Institute of the History of Natural Science
and Technology

USSR Academy of Sciences

SOVIET STUDIES IN THE HISTORY OF SCIENCE

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Moscow, 1977

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EDITORIAL NOTE

This collection is being published by the Institute of History of Natural Science and Technology of the USSR Academy of Sciences together with "The Social Sciences Today" Editorial Board. The collection is keynoted by the motto of the 15th International Congress of the History of Science (Edinburgh, August 1977): "Scientific Progress and Man: Historical Perspectives". It includes works by Soviet scientists on various aspects of the development of science. In subject-matter it consists of three parts.

The first part deals with theoretical problems connected with the history of science and the present state of research in this field. There is also a consideration of the unity of the social and objective factors of development of science, the criteria of scientific revolutions, the conceptions of the intensive and the extensive development of scientific knowledge, the socio-ethical regulation of science, the establishment of scientific schools, problems of periodisation, and other aspects of the history of natural science.

The second part deals with the history of the individual scientific disciplines: the relativist theory of gravitation, chemistry, problems in the origination of atomistics, the connection between mathematics and mechanics, and so on. Articles in this part cover various epochs in the development of scientific knowledge, ranging from the most ancient civilisations to the 20th century.

The third part contains articles on the history of Soviet science. In November 1977, the USSR will mark the

60th anniversary of the October Revolution, which led to the foundation of the Soviet State and created the conditions for its economic, cultural, scientific and technical progress. One of the articles describes how the new socio-economic conditions, created in Russia in October 1917, promoted the rapid progress of science. Other articles deal with the principles and forms of science-organisation in the USSR, the development of research into the history of chemistry, biology, the hydrosphere of the Earth, the shaping of modern science in one of the Soviet Central Asian republics, which like all the other republics of the USSR has travelled a long way from backwardness to progress.

Of course, for reasons of space it is impossible to provide information about the whole range of research into the history of science being carried on by Soviet scientists and its organisational principles. But the Editors hope that the material presented here gives an adequate idea of the diverse topics in the research into the history of science being pursued in the USSR, and also of the main trends in the development of this research. This collection is being published in the "Problems of the Contemporary World" series of the USSR Academy of Sciences, which is widely known in scientific circles.

HISTORY OF NATURAL SCIENCE AS A SCIENCE: PRESENT STATE AND THEORETICAL PROBLEMS

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The advance of studies in the history of science is closely bound up with the development of science itself and its changing status in society. The revolution in natural science at the turn of the century helped to change the notions about science, dispelling the idea that it was a hard-and-fast system of knowledge containing in final form the answers to the main questions about the nature of the surrounding world. That kind of science ceased to be an ideal of cognition. The radical transformation of the concepts of matter, space, motion, outer space and the microcosm, the basic processes of vital activity and the development of the organic world led to the idea of science as being in constant flux. As a result, there was a surge of interest in analysing the history of science and bringing out the causes, uniformities and trends in its development.

Interest in these questions became most pronounced with the development in the middle of this century of the scientific and technological revolution, as science came to exert an unprecedented influence on every aspect of the life of society and even of the individual. Since then analysis of the conditions, causes and laws of the development of

science and its role in the life of society has become a vital social necessity.

In our day, science exerts a tremendous influence on production and the economy. Science, technology and production are being integrated. Under socialism, scientific and technical progress has become the chief instrument in building the material and technical basis of communism and boosting the people's material well-being and cultural standards. It is now safe to say that under socialism science has become a great transformative social force.

Science's changing status in society has naturally generated a greater interest in its history, and while the history of science originated long ago (indeed, it may be as old as science itself and has always attracted the attention of natural scientists and philosophers) the rapid advance of studies in the history of science began in the late 1940s. That was, incidentally, one of the striking indications of the decisive influence exerted by social requirements on the development of science. In the 1950s and 1960s, the history of science becomes a major branch of knowledge in its own right, even against the background of the overall and unprecedented sweep of scientific activity itself. An objective indication of this is the growing number of publications on the history of science and technology. Since the mid-1950s, over 2,000 books and articles on these problems have been published throughout the world every year. The number of special journals on the history of science has multiplied. There are now more than 70 such journals, while 500 journals regularly publish articles on the history of science.

Main Lines of Science-History Development

The first history-of-science chair was set up in France in 1892. Today, there are over 100 such chairs in various countries. In addition, there are about 40 research insti-

tutes and scientific societies studying the history of science. The number of scientists professionally engaged in this field of research has grown considerably. In addition, a growing number of prominent natural scientists in the various countries have recently taken up such research. All of this is an important indicator of the mounting interest in the history of science and recognition of its importance. There is also the steady increase in the number of participants in international congresses on the history of science. From the 8th Congress in Milan in 1956 to the 13th Congress in Moscow in 1971, the attendance has multiplied 10-fold.

The history of science, as a branch of knowledge, has gone through several stages in its development. For a long time, the prevailing type of science-history research was a chronological description of the successes in this or that science, without any attempt to show the logic of its development, and the conditions and factors behind its advance, or virtually the same kind of description but in a biographical context. The latter tended to convert the intricate development of science into a monotonous and tiring enumeration of the "acts" of the individual scientists, and this was often presented in such a way as to leave one with the impression that these men lived and worked outside the context of time and space. I do not refer here to the scientific biographies, which are of unquestionable interest, but to the chronicles set forth "by personalities".

However, works of that type ceased to satisfy the historians of science, and works tracing the development of ideas and problems in the various fields of knowledge gradually become the leading type of research into the history of science. It was Einstein who first suggested that the history of science was not a drama of men but a drama of ideas, and this came to be gradually accepted as a metaphorical definition of such works. That was a definite advance in the formation of the history of science as a scientific discipline.

However, historians frequently failed to grasp the whole complexity of science as a social phenomenon, and the dissatisfaction with the mere chronicling of the history of science was expressed in a peculiar rationalism. Everything that did not relate to the sphere of pure thought was as a rule ignored, and science was seen only as a straightforward and irreversible advance of human reason. All attention was concentrated on the movement of scientific ideas, which in these works existed independently of men, of their world, their activity, their relations, and so on. The scientist's personality, the social soil on which the tree of knowledge grew, remained entirely or almost entirely outside the field of vision of those who wrote the history of science. This approach, in effect, reduced the development of science to a simple filiation of ideas.

Most authors of such works saw their task as amounting to a thorough examination of the process leading to the accumulation of facts and the development of ideas in their field. With rare exceptions, they did not go beyond the subject-matter of their field of natural science. The importance of such works is not being questioned, and moreover, in this period of the rapid increase of knowledge and especially of the snowballing of publications, which the active scientist cannot conceivably hope to cope with, their importance has even increased. Solid works of this type make it possible to some extent to specify the notions about the general state of this or that science and of allied fields of science, but they do not deal with all the tasks and problems in the study of the history of science.

In the past 15-20 years, as the social role of science has grown, together with the corresponding requirements of society in intensifying scientific activity, there has been a marked extension of the range and depth of the problems in science-history research. This has resulted from the growing professional standards among historians of science and their training under special programmes in many coun-

tries involving a mastery not only of the natural sciences, but also of philosophy and some social sciences.

The problems in science-history research have been amplified along three main lines.

First, more attention is being given to the recent history of natural science, a period immediately preceding our day, and overlapping with it. The erstwhile sharp distinction between history and the present has given way to an understanding of their relation as that of "what has taken shape" and that "which is taking shape". This naturally implies as a task in research the study of the past for the sake of gaining a better knowledge of the present and for anticipating the future. With this definition of the tasks in the history of science, the re-establishment of the past ceases to be an end in itself and becomes only a stage on the way to the attainment of the goal. Discovery of the laws of the development of science and the conditions and factors promoting this becomes the goal, which above all shows the importance of the history of science for the present, because nothing can be a more reliable reference point in the advance from the past through the present into the future than the discovery of the laws of the development of the given object.

Second, alongside the studies containing an analysis of the development of the substantive problems of natural science, which in the 20th century became traditional and the most common type of studies in the history of science, research into the social history of science came to occupy an ever more prominent place. This was a study of the genesis and development of science in connection with the development of society, the changing social functions and role of science, and its interaction with the economy, ideology, policy and culture. This is a process leading to the professionalisation of scientific activity and the institutionalisation of science, the formation of the scientific community and the principles governing the rules of behaviour with-

in it, the history of science-organisation thinking and the evolution of the forms of science-organisation, and so on. It is no exaggeration to say that as a result of this extension and deepening of problems, the history of natural science as a branch of knowledge has been invested, since the mid-1950s, with a spirit of social and sociological research.

The third line along which the problems in the study of the history of science have been extended and deepened is connected with the analysis of the internal laws of the development of scientific knowledge, its logical and theoretical problems, most of which had until then either been not considered at all or had been dealt with by philosophy only in the most general terms. These were problems like the relation between the periods of the evolution and of revolutions in science, the factors, conditions and substance of the formation and change of scientific theories, the evolution of the structure of science and its methods, the differentiation and integration of knowledge, the change throughout history of the styles of scientific thinking, of the language of science and of the very concept "science", and so on. In studies of the history of science all of this no longer appears in abstract-logical form alone, but is analysed on the basis of an examination of the concrete situations in concrete historical conditions.

Successes in the history of science, a more thorough historical analysis of the advance of scientific knowledge, and for West European and US historians of science, the crisis of positivism and the abandonment of the positivist unhistorical approach have resulted in a peculiar coalescence of the history and methodology of science. Studies over the past decade provide convincing evidence of this process. Historians of science no longer confine themselves to shedding light on events in the past, but seek to analyse these in order to comprehend the problems of the methodology of scientific cognition. At the same time, many philosophers turn to the history of science not just to collect examples

to illustrate their various conclusions, but to draw their conclusions from an analysis of the real processes in science, which means a deeper insight into its history. While Marxists have always taken this approach, this is a new departure for the non-Marxist trends in philosophy.

Past experience in research has enabled the history of science, while retaining its independence, to become a basis for the emergence of a new science—the science of science—in the second half of the century. This, for its part, has provided an impetus for extending the range of problems in science-history research, while the deeper analysis of the development of science has enhanced the practical importance of science-history studies.

Specific Features of Science-History Studies

This characteristic of the main lines of science-history studies in this century, however brief, shows very well that the history of science has been actively developing as a branch of knowledge. But we are aware that each actively developing branch of knowledge tends to produce new methodological problems. Their number and diversity is especially great in a branch of knowledge like the history of science. On the one hand, this springs from its complexity as a subject, its broad range of problems and the impossibility of using experiments in this field. On the other, it is connected with its special status as a branch of science that is allied both with natural science and with philosophy and the social sciences, as a branch of knowledge in which the analysis of natural-science problems cannot be isolated from the analysis of social problems. The historian of science creatively working in this field is confronted with this problem virtually all the time.

