences –primarily mathematics and some branches of theoretical physics–created a conceptual and theoretical apparatus that was later used in constructing cybernetics.

The wide range and synthetic nature of cybernetics were clearly expressed in the work of its creators. At the time when the ideas of a new science were maturing in the mind of Norbert Wiener, the mathematician, he was working in the USA and Mexico together with specialists in other sciences, in particular with the physiologist A. Rosenblueth. C. Shannon laid the foundation of the mathematical theory of information taking communication technology as his starting point. The interests of J. von Neumann, one of the men whose ideas fathered modern computers, ranged from logic and the foundations of mathematics to the theory of games and mathematical economics. The British mathematician A. Turing who gave the first description of an "abstract automaton"–the prototype of the later computers, was the first modern scholar to pose the question: "Can machines think?" The Soviet scientist A. N. Kolmogorov, who made a great contribution, like Wiener, to the mathematical foundations of the new field of knowledge, extended his "cybernetic" interests, after the recognition of cybernetics, to include the problem "automata and life" and mathematical versification. Specialists in automatic control–in particular, scientists in the USSR–have placed their research on a cybernetic basis. I. P. Pavlov's theory of higher nervous activity, reflexology and the psychology of behaviour, on the one hand, paved the way for cybernetics, and, on the other hand, formed a close union with it when it took shape. Suffice it here to point out the writings of P. K. Anokhin, and of N. A. Bernshtein who laid the foundation of the "psychology of activity" and applied mathematical methods in his work.

Cybernetics more than any other science deserves to be called a *crucible of ideas*: it is a crucible smelting ideas, old and new, into a fusion of *new*, fundamentally important scientific results.

It is generally known that the path of new ideas is not always strewn with roses. This is also true of science. In science, as in other fields, one meets with all sorts of people. Some are progressively-minded and are unafraid of difficulties and risky problems, others are careful men with a penchant for a "quiet life". But there are also conservatives fearing the new, usually trying to defend their positions by reference to authorities. In the past they used to accuse their opponents of sinning against dialectical materialism. In the early 1950s, these worthies made a stand against "the false science of cybernetics", masquerading as orthodox defenders of dialectical materialist philosophy. We all know the harm done to Soviet science by these views. The translation of Norbert Wiener's book *Cybernetics* was held up for ten years. And even after the publication of Wiener's book and after cybernetics was widely recognised, "anti-cybernetic" views can from time to time be traced in books and papers—sometimes in veiled form. The fight is by no means over. To demonstrate "originality of thinking" rather than anything else, some scholars insist that the interdisciplinary science of control and optimisation does not exist, and that cybernetics is a seasonal, transitory phenomenon, a kind of fashion....

These views inhibit the development and application of cybernetic, mathematical, quantitative and precise methods and technical instruments, particularly digital computers. This applies not just to the humanities (psychology, pedagogy, linguistics, economics, etc.), where cybernetic ideas seem to some people to be something alien even now: the negative attitude towards cybernetics also produces a harmful effect on the applications of new ideas and methods in the natural sciences (biology, medicine) and the technical sciences.

The theoretical foundation on which the independence of cybernetics in the system of modern knowledge is based is the content of its fundamental concepts and the nature of the methods applied. These are the concepts of *control*, *information* and *optimisation*, and the methods of ***modelling*** and *algorithm construction*.

There exist several definitions of cybernetics at present. Some of them are based on the information aspect, others on the algorithmic one. Still others point to the concepts of causal network of feedback as expressing the specific features of cybernetics. An obligatory feature of all definitions, however, is reference to the goal of studying the *systems and processes of control* by mathematical methods. We may say that there is a well-established conception of the subject matter of cybernetics in Soviet science. It is reflected, for example, in the definition of the concept of "cybernetics" in the Soviet *Philosophical Encyclopedia*: "Cybernetics ... the science of control processes in complex dynamic systems, based on the theoretical foundation of mathematics and logic, as well as on the application of automata, particularly electronic computers, programme-controlled mechanisms and information-logical devices."[1]

Cybernetics studies primarily the general laws characterising control processes in various fields. There are three main fields where control is important: technology, human collectives and living organisms. But these are only the main fields. Many control processes are not so easily classified. A good example is provided by control processes in the earth's biosphere. They refer not only to living nature, but also to the social sphere and to technology: civilisation is interfering more and more with the processes in the animate world. Another example is control processes in systems consisting of machines and human collectives.

The object to which the control processes studied by cybernetics are geared is *complex dynamic systems*. We cannot discuss the concept of a complex dynamic system here,[2] and will merely cite examples of control processes in tech-

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[1] A. Berg, N. Bernshtein, B. Biryukov, A. Kitov, A. Napalkov, A. Spirkin and V. Tyukhtin, "Cybernetics", *Filosofskaya entsiklopedia*, Vol. 2, Moscow, 1962, p. 495.

[2] We refer the reader to I. B. Novik's book *On the Modelling of Complex Systems* (Moscow, 1965, in Russian), which considers the philosophical aspects of this concept.

nology; management in organisations and bodies of people performing certain tasks (e.g. financial, military, etc.); control (regulation) of physiological, biochemical and similar activities in organisms; the processes of man's deliberate interference with nature. Cybernetics regards all these processes occurring in complex dynamic systems.

Further particularisation of conceptions about the subject matter of cybernetics implies the specification of its basic concepts, which is the task of the theoretical branches of the science. These include the concepts of a "control system", "information" and some others. Control always presupposes information processes, so that cybernetics may also be viewed as the *science of information* or information systems. Accordingly, cybernetics studies the problems of the effective collection, storing, systematisation, coding, transmission, retrieval and communication to the addressee and exploitation of information, etc.

Furthermore, there exists a whole system of concepts in terms of which the control and information processes in complex dynamic systems are described. These include the concepts of the channel of information, coding of messages, feedback, goal (task) of control, homeostasis, self-regulation, teaching, adaptation, optimisation, etc. Some of these concepts, such as teaching, homeostasis and optimisation, are especially important in characterising the most perfect complex dynamic systems. These are systems possessing a capacity for self-organisation at various levels and for determining the goals of control and the ways of achieving them. They include, first and foremost, living organisms–man and animals, as well as communities of some living organisms. Another kind of system of this type is the man-machine sort. These are instruments and machines (in automatic systems, communication and information processing, etc.) together with the men operating them. Man in such systems compensates for the lack of any ability for self-organisation in modern machines. In these man-machine systems man provides, in the final analysis, the goal of control and the general criteria for evaluating the actions leading to its attainment. Although determining the goal–defining the goal function

and the criteria for assessing actions–may, within certain limits, be entrusted to machines even now, man retains within modern systems the solution of the most important and complicated problems of optimisation.