Let us say, for instance, that he has to re-establish an integral picture of a remote epoch in science on the strength of scattered and incomplete data. This work is like

that of the palaeontologist, and in a sense, the history of science may be called the palaeontology of knowledge. Even when he has to study a recent period, the historian of science always has to deal with something that is no longer there. I have in mind the process of creativity and the unique conditions in which the process of the creation of new elements in science has proceeded. Therein lies the special complexity of the work of the historian of science. After all, very rarely does research retain the traces of the creative process, the lines along which the scientist's thought had run. They disappear, like the scaffolding when the building is finished. Scientific publications usually contain only the results of research: a description of the facts, the conclusions, and the rationale. The scientist's quest and the motives for his creative effort are virtually never documented. Only now and again is it possible to gain an idea of these from his letters, reminiscences, and so on. But the historian does not have these in his possession at all times (they may be non-existent or may have been lost). But even when luck is on his side, and he discovers the necessary factual material, he needs to take a doubly critical attitude, because once the discovery has been made, the scientist himself is very rarely able to re-establish all the zigzags of the way he had travelled to that discovery. Success can be achieved, and not always even then, only through tremendous, painstaking and thorough effort, with a study of indirect evidence, comparisons and analysis of a great many sources,

But it is up to the historian of science not merely to relate what had been achieved in this or that period. He has the much more complicated task of divining the spirit of the epoch which he is studying and of understanding the peculiarity of its mode of thinking.

Let me emphasise that these difficulties spring from the very substance of the tasks in science-history research. The need for a thorough search for details and for the con-

ditions of scientific discoveries and generalisations expresses the fact that the historical path and the inner logic of the development of science are inseparable, that the historical and the logical are interconnected. That is why the value of a historical study is proportional to the depth of insight gained into the one and the other.

However, this does not explain the whole complexity of science-history research. Because of its subject-matter, the history of science requires an organic combination of profound analysis and natural-science and socio-historical material, a point at which more than purely individual difficulties arise for the historian. In contrast to the social historian or the historian of philosophy, whose work may be successful if he has mastered a definite knowledge in his field of the social sciences, the historian of natural science must have a knowledge of his chosen field of natural science on a par with that of the natural scientist himself, and not just of its contemporary state, but also of its development in the various epochs. In addition, he must have extensive and profound knowledge in the social sciences.

The methodological difficulties are much more serious. The historian of science cannot confine himself to a description of two parallel theories: the development of scientific thought and social development in this or that epoch. In each concrete instance, he must show the interconnection between these, the concrete forms of their interaction, and explain how the socio-economic, cultural and historical conditions, ideology, and so on, are woven into the fabric of scientific thought and influence its style and orientation.

The complexity of the methodological problems in the history of natural science, which are connected, as I have said, with the nature of its subject-matter, also consists in the fact that while being directly allied in terms of subject-matter with the natural science, it is also a reflection of socio-historical practice and is, consequently,

a part of general history, the history of the productive forces, the history of culture and of education. Moreover, as a reflection of the history of man's cognition of nature and of the very methods of scientific cognition, the history of natural science enters into close contact with the history of philosophy, the history of the formation and development of the materialist world outlook.

The history of science, analysing the process of scientific cognition in accordance with its tasks and on the strength of the data on the development of natural science, is one of the most important instruments for showing laws of cognition. This idea was repeatedly emphasised by Lenin, who said that the history of the individual sciences, together with a generalisation of the data of zoopsychology, linguistics, psychology and the physiology of the sensory organs, constituted "the fields of knowledge from which the theory of knowledge and dialectics should be built".[1] He added: "Continuation of the work of Hegel and Marx must consist in the dialectical elaboration of the history of human thought, science and technology."[2] Consequently, a study of the history of science and technology is an essential element within the complex of research required for the further development of materialist dialectics.

However, while the history of science may be closely connected with social history and philosophy, their subject-matter and tasks are not at all identical. Neither in subject-matter nor in task can the history of science be reduced either to general history or philosophy. Indeed, only by retaining its own independent research function and, consequently, existing as a special branch of knowledge in its own right, can it be useful and necessary for general history and philosophy. But it is necessary above all for natural science.

The history of natural science studies the consistent accumulation of knowledge about science and its development,

about the laws of nature and their mastery by man. Hence its close connection with natural science. The history of natural science makes a study of the ways and logic of the cognition of nature, the origination, development and transformation of the theories and methods of natural science, the place and role of these theories, and the hypotheses and methods in the cognition of nature, and so enriches the natural scientist's thinking, helping to specify and elaborate the theoretical principles of contemporary science and its methodological problems. It is a peculiar form of critical analysis of the ways and means for gaining a knowledge of nature, which becomes especially important in this period of the headlong rush of science.

As science develops, many of the established facts tend to appear in a new light and are seen from an aspect that had earlier been ignored. New aspects in the development of science which had not and could not have been noticed, begin to stand out. In short, at every new and major stage in the development of science a new reading is given to its history. This does not, of course, amount to historical relativism, let alone the putting of a new face on history from time to time. It means only the need for constant and ever deeper and more comprehensive study of history in the light of the latest achievements and tasks of science, to gain a better comprehension of its contemporary problems and a fuller insight into the laws governing the development of science and the objective logic of its advance.

What has been said here suggests the need for studying every stage in the development of science, including the earliest ones. Otherwise, there can be no question of showing the history of knowledge as a law-governed process. The meaningfulness of science-history studies is determined not so much by the period in the development of science which they analyse, as by the problems the researcher sets himself and solves.

The level of knowledge in every epoch is expressed in the most concentrated and generalised form in the leading theoretical notions and concepts, but a genuine study of the advance of science requires more than a knowledge of the evolution of its basic theories and concepts. The general theoretical concepts express the results of a definite stage of cognition, while history has the task of showing not only the results but also the process in which the new knowledge has been made, what may be called its "technology". Let us bear in mind that with all the diversity and complexity of the ways in which scientific theories originate and develop, with all the importance of earlier cogitations for science, new scientific theories, as a rule, originate from the clash of old theories and new facts.

This makes it clear that historical studies should not only show the evolution of the basic theories but should also clarify the factual material at the disposal of science in this or that epoch, and the influence it has had on the shaping, development and transformation of the leading theories and concepts. No aggregation of facts can in itself produce a theory, but it is hardly possible to discover the essential aspects of the mechanism underlying the origination and succession of scientific theories, while ignoring the role the new and earlier unknown facts have to play in this process. Otherwise, the problem of the origination of new science is bound to be replaced by the problem of choice between two existing theories, as will be seen from Th.Kuhn's book <u>The Structure of Scientific Revolutions</u> .

The main task of science-history research is to show how the new knowledge has been obtained in each concrete case and to describe the general mechanism through which it has been obtained. This calls for the clarification of two other points: the genesis of scientific knowledge, and the determining factors in the development of science. These are not only the two main theoretical problems in the history

of science, but are also its main methodological problems, because without their preliminary solution it is impossible correctly to understand or explain the development of science and its laws. They are the starting points for research into the history of science. For a long time historians of science failed to realise the methodological importance of these problems. It was Marx and Engels who first formulated the truly scientific concept which helps to comprehend these problems, and also to show the place and role of science in the history of society. But throughout the 19th century and the early decades of the 20th century, the views of Marx and Engels of the nature of science and its development remained unknown to most historians of science, or were misunderstood by them. This exerted a heavy drag on the elaboration of theoretico-methodological problems in the history of science.

It is a characteristic fact that scientists in the 19th century virtually ignored the highly interesting study produced by Alphonse de Candolle, a botanist of world repute, entitled Histoire des sciences et des savants depuis deux siècles (1873), in which he made a remarkable attempt to use statistical methods to show the social factors promoting or deterring the development of science. This can be explained only by the fact that at that time the social role of science had yet to be brought out to an extent that would have attracted broad attention to the problem of the connection between its development and social development.

Shaping of Main Methodological Lines in Foreign Science Historiography

Only at the turn of the century did scientists start seriously to consider the need to elaborate, alongside the history of the individual sciences, the general history of science, and not merely as a collection of facts, but as a history of scientific ideas in the context of the overall progress of civilisation, development of culture and socie-

ty's political and intellectual life. A great deal to establish this approach was done by G.Sarton (1884-1956), who laid the foundations of the new line in the history of science, which we now call cultural-historic, in the early decades of the 20th century. This was undoubtedly a large stride forward over the chronicling and purely descriptive approach to the history of science.

However, the limitations of the cultural-historical approach were soon also manifest. Indeed, in analysing the development of science, it did not go beyond the intellectual sphere, leaving aside the internal connection between the development of social practice, above all, the material conditions of the life of society and the development of science. That is why the intellectual atmosphere itself in the various historical periods appeared as a mere background against which science advanced. On the other hand, the preoccupation with reconstructing the details of the cultural-historical situation in itself, which far from always explained the specific features of science in a given period, distracted attention from the inner laws of the development of science. It helped to increase interest in works emphasising this aspect of the matter, and this for its part led to the establishment of the so-called immanent, or internalistic line, which considered all these questions in a highly one-sided manner, and for that reason incorrectly. Below, I shall give a characteristic of this line.

A powerful impetus to the elaboration of the laws of the development of science and its motive forces came from the spread in the West of the Marxist view of science, with the decisive role played by the papers presented by the Soviet delegates at the 2nd International Congress of the History of Science in London in 1931, which were published in London that same year in the form of a collection.[3] Several reprints of the collection subsequently appeared, including two in Japan.

The Congress was held at the height of the world economic crisis, which rocked the capitalist world to its very foundations. In these conditions, the Marxist view of the connection between the development of science and socio-economic conditions left a tremendous impression. This was especially true of the paper presented by the Soviet scientist B.Gessen, entitled "The Social and Economic Roots of Newton's 'Beginnings'", which showed foreign historians of science the fruitfulness of applying the principles of Marxist analysis to a concrete science-history problem. It was the subject of lively debate among British scientists and provided an impetus for the publication of several books on the social factors behind the development of science, including J.B.Bernal's 'The Social Function of Science (London, 1939), J.Haldane's 'Daedalus or Science and the Future (London, 1924), Lancelot Hogben's 'Science for the Citizen (London, 1938), and J.G.Crowther's 'The Social Relations of Science (New York, 1941). Gessen's paper stimulated R.Merton's work on the sociology of science, and his first book on the subject, which appeared in 1938, echoed the subject of Gessen's paper.[4]

There is much testimony to show the impact of the Soviet delegates' papers on the subsequent development of thinking in the history of science in Britain and the United States. This has been described by E.Burhop[5] and others. The American sociologist B.Barber said in his article "Sociology of Science" that the Science at the Crossroads collection was valuable for every scientist, regardless of his field, while the analysis of social and economic principles behind Newton's discoveries as presented by Gessen was "brilliant".[6] Derek Price noted that the main event at the Congress was undoubtedly the considerable contribution made by the Soviet delegation, especially Gessen's paper, in which the whole power of the dialectico-materialist method was used to analyse Newton's world.[7] The Japanese historian of science Shiguri Nakayama wrote that the Soviet pa-

pers had an explosive effect.[8]

Acquaintance with Marxist views led to the establishment of a new line in the foreign history of science, which set itself the task of showing the social function of science, the connection between its progress and the development of society, and also of bringing out the impact of socio-economic conditions on science. In the West, it was designated as the externalist approach, and was led by J.D.Bernal.

I do not think that this is a correct designation, because "externalist" is a term that can hardly be applied to everyone who believes that socio-economic conditions and the development of social practice are the definitive factors behind the advance of scientific knowledge. Thus, Marxism, which first established the definitive role of material social practice in history, eschews the externalist derivation of all the complex phenomena in the development of science directly from the economic conditions, and the assertion that the development of science is determined exclusively by factors which are external to science. It has never ignored the relative independence and activity of the mind. Nor did Bernal himself accept such primitive notions in his works, which is why we believe it is not right to include him among the externalists.

At the same time, attempts were made in some works to derive the complex phenomenon in the development of science from purely economic causes, ignoring the specifics of science as intellectual production, and allowing vulgar sociologisation. These defects will also be found in some Soviet works of the 1920s. These can, indeed, be characterised as externalist, and similar works appeared in the capitalist countries in that period and later. Gessen's above-mentioned paper also reveals some straightforwardness in explaining the connection between socio-economic conditions and the development of natural science.

Almost simultaneously, and largely as a response to the spread of Marxist views on the history of science, the opposite line, designated as internalist, began to take shape with the French historian of science Alexandre Koyré (1892–1964) at its head. His book, Etudes galiéennes, expounding the internalist concept of the development of science, was published in 1939, the year of the publication of J.D.Bernal's famous book, The Social Function of Science , but maintaining the opposite views. In contrast to Bernal, who regarded Marxism as the theory which was able to explain the development of science, Koyré joined the idealistic flank in philosophy. He held that man was a spiritual substance and could not be explained through the properties and qualities which belonged to its material (or social) nature. Accordingly, science, as intellectual activity, could not be explained otherwise than on its own basis.

Of course, the internalists agree that economic, social and other factors external to scientific knowledge can influence science, but only in one sense, depending on whether these are favourable or unfavourable factors, either helping to advance or retarding research. However, they can have no effect on the internal structure of scientific knowledge, on its problems and the approach to the solution of scientific problems. Accordingly, the history of science is reduced to the movement of scientific ideas on their own, so that the understanding of the development of science cannot be advanced by going beyond the limits of the analysis of the range of scientific ideas as such.

Nor was the internalist approach altogether barren. Despite its false idealistic premise, it has done a great deal to attract attention to the logico-theoretical problems in the analysis of the development of science. In contrast to the chronicle or purely biographical approach to the history of science, it brought to the fore the analysis of the history of the scientific problems, theories, the conditions

in which theories succeed each other, elaborated the concept of the system of thinking prevailing in major historical epochs, and did much to shed light on the scientific revolution of the 17th century. But having excluded from its analysis the influence of socio-historical practice on the development of science and the question of the motive forces behind scientific cognition, reducing the history of science to a filiation of ideas, it was unable to produce an adequate reflection of the advance of scientific knowledge and to answer this key question: how does new knowledge originate, and why has it been transformed and developed throughout history?

We find, therefore, that the central point of the ideological demarcation among the historians of science, which was clearly brought out in the 1930s, and which is still there, was the question of the motive forces behind the development of science.

The internalist approach has now been markedly weakened, but that is not to say that the struggle against it can be folded up. It has not left the stage, and fresh efforts can well be made to bolster its positions. This will be seen, in particular, from the discussions in the West over Thomas Kuhn's book, The Structure of Scientific Revolutions. Although Kuhn has said that in his book he does not deal with the role of technical achievements or external social, economic and intellectual conditions for the development of science, one of the main, if not the main topic of the subsequent discussion has nevertheless been the problem of the relationship between the logical and the social. This led to the problem of the rational and the irrational in explaining the development of science. This merely went to reaffirm the fact that this is one of the key methodological problems in the history of science. Kuhn's explanation of the development of science is designated by nearly all his Western opponents either as sociological or socio-psychological, and many regard this as repudiation of the rational

explanation of the development of science. But this criticism is not convincing. After all, one could also say that this merely goes to show that any serious explanation of the development of science is ultimately bound to suggest the need for including social elements in it.[9]

The objective difficulty in comprehending that the development of science is socially determined lies in the fact that nowadays science apprehends and formulates social requirements and tasks, whatever the form in which they appear. But this tends to produce a distorted notion that the tasks and lines of scientific development are, in principle, determined by it altogether independently of the requirements and state of social production and of socio-historical practice. Indeed, social production has never determined and does not determine the way in which this or that problem arising in its development is to be solved. For instance, following the great geographical discoveries, the growth of trade and of handicraft production increased the demand for diverse natural, including vegetable, raw materials, and the need emerged first to inventory and then to classify the types of plants and animals, society naturally did not see how the system of classification was to be fundamentally advanced. Its principles had been elaborated by Carl Linnaeus, but the task was itself put forward by social practice. Was it, after all, accidental that it was Britain in the mid-19th century, with its highly developed livestock farming and high level of systematic artificial selection, that produced the doctrine of natural selection? Of course, this was determined not only by the development of animal farming and artifical selection, but also by various aspects of the material and intellectual life of British society in that period. The connection between them and the origination of Darwinism is unquestionable and has been proved by research.

The fact that the development of science is determined by social history is obscured by the fact, furthermore,

that science is unable to solve a problem before the theoretical and experimental and methodical premises for this have matured, and this again creates the impression that it is absolutely independent of socio-economic conditions, or that the socio-historical and the logical run parallel to each other.

The laws of the advance of scietific knowledge are highly complicated. Each branch of science, like science as a whole, has its internal logic and inner laws of development which are determined by its subject-matter and the specific features of scientific cognition. But this does not rule out the basic fact that it is in the process of men's socio-production activity in mastering nature for the purpose of ensuring and improving the conditions of their existence, that it is under its impact that the incentives and premises of cognition were created, the world outlook and style of thinking, the structure of science inherent in the given epoch, its main problems and modes for solving these were formulated and worked out.

Consequently, we reject as incorrect the immanent (or internalist) approach, but do not share the externalist standpoint either.

That is self-evident for Marxist historians of science. For them the main thing now is to obtain concrete material from the history of science to show how socio-economic factors influence the inner structure of science, and how the social is included in the logical and goes to transform it. I think that the system of thinking is the intermediate link between the socio-economic conditions and the intellectual sphere, notably science, when we deal with its inner structure. The role of its transformation in the advance of science is clearly seen throughout its history. The main thing then is to show in concrete terms how socio-economic and cultural-historic changes influence the system of thinking and modify it.

To sum up some of the results:

1. The history of science has a history of its own. It has gone through a number of stages of development, and for its further successful advance these need to be well brought out and comprehended.

2. At one point, the switch from the description of the history of science by personalities to presenting it as development of scientific problems was a major stride in the formation of the history of science as an independent branch of knowledge. It is now quite evident that the problems of the history of science include much more than this.

Ever greater importance attaches to problems like the genesis of science, its place and role in the history of society, its interaction with culture, ideology and policy, the change of the forms of science organisation, the problem of the scientist's responsibility to society, the relationship between the evolution of science and scientific revolutions, the formation and succession of scientific theories, the evolution of the structure of science, of its methods and styles of thinking.

3. Whereas it is being said that sociology is becoming ever more historical, it may be said that the history of science needs to be more sociological, if it is to fulfil its tasks.

4. Science is made by men, and its purpose is to serve men. That is why its history should not be reduced to dry logical schemes. The history of science, describing the accomplishments of men, should show the origins of these accomplishments, the forces impelling men to go on in the hard endeavour of gaining a knowledge of nature and harnessing its forces. One of its chief tasks, which is of growing importance in our day, is to reinvest dry scientific conclusions with their truly humanistic nature and purpose.

The only way science can do this is to deepen the social aspects of science-history studies.

5. The study of history is being increasingly comprehended as an instrument for a deeper understanding of the present and prognostication of the future.

6. The alternative of internalism or externalism does not exist. Neither trend can adequately reflect the development of science. There can be no choice between the two, just as there is no choice between vitalism and mechanicism.

7. The spread in the capitalist countries of the idea that the Marxist concept of the development of science as externalist does not correspond to reality. The Marxist concept, while accepting the definitive role of material social practice, takes account of the relative independence and activity of consciousness and, consequently, also of the inner logic of the advance of scientific knowledge. But this does not amount to a synthesis of internalism and externalism. No such synthesis is possible, just as no synthesis of vitalism and mechanicism is possible, because the two theories proceed from false premises and are incorrect.

8. The Marxist concept of the development of the history of science is the only one capable of adequately reflecting it. This does not mean that we have already solved all the problems and have all the answers. On the contrary, in the light of the Marxist concept of the development of science there is need for the most thorough analysis of how the advancement of various sciences and of natural science as a whole actually proceeded in the various epochs and in the different conditions. The Marxist concept is not a stereotype scheme, or a set of ready answers for every possible question, but a guiding thread which helps one to find one's way in the labyrinth of the multitude of actual and imaginary facts which surround us on every hand as soon as we get down to research.