The foremost of these tasks is the construction of the *theory of optimisation* itself. The solution of this problem dominates, in fact, all of the three levels of research in cybernetics: theoretical, technical and applied. Theoretical studies concentrate on the creation of methods for optimal control in complex systems of various types. Technical research is directed towards constructing the apparatus and devices needed for the implementation of these methods. Applied work has the goal of exploiting the methods and technical means of optimisation in concrete fields.

It should be noted that we have not yet managed to construct a unified theory for optimising processes in any given systems. It is not clear if such a theory is at all possible, since systems in which control processes are effected vary too much–even if we restrict ourselves to the purely cybernetic and information aspects of the problem. Systems may be determinate or probabilistic, open or closed; their structure and functioning may be discrete or, conversely, they may implement the idea of continuity. Besides, the requirements of optimality themselves may vary. That is why cybernetics develops many different methods for, and theoretical approaches to, increasing the efficiency of control processes and their optimisation. The theoretical, i.e. mathematical, apparatus used here is extremely varied. Among the instruments used are the theory of probability, the Shannon information theory, mathematical statistics, the theory of experiment planning, the theory of mass servicing, operations research, the theory of finite automata, the theory of graphs, the theory of algorithms, mathematical logic, the theory of games, linear and dynamic programming and many other new and rapidly developing fields of mathematics.

The goal of ensuring optimum conditions for controlling processes is the dominant feature of cybernetics. Modern cybernetics is the science of optimum control of complex processes and systems. Its main task is to devise methods of achieving goals with the least expenditure of labour, time, materials, energy and information.

Cybernetics is in a state of continual development, and it is difficult to do it justice in a short article. It is an extremely ramified and multiform trend represented by hundreds of powerful scientific bodies, an enormous number of projects and a vast flow of scientific publications. We shall, therefore, attempt to touch on the main points only. These main points are, in our view, *the significance of cybernetics for the general world outlook and methodology, and its role in the global development of science and technology and the productive forces of the USSR.*[1]

New Aspects of the Scientific Picture of the World

Cybernetics is a rich source of the new ideas making up the present-day philosophical interpretation of reality. This becomes immediately clear when we try to establish its contribution to the scientific picture of the world, to the methodology of cognition, and to the ways and tendencies of the practical modification of the world by man. The main point here is that cybernetics represents a new and powerful breakthrough of knowledge into a hitherto uncharted domain–*the domain of control and information processes.*

The idea of the existence of general laws pertaining to control and information and effective in qualitatively different spheres of reality had not been developed before cybernetics appeared. Idealism and fideism attempted to fill the vacuum which existed in problems of this sort. The significance of the new science is, therefore, clear: in a way, it completed the scientific picture of the world; for the first time in the history of cognition, the way was opened to an objective *natural scientific and mathematically precise study* of everything that is involved in the processes of control and information processing in nature, technology and society. Following this path, cybernetics has made an essential contribution to the solution of such cardinal problems of science as the origin and essence of life and consciousness.

One of the ideas of cybernetics of lasting philosophical significance is "the establishment of the fundamental incompleteness of the picture of objective reality which 19th-century science built on the basis of four fundamental concepts: *matter, motion, space* and *time*".[1] To obtain an integral picture of reality, it was necessary to include in the conceptual treasury of science the concept of *information,* which had always been part of the ordinary language, but not a scientific concept.

Material processes are processes of transfer and transformation of matter and energy taking place in space and time. This was common knowledge even before cybernetics. Now it has become clear that systems of material objects, and material and energy processes existing in the spatio-temporal continuum are at the same time, in some sense or other, the sources, carriers or users of information. There is neither matter nor energy unrelated to information processes. This is implied by the interpretation of information current in cybernetics, as the measure of the diversity of real objects.[2]

Information processes are present in all acts of the functioning of living matter. Information penetrates man's life and social structures through and through. Man lives on the earth in the gravitation field, in all sorts of energy and radiation fields, but not only in these fields. He also finds himself in a kind of information field which continually affects his sense organs. It is clear in the light of cybernetics that if

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[1] The fundamental world outlook and methodological aspects of cybernetics were discussed at the Second All-Union Conference on the Methodological Problems of Cybernetics in 1970 (see *The Methodological Problems of Cybernetics.* Materials for the All-Union Conference, Vols. I-II, Moscow, 1970, in Russian).

[1] V. V. Parin, B. V. Biryukov, Y. S. Geller and I. B. Novik, *Problems of Cybernetics. Some Results and Problems of Philosophical and Methodological Research,* Moscow, 1969, p. 42 (in Russian).

[2] This approach to cybernetics was developed by Ashby (see W. R. Ashby, *An Introduction to Cybernetics,* London, 1956); see also V. M. Glushkov, "On Cybernetics as a Science", *Cybernetics, Thinking, Life,* Moscow, 1964 (in Russian); A. D. Ursul, *Information. Methodological Aspects,* Moscow, 1971 (in Russian).

living beings did not possess sense organs or other "devices" for the reception of information, or if the "information field" did not exist, life on the earth could neither appear nor exist. Man cannot live in a material, energy or information vacuum.

The concept of *information* in cybernetics is specified in the mathematical theories of information. These theories–statistical, combinatorial, topological, semantic and others–throw new light on a number of aspects of the philosophical concept of *reflection.* Quantitative assessments of information introduced in these theories, and descriptions of its transfer and transformation provide the necessary apparatus not only for a mathematically precise study of the processes of control–they open up new perspectives in the study of *interactions* between material objects in general. And it is these interactions which realise the ability of reflection which lies "at the foundation of the very structure of matter", of which Lenin wrote. The fundamental interpretation of the concept of information based on the idea of reflection as the common attribute of all matter has become firmly established in Soviet philosophical literature.[1]

Another basic concept of cybernetics–*the system of control*–is also of fundamental significance for the general world outlook. The introduction of this concept has drawn into the sphere of scientific study material entities (or aspects of material entities) which had not been included in the picture of reality before. Of particular importance is the concept of systems of control possessing the properties of adaptation and self-organisation. Systems of this type are open systems; their study presupposes taking into account their interaction with the environment. A characteristic feature of these systems is their ability to retain steady-states (or certain characteristics of such states). If external influences force them outside the "space" of such states, they tend to revert to them. The stability of such "homeostatic" systems (the name comes from their prototype, the well-known Ashby homeostat) is ensured by internal restructuring of the system–changes in the structure, "shifts" in the functioning of its parts, etc. Usually such control systems consist of a hierarchy of subsystems, some of them dominating others. The subsystems interact through the transmission of commands and feedback information concerning the behaviour of parts of the system.