The Marxist concept of the development of science includes the positive and creative solution of the problem of the continuity of scientific progress, each stage of which is specific, fundamentally novel and unidentical; it impels one to fresh analysis. This is a highly meaningful problem. The pseudoradical theorists of the "great repudiation", including Herbert Marcuse, present man with a future which has no links with the past. Marxism regards the past as an object of analysis showing the historical causal origins of the present, and it is in the present that Marxism discovers the forces that lead to the future. Marxism-Leninism regards scientific revolutions as links in the irreversible and continuous, causally determined transition to ever more precise and adequate notions of the world approximating reality. This is a real transition, which occurs in time and space, a transition in which the inner logic of cognition makes headway in living interaction between every aspect of the overall historical process.

NOTES

[1] V.I.Lenin, Collected Works, Moscow, Vol.38, p.353.

[2] Ibid., pp.146-147.

[3] Science at the Crossroads. Papers from the Second International Congress of the History of Science and Technology, Second Edition, London, 1971.

[4] R.Merton, "Science, Technology and Society in the Seventeenth Century England", Osiris, Bruges, 1938, Vol.4, pp.360, 632. See also: A.R.Hall, "Merton Revisited or Science and Society in the Seventeenth Century, History of Science, Cambridge, 1963, Vol.2, pp.1-16.

[5] E.Burhop, "Scientist and Political Activity", The Science of Science, London, 1964.

[6] B.Barber, "Sociology of Science", Sociology Today. Problems and Prospects, New York, 1962.

[7] D.Price, "The Science of Science", The Science of Science, London, 1964.

[8] S.Nakayama, "Externalist Approach of Japanese Historians of Science", Japan Studies in the History of Science, Tokyo, 1972, Vol.II, pp.1-10.

[9] I do not refer here to the evaluation of Kuhn's concept as a whole, which I have given in an afterword to the Russian translation of his book The Structure of Scientific Revolutions, Moscow, 1975.

UNITY OF SOCIAL AND OBJECT FACTORS IN THE DEVELOPMENT OF SCIENCE

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Clarification of the factors behind the development of science, i.e., those providing the motive force of scientific progress, is, of course, the prime task facing historians of science and the be-all-and-end-all of the science of science. The solution of this problem largely predetermines the possibility of solving the second chief problem of the science of science, namely, the problem of how science develops, how the succession of extensive and intensive ways of its development occurs, and how invariant and transient ideas are combined in science.

There is no doubt that clarification of the factors behind the development of science is attendant with great difficulties, and this apparently explains to some extent why the problem of the antithesis between externalism and internalism still remains on the agenda of international congresses. But these difficulties can in some measure be surmounted, given observance of three conditions, without which the history of science and the science of science in general cannot claim the status of a scientific discipline. The first condition is reliability and authenticity of factual historico-scientific material used by the researcher who has got down to tackling the problem; the second condi-

tion is the fullest possible scope of the facts from the history of science being studied in the sense of coverage of different historical epochs and scientific trends; the third condition is soundness of the methodology used in the study of science.

The importance of the first condition is obvious and indisputable. One need merely add that this condition is far from always being observed. It has happened that historians of science, operating with second-hand material, repeat from book to book erroneous characteristics of scientists of the past. Thus, the stand taken by Berzelius in the controversy with his opponents over the problem of catalysis was characterised as vitalism back in the first half of the 19th century only because he had introduced the concept of catalytic force (Katalitischen Dinamide). This erroneous assertion migrated from one textbook on the history of chemistry to another, whereas actually, his catalytic-force theory was a departure from vitalism and was a highly progressive advance.

Another scientist, C.L.Berthollet, was ascribed anti-atomistic-continualistic ideas up until recently, following Ch.Würtz's erroneous assertion in 1868. The ground for this was provided by Berthollet's attack on Dalton's idea about the discreteness of chemical relations. Actually, Berthollet was an active advocate of the corpuscular theory and his objections to Dalton were based on the exceptionally progressive idea of the continuity of change of the "cohesive force" of the elementary particles in their interaction. Such distortions of reality obviously confuse the whole picture. The only conclusion to be drawn is that there should be a thorough study of the first-hand and nothing but the first-hand facts from the history of science.

The importance of the second condition does not require any substantiations either. The fuller the facts from the history of science that are being studied, the more reliable the empirical basis for analysis in the theory of the

development of science. What this means, in effect, is that science should be studied as a coherent and developing system. It is clearly hard or perhaps even impossible to obtain any idea of the whole line of development of a science from casual fragments taken from its history.

The importance of the third condition—soundness of methodology—consists in avoiding subjectiveness and one-sidedness in evaluating the results of research into science. In this sense, the Marxist methodology of analysis is the most reliable one because it requires as the elementary condition: 1) the most comprehensive possible study of all the factors in the development of science, 2) the analysis of the mechanism of their operation in its entirety, and 3) the results of the analysis which follow from empirical facts and are not invented.

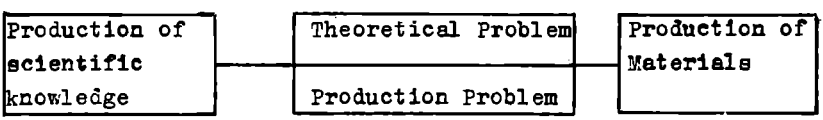
The present article considers the study of factors behind the development of chemistry. It is the result of many years of study of the world history of chemistry by a large group of Soviet historians of science; it contains, however, only some of the conclusions of our research, but these are conclusions, and not just some standpoint of the authors.

At the time when we were just starting out, we were unable to answer many cardinal questions bearing on the history of chemistry. No book, no textbook on the history of chemistry contained any substantiated answers to such questions as: 1) Where should one seek the origins of chemistry as a science? In the works of Boyle, Stahl, Lavoisier or Dalton? 2) Is chemistry a coherent entity, or should it be regarded as a sum-total of different chemistries: inorganic, organic, physical, etc.? 3) Can one regard the history of chemistry as a coherent process, or is it a sum-total of the histories of the individual sciences? 4) What are the factors that determine the advance of scientific ideas and the growth of the file of scientific information? 5) What are the factors that determine the structure of chemistry, its differentiation and integration?

Today, we have at our disposal material which suggests answers to all these questions. Below we set forth the conclusions drawn as a result of the study of the origins of chemistry in the ancient handicrafts and in ancient natural philosophy, in mediaeval production and the alchemists' treatises, and also as a result of research into chemical knowledge proper in the modern and contemporary period, up until the present day.

Conclusion One. From the early stages of its development, chemistry has been a phenomenon included in the spheres of society's material production and spiritual culture. Mankind has always had need of chemistry as such only to obtain from the substances of Nature all the possible materials it needed: metals and ceramics, limestone and cement, concrete and glass, dyes and pharmaceutical preparations, rubber and plastics, man-made fiber and probably man-made foods. That is why all chemical knowledge is united by the one chief task of chemistry, that of helping to obtain substances with the necessary properties. In order to fulfil this production task, chemistry must simultaneously tackle the theoretical problem of origins of the properties of substances.

Consequently, the integrity of chemistry as a science is ensured by the existence of the biunial problem it faces: to obtain substances with preset properties, to which man's productive activity is geared, and to find the ways of controlling the properties of substance, at which man's theoretical knowledge is aimed.



Fundamental Problem of Chemistry

From this it already follows that chemistry is undoubtedly a coherent science, despite its constant ramifications and the existence of a multiplicity of relatively independent chemical sciences.

Conclusion Two. The fundamental problem of chemistry is not only its theoretical but also its historical pivot, chemistry's invariant core. It originated in ancient times and is still meaningful today. From this it follows that the history of chemistry is a coherent process, and not a sum-total of the histories of the various sciences.

But for all its invariance, this problem tends to evolve: in the ancient period it was the problem of causality behind the immense diversity of bodies; in the Middle Ages, it was the problem of the dependence of the properties on the elements constituting the given body; and in our day it is the problem of reactivity.

Conclusion Three. A most important specific feature of the fundamental problem of chemistry is that it has only five modes of solution. These are the most general modes of solving the problem of the qualitative diversity of matter, and has nothing to do with the particular methods used in the study of properties. The consistent organisation of these modes marks the succession of the conceptual systems of chemistry: peculiar evolutions and revolutions in its development, something that is determined, on the one hand, by the socio-historical conditions in the life of society, and on the other, by the nature of the substance which is the object of the study of chemistry. Here it transpires that both these "external" factors ultimately also determine the inner logic of the development of scientific knowledge.

History of Chemistry as a Law-Governed Succession of the Modes of Solving Its Fundamental Problem

The first mode of solving the problem of the origins of the properties of substance originated in ancient natu-

ral philosophy and existed for more than two thousand years, up until Boyle's time. In that period, two fundamentally different explanations were offered for the immense qualitative diversity of bodies: the atomistic and the continualistic. However, both (with their numerous shades) boiled down to the assertion that the diversity of the bodies in Nature was an accidental manifestation of substance, by which some philosophers implied atoms, and others, quality-elements. Still, both spoke about some absolute principles. This first mode of solving the problem of the qualitative diversity of matter may therefore be presented as this general Scheme I:

Substance. ——→ .Accidence

The distinctive features of this mode are: 1) speculation, acquiring the great power of abstraction but deprived of empirical foundations; 2) logical deduction laying claim to universality of explanation but essentially not resting on the criterion of practice at all; 3) the universality and diversity of an object, which is substance, instead of the specificity of a qualitatively changing material, in short, everything that characterises natural philosophy, within which this mode originated and developed. From this it will be easily seen that this was no more than a first attempt to explain the nature of bodies, and that it could essentially yield nothing for the practice of production. Indeed, was it possible in any way to make use of the atomistic ideas of Democritus or of the notions about the elements expounded by Empedocles in practical metallurgy, pharmacy, glass-making or pottery?

Finally, another feature of the first mode, which is proper to it alone, is that it is historically doomed. Being virtually fruitless, it becomes useless with the emergence of new modes for the solution of the problem, which yield more authentic explanations of the qualitative diversity of bodies, and practically useful recipes for their purposeful chemical transformation. The characteristic

thing is that once having emerged, all other modes, to be dealt with below, have continued to be in use up to the present day.

The specific features of the first mode, taken together, make it so distinctive as compared with the subsequent modes that they suggest an idea (frequently expressed but not very well grounded to this very day) about the borderline between "scientific chemistry", which starts with Boyle, and some kind of "unscientific" (or not quite scientific) chemistry, which had existed before his day.

The second mode for solving the problem of the origins of properties emerged in the writings of the English scientist Robert Boyle in the second half of the 17th century. The changes taking place in production during the Renaissance, alongside the progressive changes in economic and political life, produced the need for fundamental changes in natural science as well. One of these was the overthrow of the first—virtually useless—mode for solving the problem of the genesis of properties, and the emergence of another mode with a basically new—experimental—approach to the study of Nature.