The picture that we have drawn here, naturally, simplifies the real complexity of the most perfect objects of cybernetic analysis. There are various gradations of stability, adaptation, organisation and self-organisation. We shall point out here only one aspect of the problem. A characteristic feature of control systems of the "homeostatic" type considered in technical cybernetics is that they solve the problem of finding and retaining their state (or changing it according to certain criteria) by reacting to the states of the environment already realised or being realised at a given moment. Research shows that this adaptive behaviour is no simple matter. The "stability", "ultrastability" or "adaptivity" of such systems is usually attained by a method other than the elementary "trial and error" one. Sophisticated methods of search have to be applied, based on theoretical and technical cybernetic studies.

But nature knows an even higher level of adaptation and self-organisation–that of bioevolution, life itself. Living systems are capable of active restructuring. *Activity* is primarily an ability to anticipate and foresee. Natural "homeostatic" systems possess, apart from memory reflecting their individual and "generic" experience, mechanisms for registering the laws of the environment and for constructing general concepts and notions (or their analogues–at lower stages of life) in the course of *learning* and the accumulation of experience. It is essential that this "anticipatory" activity is linked with working out the *goal of behaviour* by the given system. The *setting of goals* determined by the *needs* of life is an inalienable element of adaptive behaviour–at any rate, beginning with the level of the animate world.

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[1] The significance of information theory for a deeper interpretation of the materialist theory of reflection is discussed in numerous works, e.g. K. Y. Morozov, "The Philosophical Problems of the Theory of Information", *Philosophy of Natural Science*, Issue 1, Moscow, 1966 (in Russian); see also V. N. Trostnikov, *Man and Information*, Moscow, 1970 (in Russian).

The discovery of the nature of such systems is an important task of cybernetics. It is essential for the construction of more and more "intelligent" automata. It may be noted that science here is at the very start of the road. We can endow machines with "individual" memory, but machine reproduction of "generic" memory is only taking its first steps. We can construct machines that predict the future behaviour of controlled objects on the basis of laws cognised by man, aided by machines or not. But the difficulty of endowing modern machines with the property of goal-setting so characteristic of the developed forms of life is prohibitive.

We are convinced that these difficulties will be overcome: living cybernetic systems are just as knowable as "dead" ones. An essential role in this will, apparently, be played by the "functional" approach to the essence of life and thinking. The justifiability of this approach was decisively emphasised by A. N. Kolmogorov.[1] His proposal is to free the definition of life and thinking from conceptions of the concrete nature of the physical processes underlying them. In Kolmogorov's view, the definition of life may be "purely functional". A description of the phenomena of life from cybernetic positions, in the opinion of the Soviet mathematician, is impossible "unless completely new [for the exact natural sciences using mathematical methods.–*A.B., B.B.*] concepts are applied and conceptions of the *purposiveness* inherent in these systems are developed".[2]

The problem of the detailed development of "cybernetics and the mathematics of life" is frequently discussed in cybernetic literature. Although this development is largely a matter of the future,[3] the significance of the conception of living

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[1] See A. N. Kolmogorov, "Life and Thinking as Special Forms of the Existence of Matter", *On the Essence of Life*, Moscow, 1964 (in Russian).

[2] *Ibid.*, p. 51.

[3] Some interesting approaches to "biomathematics" have already been attempted. A good example is the work by O. S. Kulagina and A. A. Lyapunov, "On the Problem of Modelling the Evolutionary Process" and other papers in *Problemy kibernetiki*, No. 16, Moscow, 1966, dedicated to the memory of I. I. Shmalgausen, the prominent Soviet biologist.

organisms as complex dynamic systems of control and information processing for the world outlook is clear even now. Of course, this conception lays no claims to exhaust the "specificity of life". Cybernetics is no substitute for biology, but cybernetic concepts open up the possibility of a mathematical description of the phenomena of life, in particular the mechanisms of bioevolution and adaptation to the environment. A great role should be played here by studies into the principles of the construction of self-organising systems. These studies are being conducted within the framework of theoretical, as well as technical cybernetics, including the computerised simulation of adaptation and self-organisation processes.

The development of these problems paves the way for a deeper study of the problem of the similarities and dissimilarities between living and non-living nature. This study presupposes the establishment of the nature of the phenomenon of activity in living creatures, mentioned earlier. And this, in turn, requires the investigation of phenomena expressed in the concepts of goal-directedness and goal-setting. Cybernetics permits an attempt at a specification of the notion of *goal*.[1] The cybernetic approach conforms with the well-known philosophical thesis that purposiveness and goal-directedness should be interpreted as specific systems of cause-and-effect connections. Lenin wrote: "The laws of the external world ... are the bases of man's *purposive* activity. In his practical activity, man is confronted with the objective world, is dependent on it, and determines his activity by it."[2]

Naturally, cybernetics rejects the fideist teleological interpretation of goal. In considering the goal, or task, of control in cybernetics regardless of the nature of systems, we shall observe that on the whole it is reduced to criteria of the quality of control, to the factors determining, basically, the choice and direction of the appropriate actions. Considered in its most general features, the concept of goal in cyber-

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[1] Cf. B. S. Ukraintsev, "The Processes of Self-Regulation and Causality", *Voprosy filosofii*, No. 4, 1968.

[2] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works*, Vol. 38, pp. 187-88.

netics includes the tendency towards retaining stability of organisation. This concept is closely linked with that of *optimisation* of control processes. Optimal control is necessarily control leading towards a goal, towards the solution of the problem of control.

To control means to solve some task, to attain some goal. The goals of technical systems are, as a general rule, given from outside: they are set by man. The world of life is a world in which intrinsic goals are worked out based on *need.* It is precisely due to need that goal-setting in the world of life is not only "intrinsic", but also *active.* A living being attains its goals by influencing the environment. Goal-directedness permeates every phenomenon in animate nature. Of course, this is not conscious goal-directedness: the latter is only formed at the level of rational beings. But goal-setting at any level is inseparable from control processes. As N. A. Bernshtein aptly put it, animate nature continually raises the question: "What for?" Cybernetics has helped us to understand that this question has equal status with those nature set before man a long time ago—"how?" and "why?"