Boyle's studies led him to the conclusion that the qualities and properties of bodies are not absolute and depend on the material elements of which they consist. The conclusion was a fundamentally new one, because:

it rejected the prevailing notions about quality-elements, and about the properties of bodies being determined by elemental-properties;

it established the new concept of elements as being simple bodies which could not be further decomposed, and which made up all the mixed bodies, that is, chemical compounds;

by recognising that the elements are material, he first established the common nature of the previously isolated doctrines of atomism and continualism, by advancing

the idea that the atom of an element was the smallest particle of a simple body, while a corpuscle, consisting of atoms, the smallest particle of a mixed body. Consequently, the mode for solving the age-old problem of the causality of properties, or of the qualitative diversity of bodies, was expressed by means of Scheme II:

Composition• ——→ •Property

This mode inaugurated experimental chemistry, determining it as a science of the composition of substances, or the"science of chemical elements and their compounds" (D.I.Mendeleyev). Despite the fact that the science of composition was mainly analytical, it still helped to lay the foundations of the knowledge of the laws governing the combination of elements into "compound bodies", which made it possible to proceed reliably in obtaining new substances.

The science of composition which originated in this way was launched upon a virtually boundless existence. It became chemistry's first conceptual system, that is, the first relatively independent sphere of chemical knowledge (rules, laws and theories) designed to solve any problem—with which it could, of course, cope—of qualitative chemical transformations in terms of composition-properties, or through changes in the elementary composition of chemical compounds.

The third mode for solving the fundamental problem of chemistry was engendered by the transition from the manufactory stage of capitalism, with its manual techniques and limited range of the objects of labour, to the factory system of capitalist production, resting on machinery and a new raw-material basis. This transition stimulated the processing of a vast mass of substances of vegetable and animal origin, whose qualitative diversity was astounding, while their composition was extremely uniform (5-7 elements —"organogens"). Under these conditions, and also as a result of the discovery of isomerism and polymerism in the early 19th century, there emerged a new mode for solving

the problem of the genesis of properties depending on structure as presented in Scheme III:

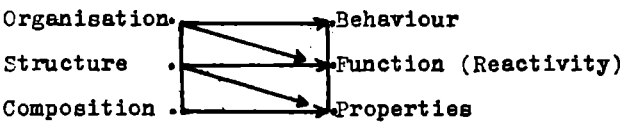


This mode caused the emergence of a series of theories which were highly abstract and generalised, unusually heuristic and of great practical value, inaugurating the second conceptual system--structural chemistry. Having risen to a new and much higher level of adequacy of reflection (as compared with the science of composition) chemistry's ideal component also became the most active in its transformation into a material force. Once mainly analytical, chemistry became a chiefly synthetic science. The period in which structural chemistry took shape is designated by historians as the "triumphant march of organic synthesis". By 1870-1890, chemistry responded to the requirements which sprang from the development of production that had engendered this mode by producing diverse dyes for the textile industry, various preparations for pharmacy, artificial silk for production and everyday needs, and—at the start of this century—synthetic rubber for the first few batches of motorcars.

That was a stunning response on chemistry's part, because up until then all these materials were to be had only in limited quantities and were extracted with vast expenditure of low-productive, mainly agricultural labour. But the amazement at the successes of structural chemistry was short-lived. The intensive development of the automobile industry, aviation, the power industry and instrument-making in the 20th century confronted materiology with absolutely unusual demands: there was a need for materials with strictly preset properties and in unprecedented quantities, including high-octane motor fuel, special lubricants, special rubbers and plastics, highly stable insulators, heat-resistant organic and inorganic polymers and semiconductors. The mode based on structural chemistry alone was no longer equal to the task of obtaining these materials: 1) it failed

to ensure economically acceptable outputs; 2) it was as a rule oriented upon active original substances, like alcohols, acids and so, of vegetable origin (let us recall that the first synthetic rubber was obtained from ethyl alcohol, with a monomer yield of 28-30 per cent, and the alcohol itself coming from grain); and 3) it did not make it possible to control the processes of synthesis.

Under the impact of the new demands of production there emerged the following—fourth—mode for solving the problem of the genesis of properties and the qualitative transformation of substances (Scheme IV):



This mode provided the basis for the new—third—conceptual system of chemistry, the theory of chemical processes, which reflected the object of chemistry much more adequately and comprehensively. The object of chemistry was presented as the transformation of substances and not as complete substances. The object of chemistry was no longer based on the structure of the molecule but on the chemical organisation of a kinetic system in which the molecule structure was only a particular factor. With the attainment of the new level, chemical knowledge became even more effective in practical terms: there were fundamentally new potentialities for organic synthesis and new methods for controlling chemical processes. This was expressed in the fact that the new chemistry helped fundamentally and globally to transform both the object of labour and the means of labour. It was the new mode for solving its fundamental problem that helped to base the worldwide production of such bulk materials as synthetic rubber, plastics, man-made fibers, detergents, ethyl alcohol and so on on oil raw materials, and the production of nitrogen fertilisers, on the nitrogen of the air.

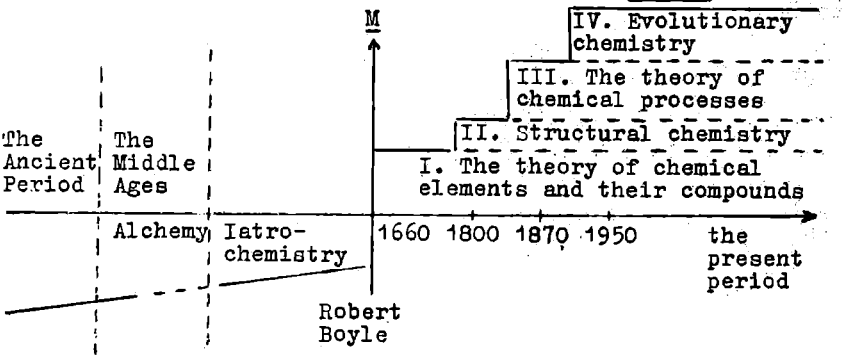
The following data show how the production of material wealth was restructured as a result of its chemicalisation. In 1935, for instance, 100 per cent of materials such as leather, furs, rubber, fibers, detergents, varnish, lacquer, acetic acid and ethyl alcohol was made from animal and vegetable, and in particular food raw materials, requiring the consumption of tens of millions of tons of grain, potatoes, fats, hides, etc. But in the 1960s, 100 per cent of industrial alcohol, 80 per cent of detergents, 90 per cent of varnish and lacquer, 35 per cent of fibers, 65 per cent of rubber and nearly 20 per cent of leather materials were being made from gas and oil raw materials. Besides, far from requiring the use of agricultural raw materials, chemistry now supplies agriculture with hundreds of thousands of tons of urea and petroleum protein, only as cattle feed, and hundreds of millions of tons of fertilisers.

Nor are these potentialities the limit in any sense. In response to the requirements of the most highly developed mode of production of material wealth, chemistry is now moving to a new—fifth—mode of solving its fundamental problem which opens up ways of using in the production of materials the most highly organised chemical systems that are at all possible in prebiological synthesis. It is beginning to use the catalytic experience of animate nature itself. This mode lies at the basis of the fourth, and final conceptual system of chemical science, namely evolutionary chemistry. On the basis of what has been said above, chemistry's historical development may be presented as follows. (See Fig. 1.)

Consequently, the development of chemistry is determined by two categories of factors: first, social factors, second, the nature of the object of analysis.

We have tried to show here the operation of only some of the most important social factors, namely, those which determine both the social purposes of our science and the existence of chemistry itself. These are requirements for the production of materials and material wealth. But among

Fig. I



where M is the mass of scientific information.

the social factors are also the level of the development of production and, in particular, the technical facilities of the whole of society's practical object-activity, and its spiritual culture, its level and requirements. These factors taken together determine the development of chemical knowledge. This makes clear the mechanism of their action: social factors are not only the motive force behind the development of chemistry, but also take part in shaping the structure of the science. After all, it is they that dictate the definite succession of the modes for solving the fundamental problem of chemistry, and together with this the sequence in which the conceptual systems of chemistry originate.

Because of the limitations of space, we are unable to show that the same structure of chemistry is also produced by its object, the specifics of the material organisation of substances. The logic of the consistent emergence of I—theory of composition, that is, of chemical elements and their compounds, II—structural chemistry, III—the theory of chemical processes, and IV—evolutionary chemistry, is a derivative of the logic of the object, of the hierarchy of material chemical systems: 1) the atom of a chemical element, 2) the molecule of a chemical compound, 3) the continuum of interacting reagents, and 4) the highly orga-

nised catalytic system. This unity of the two logics shows the most profound essence of the unity of the "external" and "internal" factors of the development of science.

But nothing of this will minimise the special role of the initial stimuli in the development of chemistry, which are inherent in it, as they are in any other relatively independent and developing system of scientific knowledge. Among these stimuli are, for instance, the contradictions between the empirical and theoretical levels of knowledge, between the theories of differing degrees of generality, between truth and error, between different research programmes (according to Lakatos) and so on. These stimuli are of much importance for the development of chemistry, ensuring its advance along the ways determined by the logic of its object and the social factors.

On the Principles of Science Classification

The conclusion that the history of chemistry may be presented as a consistent emergence and development of four of its conceptual systems is of fundamental importance for the theory of the development of chemistry. First, it provides a single principle for comprehending and systematising the whole vast material of this science, defining it as a coherent system of scientific knowledge with a uniform structure. Second, it indicates the hierarchy of conceptual systems, first opening up the potentialities for determining the levels of scientific research, and from there on also the perspectives for the development of chemistry.