Cybernetic ideas, together with those of biology and psychology, have resulted in the development of a new trend in research—"the physiology and psychology of activity"—primarily through the work of N. A. Bernshtein. Bernshtein interpreted the activity of living systems as the entire dynamics of their goal-directed struggle for existence with the aid of purpose-built mechanisms.[1] Living systems are always in need of something. They satisfy these needs by actively choosing everything that suits them. Activity is most clearly expressed in the fact that a living organism is not indifferent to the essential influences of the environment. The organism's adequate response to such stimuli often implies mobilisation of all its resources. Activity may, therefore, be viewed as the dominant factor of life, and the study of activity as having a most important significance for understanding the specificity of life as a form of the movement of matter and for discovering the nature of the psychic.[1]

We have already mentioned that the active nature of the behaviour of organisms is inseparable from anticipation (prognostication, prevision) of its results. Cybernetics investigates, on an ever increasing scale, the possible mechanisms for the construction of anticipatory "inner models" of future situations and actions. This work is done with the help of various theoretical instruments and computer simulation. Ideologically, it is largely consonant with the well-known cybernetic-physiological conception of "anticipatory reflection of reality".[2]

To an even greater degree the concept of activity refers to *man.* Man in his activity consciously sets his goals, formulates his tasks and controls his behaviour in an appropriate manner. Everyone realises the immense scientific significance of the classical works of Charles Darwin and I. P. Pavlov, but their theories cannot explain specifically human behaviour. Of course, the struggle for life is being waged in the living world, and conditioned reflexes are formed in animals, and in men too. All of this is true. Except that man does not have to experience numerous repetitions of the bell or some other stimulus to salivate, as Pavlov's dogs did. His behaviour is not motivated by immediate reward, as was the behaviour of pigeons in the experiments performed by the American psychologist B. Skinner. Man is active; he thinks and foresees the future. On this basis and on the basis of previous experience and the available information he controls his goal-directed behaviour, the behaviour that changes the world in which he lives.

Cybernetics lays no claim to ever becoming the ultimate in the analysis of the nature of man and human society. But

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[1] See N. A. Bernshtein, "Problems of Modelling in the Biology of Activity", *Mathematical Modelling of Life Processes,* Moscow, 1968 (in Russian).

[1] The philosophical problems of the "physiology and psychology of activity" are discussed in the book: D. I. Dubrovsky, *Psychic Phenomena and the Brain. The Philosophical Analysis of the Problem with Special Regard to Some Urgent Tasks of Neurophysiology, Psychology and Cybernetics,* Moscow, 1971 (in Russian).

[2] P. K. Anokhin, "Anticipatory Reflection of Reality", *Voprosy filosofii,* No. 7, 1962.

it unquestionably contributes to such an analysis. It is essential, in particular, that it emphasises the methodological significance of goal-setting and goal-directed action as components of human activity and the importance of studying the problem of activity. This circumstance should be borne in mind, since underestimating the problem of activity may have undesirable consequences. Man's effect on the natural environment is growing all the time; he is increasingly more active in adapting the material world to his needs and requirements. A few decades ago this powerful activity was only just beginning to show, but since then the achievements of science and technology have drastically changed the picture: the ability of human society to adapt the environment to its needs has grown immeasurably. Under these circumstances, it is essential to decrease the possibly harmful effects of randomness. Optimal decisions in changing conditions must be ensured. We have to strive for a better mastery of the art of predicting the future on the basis of knowledge and experience gained, and for the ability to control our actions on the same basis.

New Science, New Methods

The methods of scientific research have also undergone substantial changes under the influence of the new science. Cybernetics led to the introduction into cognition of such methods as modelling, formalisation and algorithm construction, and to the extension of the functional method in scientific work: in studying systems of control, cybernetics concentrates first and foremost on their inherent ways of *behaviour or functioning.* A great role is played in cybernetics by the study of processes and systems in terms of input and output. But this functional approach in cybernetics is supplemented by the structural one, which takes into account the structure of control systems. In other words, the input-output description (some scholars call it the *macroapproach*) is supplemented by the *microapproach.*

That the purely functional approach is insufficient is clear from the philosophical point of view. Lenin wrote that

"human thought goes endlessly deeper from appearance to essence, from essence of the first order, as it were, to essence of the second order, and so on *without end*".[1] As applied to the situation in cybernetics, this means that with increased specification of knowledge and ever more complete cognition of the object under study (on the "macrolevel") we are able to make judgements about its inner structure, i.e. realise the cybernetic "microapproach".

It should be emphasised that the structural-functional approach does not mean a refusal in principle to take into account the physical nature of the components of the system, since the physical nature—the "substratum"—of systems may also be considered from structural-functional standpoints: what appears as an indivisible component of the system at one level of consideration, may itself prove, on further analysis, to be a system with its intrinsic functions and structure. This aspect of the methodology of cybernetics is not only of general epistemological significance: it assumes quite concrete forms in the formulation of certain tasks. For instance, the cybernetically oriented functional approach to the definition of the concept of life does not yet eliminate the problem of the connection between the essence of life and the nature of its carriers.

Whether the fundamental properties of life depend on the physical nature of the components of their carrier, and if they do, in what measure—these are problems still awaiting elucidation.

In any case, cybernetics cannot be regarded as a science which abstracts itself from any qualitative specificity of control and information processes going on in some or other spheres of reality. Everything depends on the level of abstraction of the given theories. This abstraction can be very strong in the case of mathematical cybernetics (e.g. for the theory of finite automata). The situation is different in the "concrete" branches of cybernetics, where applied problems are treated. The measure of abstraction from the structural

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[1] V. I. Lenin, "Conspectus of Hegel's Book *Lectures on the History of Philosophy*", *Collected Works*, Vol. 38, p. 253.

and the "substratum" aspects of investigated objects varies in the different branches of cybernetics–theoretical, technical and applied. But this abstraction cannot, on the whole, be absolute–if only because the very nature of matter, as revealed by physics, imposes certain limitations on information processing. But, while it cannot be absolute, it has to be relative, i.e. determined by the goal of the given study of control processes. Although the functional approach to control systems cannot exhaust their essence, no other approach ensures the possibility of revealing their nature.

Cybernetics always goes hand in hand with mathematics. Both at the functional and the structural-functional level, the objects of cybernetics are studied by mathematical means. The mathematical methods of cybernetics are inseparable from the application of these methods with the aid of modern computers and automata. The possibility of this application follows from the *algorithmic approach.*

The development of the algorithmic approach is an essentially novel feature of the scientific methodology of the mid-20th century, determined precisely by cybernetics. The point is that operations in control systems are not realised randomly–they are based on sets of rigid rules, or *algorithms.* One may say that the processes of control in complex dynamic systems are reduced to the realisation of definite algorithms. The construction of algorithms of control processes in design work or cognition implies a precise description of these processes in an exactly formulated artificial language–their *formalisation.* Formalisation is founded on the methods of *mathematical logic.* Formalisation by means of mathematical logic has to be used, for instance, in describing the work of computer systems, in the study of the structure and functioning of control systems, and in developing methods for synthesising systems. Formalisation and the algorithmic approach in cybernetics are not opposed to the other methods of this scientific trend, in particular, the heuristic and experimental ones. The latter–e.g. the method of "teaching" automata, machine experiment or the automation of the search to prove theorems–necessarily include formalisation and algorithm construction.

Formalisation and algorithm construction constitute what may be called the *logico-algorithmic methods.*[1] But, apart from these methods, there are also the *probabilistic-statistical methods* of cybernetics. The logico-algorithmic methods owe their present form to the cybernetic ideas and presentation of problems. They may be said to be inseparable from the science of control processes, whereas probabilistic-statistical methods had had a long history before the advent of cybernetics. Cybernetics, however, gave them a new orientation. The probabilistic-statistical theory of information which took shape within cybernetics now forms one of the most essential elements of its theoretical basis. One may also mention the study of the methods of controlling random processes and their modelling. Probabilistic-statistical methods are of great significance for the development of adaptive control systems and self-organising systems, for the theory and practice of "teaching" control systems, for developing the methods of finding optimal decisions, and so on.

In mathematics and physics there has always been the dichotomy of the *discrete approach* versus the approach based on the idea of *continuity.* For instance, mathematical analysis, that powerful instrument of mathematical thinking which has dominated mathematics for the last three centuries, is a striking embodiment of the idea of continuity. Cybernetics has introduced a novel element into the question: it has contributed towards revealing the general scientific significance of the *discrete approach.* In cybernetics, discrete methods of describing control systems are dominant. These methods are linked with the development of discrete and finite mathematics, which embraces the methods of logic, the theory of finite automata, the theory of games and many of the "cybernetic" disciplines that are now so famous.

In discussing the methods of cybernetics, we must naturally mention *modelling,* i.e. the study of the objects of cognition through their *models.*[2]

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[1] The philosophical problems of these methods are discussed in B. V. Biryukov, *Cybernetics and Logic,* Moscow, 1971 (in Russian).

[2] See Y. Gastev, "Model", *Filosofskaya entsiklopedia,* Vol. 3, Moscow, 1964.

Modelling as a cognitive procedure arose long before cybernetics.[1] But only cybernetics showed that this cognitive procedure has a general scientific significance. It is inseparable from the methodology of scientific cognition at the present stage. Applications of cybernetics enabled the method to be used successfully in fields of knowledge and practical activity in which modelling had not played any part before.

Owing to cybernetics control systems of a different nature became the most important object of modelling. *Cybernetic modelling* came into being. True to its general approach, cybernetics concentrates on reflecting in models the information processes which take place in complex dynamic systems. Modelling in cybernetics is at the same time *mathematical modelling*, implemented through the sign apparatus of mathematics (and mathematical logic) and procedures in modern computers and automata (e.g. in control devices).

Cybernetics has introduced many new aspects into scientific research methods, but it, certainly, lays no claim to forcing out the cognitive procedures that have long been studied in epistemology and logic. Neither does it encroach on the traditional methods of the various concrete sciences. But it adds its own procedures and methods to the treasury of all the other instruments, bearing in mind that in the general context of scientific cognition its methods are used in an integral unity with the entire diversity of cognitive means.

"Cyberneticisation" of Knowledge

Our times are witnessing a rapid extension of the range of sciences and spheres of practical activity in which cybernetics is used. Cybernetic ideas and methods are gradually changing the face of many scientific disciplines, including even the most "independent" of sciences–mathematics.

Cybernetics and digital computers have not only extended the possibilities of computational mathematics–they have also (and this is, perhaps, the most important point) exerted a profound influence on the development of mathematical theories. The practical needs of research in the concrete processes of control pose new tasks before mathematicians, demand the development of existing mathematical theories in certain directions and stimulate the appearance of new trends. For instance, great demands are imposed on mathematics by economics and the science of life, setting at times tasks that could not have arisen before cybernetics penetrated into these fields.

The development of cybernetics enriches the entire field of the natural sciences and the humanities: biology, physiology, the theory of evolution, genetics, linguistics, the science of law, etc. Lenin considered it to be a major achievement of the natural sciences that they came to study objects whose description allowed of mathematical processing.[1] Cybernetics represents just such an effective method of processing. This is of immense epistemological and practical significance, as cybernetics introduces *preciseness* wherever it is used. This applies, for instance, to the registering of basic data about objects of control. Problems of this kind rate high among the applications of cybernetics and electronics in biology and medicine. Preciseness of description is no less important for control processes themselves and for their optimisation. Application of the mathematical methods of cybernetics paves the way for an effective organisation of information processing and control, and that, in turn, signifies progressive technological solutions, great power, hitherto unattainable velocities, exactness of measurements inaccessible to past epochs, and so on.

Of course, it would be a mistake to disregard the difficulties of introducing mathematico-cybernetic methods into

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[1] A philosophical investigation of the method of modelling is given in the monograph: V. A. Shtoff, *Modelling and Philosophy*, Moscow-Leningrad, 1966 (in Russian).

[1] See V. I. Lenin, "Materialism and Empirio-Criticism", *Collected Works*, Vol. 14, p. 307.

the various sciences; the process does not always run smoothly. There are numerous reasons for these difficulties: the unpreparedness of the given science for the reception of exact methods, and the complexities of formalisation and algorithm construction in a given field (e.g. in the problems involved in automatic translation, where the difficulties turned out to be much greater than had at first been expected). But, apart from the difficulties, there are also cases of resistance; the new methods are not always received with due understanding. But the struggle around them has been going on for several decades already, and the results are becoming ever more apparent: the cybernetic, mathematical, quantitative methods are being introduced into all spheres of man's knowledge and labour. The time is at hand when the distinction between the descriptive, "qualitative" sciences and the exact sciences will seem an anachronism.