Indeed, every one knows about the difficulties now arising from the systematisation of scientific trends in the field of chemistry. The differentiation and integration of science have now resulted in a situation in which the division of chemistry into its classical branches—organic and inorganic—has largely become meaningless. The discovery of new so-called hetero-organic compounds has produced the need for an integrative science, the chemistry of

hetero-organic compounds, to deal with the hundreds of thousands of organic compounds now dealt with both by inorganic and organic chemistry. The chemistry of complex compounds now operating with the overwhelming majority of inorganic compounds has rendered the subject-matter of inorganic chemistry indefinite. It turns out, therefore, that one and the same subject-matter falls within the ambit of three or four different chemical disciplines. The efforts to maintain the old principle of division of knowledge according to the subject-matter of research as the basis of science-classification have produced a mixed bag of chemistries: alicyclic-compound chemistry, the chemistry of solids, natural-compound chemistry, high-molecular compound chemistry, petrochemistry, solution chemistry, organometallic chemistry, surface-compound chemistry, etc. We find that in one case in this mixed series the object is taken to be the composition of compounds, in another, its aggregate state, in a third, the magnitude of the molecular weight, in a fourth, the genetic line (from petroleum, from vegetable or animal organisms). Accordingly, the very concept of the subject-matter of the science becomes obscure and diffuse. But the existing classification of chemistry is not confined to the subject-matter principle, for there are others alongside it, like the division according to the purpose of research: analytic chemistry and synthetic chemistry. That is a second level of classification. The third level is the division of chemistry according to research methods: non-catalytic chemistry and catalytic chemistry, with dozens of subdivisions like homogeneous catalysis, heterogeneous catalysis and so on. The fourth level of classification consists of the adjacent divisions of chemistry, like biochemistry, electrochemistry, mechanochemistry, etc.

In short, the numerous lines of modern chemistry fan out from the centre into different points of the sphere, and the attempts to bring them into a system have not yet produced any coherent structure of the science. For the time being in the textbooks on general chemistry, in refer-

ence journals and in patent rubrication we find a clearly expressed but largely artificial multistructural chemistry.

Quite naturally, this state of affairs with the classification of chemistry is fraught with many difficulties, hampering the teaching process, complexifying the search for scientific information, and leading to confusion in the establishment of scientific institutions. The existing classification, far from promoting, in effect hampers the planning and coordination of research, because it is itself latent with duplication of scientific lines.

But, in addition, the problem of chemistry classification is compounded by the existence of so-called physical chemistry.

Physical chemistry textbooks include at least the following divisions: the theory of the structure of the atom, the theory of the structure of molecules, and the theory of chemical bonds, the theory of solutions, the chemistry of solids, phase and chemical equilibria in gas, gas-liquid, liquid and condensed systems, the chemistry of surface compounds and complexes, kinetics and catalysis. Elementary analysis and organoleptic methods remain virtually alone outside the sphere of physical chemistry.

That is why physical chemistry should not be regarded as some in-between discipline which has resulted from the integration of science. Today, it is chemistry as a whole, including those of its divisions which are designated as organic and inorganic chemistry, provided of course that theory is also a part of the empirical description of the millions of individual chemical substances. However, this on the whole indisputable proposition has yet to overcome the inertia of traditional chemistry classification. That is why, despite the complete identity of the subject-matter of physical chemistry and chemistry as a whole, the former is still considered as being no more than one of the many divisions of the latter.

The classification of chemistry, based on the one principle of distribution of the whole of chemical material according to the four conceptual systems, in conformity with the four modes for solving the fundamental problem of chemistry, does away with all these discrepancies and, what is most important, creates the premises for bringing out the trends in the development of chemistry. Of course, it does not abolish the whole of the old classification, which had spontaneously taken shape as a result of the differentiation and integration of chemistry, but switches it into the mainstream of the coherent system that calls for stringent coordination and subordination of all the branches of chemistry.

In concrete terms, the main features of the new approach to an analysis of the development of chemistry boil down to the following.

1. Because the object of chemistry is determined by the one abiding task of the science—the task of producing substances with preset properties—and because this object has a systemic nature, the knowledge of it also constitutes something of a unity and is also systemic.

2. In accordance with the one task of chemistry, all the four above-mentioned conceptual systems have one and the same object of study, namely, the chemical organisation of a substance. Indeed, they indicate that chemistry is coherent. But according to the various modes for solving this problem, the study of the object by the conceptual systems is carried on at different levels, which in effect determine for each of these their own subject-matter of research, their own conceptual apparatus, that is, invest them relative independence. In this sense, the four above-mentioned conceptual systems should be regarded as subsystems with respect to chemistry as a whole.

3. The subject-matter of research of the first conceptual system is the composition of chemical compounds, which is regarded as a factor determining all the qualitative

diversity of substances. Accordingly, this system includes the following scientific lines: a) elaboration and use of the methods of elementary chemical analysis; b) discovery of new chemical elements, including their artificial synthesis; c) systematisation of chemical elements, including the development of the theory of the periodical system; d) elaboration of methods for studying chemical compounds, in terms of composition-properties, including "physico-chemical analysis", "physico-chemical methods of property computation" according to Kireyev-Karapetyants, and so on.

4. The subject-matter of research of the second conceptual system is the structure of chemical compounds in the full sense of the concept. Accordingly, the second conceptual system includes: a) research aimed at establishing the structure of chemical—both organic and inorganic—compounds, including and mainly with the use of physical methods; b) research to bring out the dependence of reactivity of compounds on their structure.

5. The subject-matter of research of the third conceptual system is the process of chemical transformation, or the system of reacting substances as a kinetic continuum.

Accordingly, the third conceptual system includes: a) research into the mechanism of chemical reactions; b) the theory of the transitional state as the most important phenomenon in any chemical process; c) the theory of processes —free-radical, ion, ion-radical and processes with cyclical transfer of electron bonds; d) the theory of catalysis; e) research into macrokinetics, including the elaboration of the principles of optimisation of the reaction system and mathematical modelling of processes.

6. The subject-matter of research of the fourth conceptual system is chemical evolution as the highest expression of the chemical form of the motion of matter. This conceptual system includes: a) research into the problems of chemical evolution and biogenesis; b) study of the functions and behaviour of bio-organic systems, depending on the level

and specific features of their organisation; and c) modelling of biocatalysts.

The Principle of Homology, or the Principle of Compression of Scientific Information and Its Practical Importance

In the development of chemistry there is not a succession but a successive emergence of conceptual systems, with each new emerging system being a higher homologue with respect to the lower system. It includes within itself the transformed scientific knowledge of the earlier system, just as ethane includes within itself methane, or as the theory of heat includes within itself the "mechanics of molecules". The theory of chemical processes includes within itself all the scientific information of structural chemistry as the basis for solving new problems of the chemical reconstruction of a substance on a new and higher level.

With the rise from the first conceptual system to the fourth, there is consequently a compression of scientific information. The mechanism of this compression is still far from being altogether clear, but the study of it is of crucial importance both for the purposes of the science of science and especially for the organisation of teaching. After all, only by being guided by the principle of the compression of knowledge is it possible to find the most rational solution for the problems of programming instruction with the present growth of scientific information.

Revolution in Science

In this article I have not considered the question of revolutionary and evolutionary ways of advance in scientific knowledge, because this requires special study,[1] but I must emphasise that our analysis of the development of chemistry makes it possible to determine quite clearly the evolutionary ways of the development of science within one conceptual

system and revolutionary transitions from one conceptual system to another at periods in which new modes for solving the invariant problem of determining properties arise.

NOTE

[1] See B.Kedrov's article in this collection.

CRITERIA OF THE SCIENTIFIC REVOLUTION

Academician Bonifaty KEDROV

The essence of the revolution in science. That essence consists, not only in the demolition of hitherto established concepts, theories, principles, and laws affecting a particular area of scientific knowledge but also a revolution in scientists' thinking, in their overall mode of perceiving the world they study. Hence it follows that the scientific revolution always takes place in the field of thinking, i.e., in the sphere of theoretical ideas, generalisations and explanations, but not in the sphere of purely empirical discoveries and observations, which are merely the premise for a revolution in science but do not as yet comprise such a revolution.

For instance, the empirical discovery of what came to be known as oxygen (its actual discovery in Nature) was not yet a revolution, and was fully interpretable from the positions of phlogiston ideas. It was only after Lavoisier, on the basis of a correct theoretical interpretation of the discovery, demolished the phlogiston theory to its very foundations that a revolution took place in chemistry at the end of the 18th century. In exactly the same way, the empirical discovery of the phenomena of radioactivity was not yet a revolution in physics since it could be reconciled with the idea that the atom was something constant and indestructible. It became a revolution only after Rutherford and Soddy, in the early 20th century, brought forward an explanation of radioactivity as spontaneous atomic decay,

as a transformation of elements. Again, the phenomenon of nuclear fission, which was observed in 1934-1938, could be and was explained as a simple consequence of the formation of transurania, which meant that it was in full accord with previously existent ideas, without yet leading up to any particular revolution. It was only in 1939, when O.Hahn and Strassman advanced a theoretical explanation of this phenomena as fission of the nucleus, that a new stage of a revolution began in 20th-century physics.

Each of these discoveries was not only revolutionary in content but also brought about and embodied a revolution in science since it demolished the entire system of previously held ideas, the entire mode of scientific thinking.

An overall criterion of a revolution in science. Such a criterion follows directly from what has just been said: if what we have is a demolition of a system of fundamental scientific concepts, a process that takes place under the impact of new discoveries in science; if there takes place thorough-going restructuring and a complete change of the entire system of scientists' thinking, the very mode of their understanding and explanation of the world they are cognising, then that goes to prove that what we are witnessing is a revolution in science.

The history of the collapse of the phlogiston theory in chemistry, as well as of a number of other doctrines (e.g., the Ptolemian geocentric theory in astronomy, the thermogenic theory in physics, teleological theory in biology and Hegel's idealistic philosophy) shows that in each of these there took place a collapse of the entire previous thinking of scientists within the framework of the corresponding branch of knowledge; in other words, there was a complete breakdown followed by a restructuring of the mode of perceiving and explaining the world as studied by scientists. Therefore, we are here dealing with different instances of a revolution in science, all of them epistemologically being varieties of one and the same type of sci-

entific revolution, namely the very first type. Irrespective of the area of scientific knowledge within which such a revolution in science takes place, its essence takes the concrete form of a breakdown in faith in what is immediately discernible, in other words, the collapse of an unreserved recognition that reality consists in what we see directly (what seems to us) at first glance.

Thus the Ptolemian theory was based on the seeming movement of the Sun and the stars around the Earth; the phlogiston theory was based on what seemed to be the decomposition of burning bodies into their components; the thermogenic theory proceeded from the seeming escape of the heat substance concealed in bodies, when struck or rubbed; the teleological theory in biology was based on a recognition of the seeming purposefulness in the structure and functioning of living creatures; in philosophy the Hegelian doctrine was built on the seeming primacy of the mind (because of its activity) as against matter, and so on and so forth. In all these instances, the revolution in science consisted in a thorough demolition of a given mode or system of scientists' thinking, or, in other words, of the previously existent mode of perceiving and explaining (understanding) the processes and the relations between things they could observe.