A few examples may help. They are drawn from applications of cybernetics in the *biological and medical sciences*, in particular, surgery, diagnostics and prophylaxis. In the Soviet Union, as in many other countries, contacts between exponents of the exact sciences and physicians and biologists are becoming closer and closer. Work on the application of advances in electronics and cybernetics to medicine has been going on since 1959, and the results obtained within this period are gratifying. Considerable success has been attained in the automatic diagnosis of some grave diseases, e.g. heart diseases and some malignant disorders. Progress has been achieved in the application and "teaching" of computers to diagnose lung cancer. Methods of computer diagnosis of some diseases has been tested experimentally. Moreover, they are beginning to be applied practically at some clinics, for instance, at the A.V. Vishnevsky Surgery Institute of the USSR Academy of Medical Sciences.

Computers are becoming the physicians' reliable assistants. Research has shown that the computer's efficiency is in some cases extremely high. Operating with great volumes of information, the computer may, under some circumstances, diagnose the disease correctly even when the physician is unable to do so. More than a dozen scientific bodies are

now working on the automation of diagnostics, and measures are envisaged to further this research.

It may now be asserted that medical and biological cybernetics have developed into independent scientific trends. The achievements of Soviet science along these lines were discussed at the First All-Union Conference on Biological and Medical Cybernetics (Moscow, December 1971); presented at the conference were the reports of such Soviet specialists as P. K. Anokhin, A. A. Vishnevsky, B. V. Petrovsky, M. L. Bykhovsky, S. N. Braines, Y. B. Babsky, A. A. Malinovsky and others.

The cybernetic methods and instruments are increasingly used in *the humanities*, e.g. law. There are good prospects here for applying cybernetics both in legal science and in the practice of forensic inquiry. Work is already being done on designing systems for the accumulation and automatic processing of legal information.

The study of *human thinking* is of great significance for fully understanding control and information processes. To construct ever more perfect computers, control and information-logical machines and systems, we must have a better understanding of the laws of man's intellectual activity. After all, man is capable of solving the most complicated problems of control. His brain is a highly accomplished and economical organ for information processing. An essential requirement for the cybernetic modelling of cognitive processes and for reflecting them in algorithms that may be introduced into automatic man-made information-processing systems is knowledge of the logical structure of thinking. Here we are considering the task of studying thinking by *objective and exact methods*. Great possibilities for this are being opened up within modern formal (mathematical) logic. Interaction between cybernetics, logic and linguistics has resulted in the formation of mathematical linguistics. Another manifestation of this interaction is the development of artificial languages for storing and processing information, functioning within definite spheres of science and practical activity.

Special attention should be paid, in connection with cybernetics, to the problems of *psychology and pedagogy*. It may now be asserted that there is an urgent need for extending research work aimed at introducing mathematical and cybernetic methods into psychology (engineering psychology, pedagogical psychology, the psychology of different age-groups, etc.). Work is proceeding abroad on numerous projects in the fields of mathematical psychology, mathematical methods in pedagogy and cybernetic theories of learning.

In the USSR *engineering psychology* has gained wide recognition, which is hardly surprising, since its most important task is the search for optimal interaction between man and machines, man and automata.

Indeed, as the complexity of the processes controlled by man grows, as the machines and automatic devices with which he has to work develop, so the volume of information to be exchanged between man and machine increases too. But man is characterised by definite psychological and physiological properties determining the optimal conditions of assimilating information. For this reason, not only specialists in mathematics, automation and electronics take part in designing cybernetic devices, but psychologists as well. Their task is the study of man's "information parameters" to determine the organisation of man-machine interaction in which man works under optimal conditions without excessive strain, and the machine retains its high efficiency.[1]

Furthermore, throughout the world work is now going on in the *mathematisation of psychology*,[2] including pedagogical psychology–a science that not so long ago seemed inaccessible to formalisation and algorithm construction. This work is of great importance. We are concerned with developing in schoolchildren, adolescents, young men and women the desire for work, for mastering knowledge, for socially

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[1] There have been many studies in Soviet engineering psychology; see, for example, B. F. Lomov, *Man and Technology. Essays in Engineering Psychology*, Moscow, 1966 (in Russian).

[2] A fundamental compendium in this field is the *Handbook of Mathematical Psychology*, Vols. I-III, New York and London, 1963-1965; see also *Experimental Psychology*, Vols. I and II, Moscow, 1966 (in Russian).

useful activity. Pedagogical psychology, the psychology of different age-groups and social psychology, among other trends in psychological science, should contribute to the accomplishment of these tasks. But these trends need more and more help from representatives of the exact sciences and engineers–the creators of modern automatic devices. One can hardly expect to achieve success in the accumulation and processing of information about psychic processes without modern equipment, including cybernetic equipment. Future educationalists will need a much higher level of training in psychology and the exact sciences than the one considered to be sufficient at the beginning of the century. Only then will they be able to learn something essentially new about the information content of the physiological processes in man's nervous system.

Co-operation between cybernetics, psychology and physiology has had the result that one may expect apparatus and machines to be developed and manufactured in keeping with the psychophysiological properties of the operators, i.e. machines that are adequate to the tasks man sets himself in work and education. On the other hand, studies of biological systems and the psyche conducted with a cybernetic aim in view are holding out new perspectives before automation. Investigations of this kind pertaining to a new field of research that has been named bionics are already beginning to contribute to the formulation of new principles in constructing technical systems of control.[1]

From the philosophical viewpoint, it is important to stress that neither cybernetics nor mathematics can substitute for the sciences of society and man. The specificity of the subject matter of the latter, and the fields of their inquiry are neither eliminated nor narrowed by the application of mathematical and cybernetic methods and ideas. On the contrary, this application only contributes to the extension of

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[1] Applications of cybernetics in various fields of knowledge (particularly Soviet studies) are discussed in *Cybernetics in the Service of Communism*, Vol. 5, Moscow, 1967 (in Russian).

research conducted in them.[1] All other things equal, cybernetics only helps to solve problems that arise in the concrete humanities. And this help should not be neglected.

Increasing the Efficiency of Labour and Education

The cardinal task of our society is that of increasing the effectiveness of man's activity. *Labour* and *education* are the two main spheres of this activity, and cybernetics is playing an increasingly greater role in both of them. First, let us consider cybernetics in the sphere of labour activity, production activity.