The fundamental tasks of a revolution in science. Any revolution in science pursues two main objectives and possesses two main functions, which it sets about accomplishing sometimes simultaneously in their interaction, and sometimes consecutively. In the latter case, they perform as stages or phases of the implementation of a scientific revolution itself.

The first task of a revolution in science (its first function or first phase) is negative, destructive in character: there exists a necessity for the revolutionary overthrow, i.e., in a decisive fashion, down to its very foundations—of the entire system of the old concepts, theories,

principles and laws; and simultaneously and principally, of the entire previously existing system of thinking in scientists, the mode in which they have perceived the world they have studied. Without the accomplishment of this negative, destructive and profoundly revolutionary task, there can be no elimination of the main obstacle to the evolution and acceptance of the new views and the new mode of thinking in scientists; the road cannot be cleared for the penetration of the new views into science, and their establishment therein.

The second task of a revolution in science (its second function or phase) is fundamental and decisive, positive and creative in character: the need exists for the evolution, substantiation and establishment of a system of new concepts, theories, principles and laws in science, and together with that and most important, a new system of thinking in scientists, a new mode of perceiving and understanding the world they study. Without the accomplishment of this positive and constructive task as the main thing in any revolution, the revolution itself cannot be brought to its actual realisation; it would come to a standstill at the halfway mark, or, more precisely, at the very outset, without performing its main historical mission. That is why to correctly and fully apply the criterion of a revolution in science, one must prove that the revolution in question has been taken in the full scope of its progress, from the initial to the final and concluding phase (or until the concluding phase of a particular stage in it).

The external distinction between two phases in a revolution in science. That distinction hinges on the difference between their nature and inner content. The first stage (the destructive and negative) sees coming into the foreground a destructive criticism of outmoded and radically rejected views, their revolutionary overturn. That is expressed in decisive oral and published attacks against the old ideas, and the appearance of ever fresh arguments

to prove their untenability, their complete erroneousness, and need for their rejection. Like any other revolution, this phase is rapid and violent; it is directed towards overcoming and crushing all resistance from adherents of the old views and to clearing the way for the acceptance of the new views that must take their place.

In the second phase (the constructive and positive), the scientific revolution changes sharply in its external manifestation: the violent attacks against outmoded views whose demolition is essential yield place to day-by-day and creative seekings (which at times seem pedestrian) aimed at evolving, perfecting, experimentally verifying and then establishing new theoretical views in science. That work cannot be completed at one swoop, in the way that a system of old concepts and views can be reduced to rubble. It is now a matter of thorough and careful sifting of whatever is valuable and scientifically worthwhile in the material previously accumulated, its reappraisal, and blending with the new knowledge, so as to achieve a theoretical synthesis that will sum up the positive results of the new revolution in science.

What must now come into the foreground is the systematic and constant critical appraisal to which a given scientific revolution (i.e., the scientists that have brought it about, and their followers) subjects its own critical conclusions and structures. That continues until the constructive task the scientific revolution has set itself is accomplished at least in its main features. That is why the second phase of a scientific revolution sees the attention of scientists drawn to creative discussions, both oral and in print, bearing upon the new theoretical views that are replacing those overturned during the first phase of that revolution.

The constructive task of scientific revolutions of the first type. Such revolutions result primarily in a re-

cognition that behind what is immediately visible in things and phenomena (their seemingness) lies their essence, for instance in the form of definite laws of Nature, which is hidden from our sight and cannot be sensed tangibly. Such are the laws of the movement of celestial bodies, laws which are not of course inscribed in the Heavens but lie concealed in the movements of individual bodies which we can observe and which therefore must and can be deduced from those movements by the mind. To search for and find the hidden essence in things and phenomena under study comprises the constructive task (function) of scientific revolution of the first type.

Therefore, if one examines a scientific revolution, not only from the viewpoint of its first or negative task (function or phase) but at the same time from the viewpoint of the second or constructive task, the revolution itself will be seen as a sufficiently lengthy historical process, which begins with the demolition of the old mode of thinking (one based on the acceptance of what is immediately visible) and is completed by the establishment of a new mode of thinking (one based on the discovery and recognition of the hidden essence in things and phenomena). When things and phenomena (movements) can be measured and reveal their quantitative aspect, the relevant laws can be expressed with the aid of mathematical relationships. But since mathematics, as an abstract science, does not possess the substance of sensual perception, its penetration into any branch of scientific knowledge promotes searchers for the hidden essence in things and phenomena, and then the expression of that essence when it is found, since in fact it replaces immediate sensual cognition with cognition achieved with the aid of thinking in abstract terms.

The mechanism of a scientific revolution of the first type and its specific criterion. The notions of a subject under study, which come into being on the basis of its immediate appearance, reflect that object, its connections

and relations in a kind of inverted fashion, upside down, as it were. This produces a picture that is the diametrical opposite of what actually exists. Thus, according to the Ptolemian geocentric theory, it is not the Earth that rotates on its own axis and revolves about the Sun, but the Sun and the stars that travel round the Earth, which seems to be the hub of the Universe; in just the same way, it is not oxygen as a simple substance that unites with burning bodies but the latter and allegedly complex bodies that decompose into phlogiston and "earth", i.e., combustion is not a joining together but a decomposition, and so on. Hence the mechanism of a scientific revolution of the first type consists in placing things and objects under study on their feet, instead of having them standing on their heads. It is this "overturning" of previously held ideas so as to give them a diametrically opposite nature, with a demolition of the entire mode of thinking in scientists, that can serve as a criterion of scientific revolutions of the first type.

How scientific revolutions of the first type proceed. In their pure or "classical" form, such revolutions took place in the course of 250 years: from the mid-16th century (the Copernican revolution in astronomy) until the end of the 18th century (the revolution in chemistry initiated by Lavoisier). The first or negative and destructive phase usually took the form of a revolution in theoretical views, this followed by a more or less lengthy struggle between adherents of the old and demolished views, and those who had overthrown the latter. Thus, for many decades, the Inquisition persecuted supporters of the Copernican doctrine even after its author's death (the trials of Galileo and Giordano Bruno); defenders of the demolished phlogiston theory (Priestly) were still active even in the early 19th century.

The second or positive and creative phase of scientific revolutions of the first type proceeded at a comparatively slow pace, beginning with the first step taken in im-

mediate connection with the demolition of the former theoretical views (their being placed on their feet, as it were): e.g., Copernicus's initial and simplified views regarding the structure of the solar system in accordance with the principle of heliocentricism; Lavoisier's oxygen theory, which absolutises the role of oxygen. However, this was followed by deeper penetration into the essence of the range of natural phenomena discovered by revolutionary means, and at the same time into a wider range of phenomena: mechanical and physical (in the first instance), and chemical (in the second).

The entire 17th century (down to Newton inclusively) was, in essence, a period of a scientific revolution in mechanics, inasmuch as it was with the aid of mathematics that science was able to penetrate into the essence (laws) of mechanical movement. That made possible ever broader accomplishment of the second or constructive task of the scientific revolution which was ushered in by Copernicus. The same situation obtained in chemistry in the late 18th and early 19th centuries. Through his revolutionary overthrow of the phlogiston theory and the establishment of his oxygen theory of combustion, oxydation and respiration, Lavoisier was able to show that the quantitative chemical analysis was able to reveal the essence of chemical phenomena concealed from the chemist's eye. Early in the 19th century, Dalton took a decisive step towards accompishing the constructive task of the revolution in chemistry initiated by Lavoisier's demolition of the phlogiston theory. Dalton's atomism was based on quantitative ideas of atomic weight and the simple and multiply relations between the components of chemical compounds. As a result, the essence of chemical processes now appeared as a theoretically abstract depiction of the movements and interaction between invisible atoms, an approach which made possible precise quantitative calculations in respect of substances participating in chemical reactions.

The nature of scientific revolutions of the second type, and their specific criterion. As a rule, such revolutions, in their pure form, are direct and logical sequels to scientific revolutions of the first type. They take place through the utter destruction of the old ideas of the immutability of Nature, and the movement of natural phenomena along one and the same eternal circuit (the destructive task), and the establishment of the ideas of changes in Nature, and the development of and interconnection between all things and phenomena. Faith in the immutability of Nature and, in general, of the relations between things and phenomena stemmed logically from an absolutisation of the outcome of the accomplishment of the constructive task in revolutions of the first type: the discovered essence of things and phenomena was treated as their eternal and unchangeable foundation; though phenomena were fluid, their essence was considered absolutely stable and constant.

In their first stage, scientific revolutions of the second type were aimed at radically changing concepts that had evolved on the basis of the victory of scientific revolution of the first type. In their second or constructive phase, scientific revolutions of the second type dealt with the task of evolving theoretical concepts, whose backbone was the idea of the development and universality of the links between phenomena of the world. Hence, what serves as a specific criterion of scientific revolutions of the second type was a recognition of the fluidity, changeability and transformability in areas where stability, immutability and constancy had formerly been recognised, all this against the general background of the downfall of the old and metaphysical mode of scientist's thinking and a transition (even if unconscious and spontaneous) towards the new and dialectic mode of thinking.

The difference between the two modes of thinking consists in the former operating in petrified, permanently fixed, invariable and immobile categories and concepts,

while the second operates in categories and concepts that are fluid, flexible, changeable, in motion and development (in keeping with how the object of research is treated). Hence, a scientific revolution of the second type is marked by the application of the specific criterion of the discarding of the absolute unchangeability of things and phenomena previously accepted as the truth, and a corresponding radical change in the entire system of scientist's thinking.

The constructive task in scientific revolutions of the second type. The main creative task pursued by revolutions of the second type is the evolution, substantiation and establishment of scientific views (theories, hypotheses, doctrines, principles and concepts) that rest on a broad evolutionary foundation, the idea of universal development and universal nexus in respect of the object under study. Such scientific views began to develop in the second half of the 18th century and the first third of the 19th century, first in individual branches of natural science (astronomy, chemistry, and geology), bringing about local scientific revolutions in them, while, in the second third of the 19th century, they penetrated into its other branches (physics and biology), merging in a global scientific revolution in natural science as a whole.

At the same time an even deeper scientific revolution was taking place in the mid-19th century in the humanities (philosophy and the sciences dealing with economics, history and the state), this as a result of the appearance of the Marxist doctrine.