There are many vital fields of practical production activity where cybernetic ideas and methods yield valuable results. We cannot discuss all of them in this short article. We shall only touch on one of them, the *sphere of economics.* The necessity of using the methods and means of cybernetics in economics is now generally recognised. This necessity follows from many factors, one of which is the task of comprehensive mechanisation and automation of production processes in industry. Partial automation of separate production operations may prove to be a relatively simple task, quite within the possibilities of the "old" technology, whereas the comprehensive automation of complex and multiform technologically interconnected processes is, undoubtedly, very difficult. To accomplish such a task, we must first of all ensure the economic efficiency of control.

Furthermore, the control of technological processes itself can be automated. The automatic control must see that the goal–producing a high-quality commodity–is attained within the shortest time possible, i.e. in the most efficient, optimal way. For many practical purposes this problem may be solved

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[1] As applied to studies in culture and art, this was clearly shown by the Symposium on Precise Methods in Studies of Culture and Art held at Ruza (near Moscow) in 1971. See *Precise Methods in Studies of Culture and Art*, Parts 1-3, Moscow, 1971 (in Russian).

on the basis of preliminary theoretical, mathematical study. Often we have recourse to computer simulation of the processes involved. Other methods of optimisation are also beginning to be applied, where the controlling device finds the optimal conditions itself in the course of its functioning.

Cybernetics, its apparatus, ideas, methods and instruments are widely applied in the economy. The field where the role of cybernetics is revealed most strikingly is the construction and exploitation of automated control systems. This is quite understandable, since the personnel engaged in economic management in the USSR now number more than ten million people. The volume of work is continually growing, and so is the need for economic managerial personnel. But the management of the dynamic Soviet economy has become so complicated that a mere increase in the numbers of personnel engaged in management is ineffective. The aim now, therefore, is to create automated systems of control using powerful computers and the entire range of cybernetic methods and instruments at all major links of the economic chain–from the USSR State Planning Committee to individual enterprises. Many enterprises and other economic units already have computing centres at their disposal.

It is generally known that the computer can work effectively only when its task is well defined and a specific programme is fed in. The introduction of computer technology into the economy has, therefore, stimulated research into the complicated processes of economic management. Unless such research is undertaken, it is impossible to formulate either the task or the programme for its accomplishment. For that a special theory and special methods are created. This field of inquiry has been named *mathematical economics,* or *economic cybernetics.*

In what directions is economic cybernetics developing? What is its contribution to practice? The main objective of research here is to create the mathematical foundation of constructing control systems for the national economy. These systems are intended to perform production control, the analysis of the quality of technological processes, the planning of the work of enterprises, etc. Research conducted in many enterprises has revealed vast reserves that may be released by perfecting the methods and forms of management. Recommendations for organisational measures and the distribution of responsibilities, material and moral incentives, more efficient paper work and methods of work in general produce results that can hardly be overestimated.

It must particularly be stressed that cybernetics and mathematics have introduced into the theory and practice of economics a new principle–the *principle of optimality*. The meaning of this principle is that each decision in planning the economy must be founded on the one and only solution optimal for the given conditions. Mathematics, cybernetics and computer technology open up a *real possibility of finding optimal economic solutions*. We could cite numerous examples of the realisation of this principle, for instance, pertaining to optimisation of the structure of an industry, optimal distribution of productive forces, optimal plans for freight traffic, etc. An optimal plan is usually more effective than the one calculated through traditional methods by 5 to 8 per cent, and in some cases, e.g. in construction work, by 15 to 20 per cent. If we take into account the gigantic size of the Soviet economy, we can easily imagine the practical effect of the realisation of the cybernetic principle of optimality.[1]

Another broad field for the application of cybernetics is *education*. Cybernetic ideas in education have resulted in a new branch of science–*cybernetic pedagogy*–which treats learning as the functioning of control systems.

First, a few words about the significance of the problem itself. The achievements of the USSR in training specialists are well known. At present, about 80 million people in the USSR are studying. These are people of all ages, from the youngest schoolchildren to adults. They are being educated by three million teachers in higher educational institutions, technical schools, vocational schools, secondary and elementary schools. A third of the country's population is receiving schooling of some kind, for the time has come when one has to study all one's life: this is required by the rapidity of scientific and technological progress.

This is not a simple task, since education may be regarded as one of the most conservative fields. In the second half of the 20th century, in our electronic and space age, millions of children and adults are taught by essentially the same methods as only a small fraction of that number of people was taught in the past. It is now essential to correlate the present methods and means of education and modern scientific and technical possibilities. Throughout the world, out-of-date methods have been reassessed in recent decades.

It is important for the purposes of this article that this reassessment is proceeding, to a large extent, through the "cyberneticisation" of education. There is now a gradual transition towards "cybernetic" methods of education–so far, of course, mainly on an experimental basis. These methods yield much better results, and in shorter periods of training at that. Special note should be made of the intensive studies of possibilities for applying fast computers in education, studies that are now being conducted both in the USSR and in a number of other countries.[1] Methods have been developed for teaching hundreds of students simultaneously with the help of one such machine. The application of cybernetic technique ensures the highest standards of education, since it takes into account the individual characteristics of the students, their abilities, the speed at which each of them works, etc. This is the origin of cybernetic pedagogy –the field with which the now widely popular *programmed learning* merges.

Intensive work in the field of cybernetic pedagogy is going on throughout the world, and its range is increasing continu-

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[1] The methodological questions of economic cybernetics are discussed in greater detail in A. I. Berg and Y. I. Chernyak, *Information and Control*, Moscow, 1966; Y. Z. Maiminas, *Economic Planning: Information Aspects*, Moscow, 1971 (in Russian).

[1] In June 1968 a seminar was held in Kiev on the application of computer technology in controlling the process of education and in teaching. The reports made at the seminar were published by Sovietskoye Radio Publishers (*Application of Computers in Teaching*. Reports at a Scientific-Technical Seminar. Ed. by A. I. Berg, Moscow, 1969 (in Russian).

ally. But this is only the beginning of the revolution in pedagogy. We are entering the era of the wide use of computers for instruction, working according to teaching programmes compiled by experienced educationalists. These machines can be used in group or individual instruction, instruction of the extra-mural or the more conventional type. There can be little doubt that electronic instructors capable of adapting themselves to the actual abilities and needs of students will change the whole situation in education within the next few decades.

It is perhaps as well to point out here that "cybernetic teachers" do not represent a threat to human teachers: there is no question of machines replacing or forcing out human instructors. The introduction of methods and instruments of cybernetics into pedagogy does not make the teacher, the educationalist, the specialist in methods of teaching, redundant. On the contrary, it greatly increases their importance, radically extending their possibilities. The task is not to eliminate the teacher, but to lighten his work by introducing modern scientific and technological means into the process of teaching.

Lenin once wrote: "The whole point is not to rest content with the skill we have acquired by previous experience, but *under all circumstances to go on, under all circumstances to strive for something bigger,* under all circumstances to proceed from simpler to more difficult tasks. Otherwise, no progress whatever is possible and in particular no progress is possible in socialist construction."[1]

Nowadays, important trends in this progress are associated with cybernetics. The science of optimal control of complex systems and processes is contributing to the solution of fundamental problems in labour and education.

It may be of interest to cite here some evaluations of the cybernetic aspects of Soviet progress by Americans. The *Washington Post* scientific correspondent Howard Simons wrote in an article for the *Air Force and Space Digest* that "some American experts view the Soviet excursion into cybernetics as representing the single greatest potential threat" to the West.[1] Some time ago, two research workers at the Batelle Memorial Institute, Columbus, Ohio, published an article "Cybernetics in the USSR" in the American journal *Computers and Automation,* which says: "The Soviets consider that cybernetics is relevant to contemporary scientific and technological problems, and reinforces certain statements of dialectical materialism, a philosophy of development of societies and similar complex phenomena"; "In the Soviet Union cybernetics has kept a solid scientific meaning as the science of control and communication in man, machines, and organisations with emphasis on the use of automatic computers."[2]

"Emphasis on the use of automatic computers"–this is indeed true. The search for solutions to problems involved in the development of Soviet society necessarily leads to wide application of computer technology. This has already been discussed above. That is the technical basis of cybernetics. At present, computer methods for the accumulation, systematisation, storing, processing and use of scientific, technical, production and economic information are acquiring enormous significance. The overall power of countries (in the production, economic, military and other spheres) nowadays depends not only on, let us say, their production potential, but also on their capability in the sphere of information, and on their ability to implement control under optimal conditions. All of the economically developed countries are rapidly increasing the number and raising the quality of automatic computers and computing centres.

All of this *radically* changes the situation in processing and using information. Computers are now invading all fields of man's information activity much more swiftly than printing did a few hundred years ago. We now have machines performing millions of numerical and logical operations

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[1] V. I. Lenin, "The Valuable Admissions of Pitirim Sorokin", *Collected Works,* Vol. 28, p. 192.

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[1] *Air Force and Space Digest,* August 1964, p. 51.

[2] R. W. Brainard and W. D. Hitt, "Cybernetics in the USSR", *Computers and Automation,* Vol. 16, No. 4, April 1967, pp. 10-11.

per second–as against the few operations per second that man can perform in his mind.

The potential of computers is growing all the time. What took the machine of the 1950s a whole hour to do is achieved by the modern machine in less than half a second. Computers now have qualitative capabilities that they did not possess formerly. Automatic systems are being constructed consisting of many computers unified into an integral whole by communication channels. These systems make new demands on the designers of computers, input and output systems, and systems for accumulating, storing and transmitting information. Computational mathematics and technology call for the further development of theory–the elaboration of new principles of computer functioning, including those based on the ideas of self-organisation and adaptation.

Wide practical use of cybernetics depends in many respects on the progress of automatic computers and their *mathematical servicing,* which is, in turn, closely linked with the development of radioelectronics. Cybernetics has a great interest in performing information processes in which the expenditure of matter and energy is at a minimum. This is achieved through a decrease in the size and weight of apparatus, through miniaturisation and microminiaturisation. As years go by, technology will achieve a density of storing information in the memory of machines and instruments which will be comparable with the density of information storage in the human brain. Of great significance is the decrease in energy consumed by apparatus; technology is creating supersensitive and almost inertialess devices, replacing the wieldy apparatus of former years which consumed a lot of energy.

Machines and devices must also have the properties of *reliability* and *durability.* We should mention in this connection a "system for organising production without defects" developed in the USSR (in Saratov). It is now a widely recognised system, introduced at many enterprises. It is at present developing into a "system for working without defects", i.e. a system embracing all sides of the activity of an enterprise. This important achievement of Soviet science and

technology was made in direct pursuance of Lenin's behests concerning scientific organisation of labour.

The problem of reliability is a many-sided one. It covers a wide range of questions relating to such directions in science and technology as physics and chemistry, mechanical engineering and instrument-making, mathematics and economics. It also includes the "human factor". Cybernetics has posed the problem of studying the reliability of the work of man–the most important link in modern control systems. This aspect of the problem of reliability also involves certain sociological features that have to be studied by sociologists.[1]

As applied to information, the problem of reliability is first of all the problem of its *trustworthiness.* To manage human labour effectively, to rationalise education, fully reliable information is needed; this means timely, precise, consistent information (a requirement particularly important when information is received through different communication channels), free from interference and distortions. If no reliable information is available, control and decision-making have to be based on incomplete or defective information, which may result in the failure of the whole system of control. Cybernetics is, therefore, vitally interested in raising the quality of information, its reliability–which is no less important than the quality of industrial production, construction work, the work of transport, etc.

Lenin wrote in his *Philosophical Notebooks* that truth is a process, "man advances towards objective truth *through* 'practice' (and technique)".[2] Nowadays, this road to truth "through technique" lies, to a great extent, through cybernetics. The road is *automation of intellectual labour.* A great number of intellectual functions and operations that for centuries have been believed to be man's monopoly are being gradually entrusted to computers. The computers of

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[1] See V. G. Pushkin, *The Problem of Reliability. A Philosophical Essay,* Moscow, 1971 (in Russian).

[2] V. I. Lenin, "Conspectus of Hegel's Book *The Science of Logic*", *Collected Works,* Vol. 38, p. 201.

the future will, evidently, render man invaluable services on his road towards objective truth. They will be computers whose speed will approach thousands of millions of operations per second; computers whose external memory will exceed that of man many times over; self-organising and self-teaching computers; computers capable of working faultlessly for long periods of time; not to mention computers of new types (modern scholars are persistently looking for approaches to their construction)–machines which will be endowed with the property of independence, including even the ability to adapt themselves to the environment and to perfect themselves, following general criteria given in one form or another by man.

In outlining the perspectives for a possible development of cybernetic computers, we believe it appropriate to express the view that machines *do not think*–and will hardly ever think–*just as man does,* as a rational being does living in society, endowed with intellectual needs and using natural language for exchanging ideas with other rational beings. But the man working in co-operation with computers, undoubtedly, thinks better and in a different way from the man who is compelled to restrict himself to primitive instruments in mechanising his intellectual labour.

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