This led to the birth, in all spheres of scientific knowledge (Nature, society and human thinking) of doctrines (theories) embodying the ideas of development and universal links. In this respect, of particular importance in natural science was the creation of the cell theory and Darwin's doctrine of evolution (organic science) and the doctrine

of the conservation and transformation of energy (inorganic Nature). Since the analysis of substances did not at the time go further than chemical elements and their atoms, the further penetration of the idea of development into the depths of matter (i.e., beyond those borders) was as yet impossible. However, the discovery of the Periodic Law (Mendeleyev), the creation of the theory of electrolythic dissociation (Arrhenius) and other achievements in physics and chemistry during the last third of the 19th century laid the foundation for the later scientific revolution which set in at the turn of the century.

Different variants of a scientific revolution of the second type, and their features. The historical conditions in various branches of scientific knowledge led to scientific revolutions of the second type proceeding in different ways, that depending, in the first place, on how and when a scientific revolution of the first type took place in a given area of science, and, in the second place, on whether a scientific revolution of the second type was able to achieve its logical completion or had to stop halfway.

a) That variant may be considered normal which arises after a scientific revolution of the first type has fully accomplished all the tasks—both destructive and constructive—confronting it. In that case, a scientific revolution of the second type arises as its direct continuation and on the foundation of the tasks it has accomplished. In its constructive part, a scientific revolution of the second type is, in this case, directed towards overcoming the difficulties and resolving the contradictions that still remain in the previous views. Such was the scientific revolution brought about, in the second half of the 18th century, by the cosmogonic hypothesis of Kant and Laplace: it eliminated the idea that the solar system was eternal, as well as that Newton's "initial impetus" allegedly given tangentially to the planets, but it did so entirely on the basis of the laws and concepts of Newtonian mechanics.

In exactly the same way, Gérard and Laurent effected a scientific revolution in chemistry in the mid-19th century on the basis of the initial laws and concepts of atomism already laid down by Dalton in the beginning of that century.

b) A non-normal variant is to be seen whenever the idea of development has already penetrated into a given area of scientific knowledge, though the scientific revolution of the first type has not yet been completed. As a result, the overall picture of the object under study is still an inverted one, standing on its head, as it were, though the object itself has shed its feature of absolute constancy and immutability. That is why such a revolution can never be considered completed and genuinely scientific; it must always be followed by a new revolution, one that is genuinely scientific to the hilt, and not only accomplishes both tasks of a scientific revolution of the second type but primarily accomplishes those tasks of a scientific revolution of the first type that have not yet been accomplished. In other words, in solving the question of development and change in the object under study, this revolution will place on their feet the previously held ideas, which it brings into conformity with objective reality. An example of a non-normal variant of a scientific revolution of the second type in the area of biology was Lamarque's evolutionary theory, with its naive teleologism; an example in the field of philosophy was provided by Hegel's idealist system, with its concept of an Absolute Idea, to which he attributed primacy over matter.

c) A combined or joint variant arises when the joint tasks in the two scientific revolutions are simultaneously accomplished in the course of the one and the same revolution in science, irrespective of whether or not the idea of development has already penetrated into the relevant area of scientific knowledge. That was the case when R.Mayer and other scientists discovered the law of the conservation and transformation of energy, in the mid-19th century,

simultaneously with the collapse of the "weightless fluids" concept which had been born of a faith in what was immediately discernible to the eye and was regarded as eternal and immutable. The same thing happened with Darwin's theory, which rejected not only the immutability of organic species but also a faith in a naive teleologism (as a survival of faith in the immediately observable). The same was effected by Marx when he created the theory of materialist dialectics (which overcame Hegel's idealism), and scientific political economy (which disproved the concepts of the vulgar economists, who proceeded from an acceptance of what immediately met the eye).

d) An uncompleted variant is to be seen when part of the negative and the constructive tasks of a scientific revolution of the second type is accomplished, while another part has, for some reason, as yet not been accomplished. Thus, as a result of his discovery of the Periodic Law, Mendeleyev toppled the idea of the existence of isolated, fortuitous and disconnected chemical elements, by revealing their law-governed interlinks. However, that was merely half of the accomplishment of the two tasks confronting the scientific revolution in this area; the other half consisted in a rejection of the idea of the immutability and non-fissility of atoms and the eternal indestructibility and the non-transformability of chemical elements. That task could not be accomplished until the end of the 19th century.

Specific criteria of a scientific revolution of the third type. The recent revolution in natural science, which set in at the turn of the century and is still in progress, has been accompanied by an utterly new stage in scientific thinking, a rejection of the old world-perception, which was based first and foremost on a qualitative identification of macro- and micro-objects and a recognition only of quantitative distinctions between them, i.e., in scale.

The great discoveries in physics in the second half of the 90s of the last century, on the one hand, completed the preceding scientific revolution, which it carried on into the depths of the atom, into the micro-world, and, on the other hand, and most important, revealed in marked fashion the original features in the properties and law-governed patterns in objects of the micro-world, and their irreducibility to properties and law-governed patterns in macro-world objects. At the hub of the incipient scientific revolution of the third type was the downfall of the old concept of an absolutely immutable and non-fissible atom and of eternal, non-transformable and indestructible chemical elements.

While, previously, the Universe had been regarded as something built after the fashion of houses made out of bricks, the time had come for the very idea to be dispelled of the absolute elementariness, not only of atom but also and in general of any incomparably more simple particles of matter and its species. "The electron is as inexhaustible as the atom; Nature is infinite..." Lenin wrote in 1908.[1] The adoption of this focal proposition brought about a radical change in scientists' thinking, since in this case the basis for a model of the structure of matter had now to be seen, not in certain stable, exhaustible and "final" basis of reference, but in fluid, changing, inexhaustible and boundless paths of the development of matter, a development with neither beginning nor end.

The consecutive stages in the scientific revolution of the third type, and the accomplishment of its tasks of both types. The recent revolution in natural science (which has been a revolution of the third type) has passed through a number of stages, in each of which its fundamental content has been revealed with ever more depth and completeness, to wit: its break with the old ("classic") idea of the identity, in principle, of the properties, forms of movements, and law-governed patterns in micro- and macro-

objects in Nature. In this, what was first accomplished was the negative and destructive task in respect of its surviving "classical" concept (or system of notions and representations). Then followed the accomplishment of the positive and constructive task, and, in this connection, the collapse, in the appropriate area, of the previously existent mode of thinking, and the explanation and interpretation of the phenomena under study; there emerged a new and quite unprecedented mode of thinking, one that seemed extravagant and even "abnormal" at first glance (one will recall the "bizarre ideas" that Bohr later spoke of).

a) The electronic stage (roughly between 1895 and 1923) was linked with the discovery of Roentgen rays, radioactivity and radium, the electron, the quantum theory, the theory of relativity, and the theory of radioactive decay. The first result of these discoveries was the collapse of faith in the absolute elementariness, not only of atoms but of all and any particles of matter in general; this was brought about by the electron as a component particle in all atoms, and by "radium, the revolutionary". The main constructive task in this stage was accomplished by the theoretical blending of the latest discoveries in physics and Mendeleyev's periodic system of elements, all this being completed when Bohr created and perfected the electron-nuclear model of the atom. However, the central proposition in the former "classical concept", lived on (the electron being regarded as a minute ball revolving in a precise orbit around a central nucleus).

b) The stage of quantum mechanics (approximately between 1923 and the early 30s) was linked with the resolution of the contradictions between Bohr's classical model of the atom as well as the contradictions within optics. Rejection of the "classic concept" of the electron as a minute ball and of its orbiting within the atom, and the blending of the corpuscular and wave aspects of the movement of micro-objects led to the collapse of faith in the

mechanical (sensual) perceptibility of micro-phenomena and a recognition of the impossibility of creating their model as a sensually perceptible image borrowed from the area of everyday things and the phenomena of the macro-world. The former attempts to depict micro-objects through the medium of sensual perceptibility yielded place to the need to resort to mathematical abstractions, which ousted the former mechanical models. This led to a new and ever sharper change in the mode of scientists' thinking, there coming to the fore the ever greater significance of abstract dialectical thinking and its significance in the study of micro-world phenomena.

c) The nuclear physics stage (approximately from the early 30s until the end of the 40s of the 20th century) was ushered in and rapidly developed by the discovery of a number of elementary particles (the neutrino, the positron, mesons, and especially the neutron) and new nuclear reactions (the birth and annihilation of the electron-positron couple and especially the fission of the heavy nucleus). These discoveries not only revealed the conversion of substance into light (field) and of light (field) into substance but also led up to understanding of the complexity of elementary particles themselves as built, not out of actual particles but of virtual particles capable of appearing in certain physical conditions. These unusual physical transformations and features in the inner structure of elementary particles, which are totally unlike the structures of atoms and molecules revealed by classical chemistry and physics, have called for the further destruction of the "classical concept" and that evolution of physical concepts, new in principle, regarding the structure of matter.

The scientific revolution of the fourth type and its specific criterion. The middle of the 20th century saw the onset of the present-day scientific and technological revolution, which has been marked by a blending of the revolu-

tion in science and the revolution in technology. That is why the further development of the scientific revolution cannot be considered in isolation, but only in an intimate link with the technological revolution, and its interaction with the latter. In essence, the final stage (the nuclear physical) of the scientific revolution of the third type was introductory to the scientific and technological revolution, its premise, since it culminated in the technical conquest of atomic energy, the means for whose practical release was found thanks to the discovery of nuclear fission (Hahn and Strassman, 1939) and of the chain nature of that nuclear reaction (1940).

However, the new revolution in natural science was carried on, until the middle of the 20th century, wholly under the aegis of physics, and in practice did not emerge from its confines. Since the middle of the current century, physics has been instrumental in advancing all the other branches of natural science, and in the first place such new areas as cybernetics, astronautics, molecular biology and physico-chemical genetics, quantum electronics, and so on. All this range of interlinked and interacting sciences has revealed a trend towards development, not only towards purely scientific knowledge but also towards a distinctly expressed practical (technological and industrial) embodiment of scientific achievements, thereby showing that science is ever more becoming an immediately productive force in society (as Marx put it).

The result has been a fundamental and revolutionary change in the thinking of present-day scientists, this consisting in a transition from thinking within the framework of some particular area of scientific knowledge towards an ability to grasp, in a complex, in the first place many areas of that knowledge that affect one other, and, in the second place, the practical aspects and trends in its development.

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The fundamental tasks of the scientific revolution of the fourth type. As the fourth type of scientific revolutions, the current scientific and technological revolution has not only not cancelled all its preceding types but absorbed them, subordinating them to its own tasks, a) the negative, which consists in a rejection of thinking in categories of the isolatedness and separateness of any particular science from all other sciences, or of science from practice and vice versa; and b) the positive, which consists in work on constructive solutions of ways to link together, coordinate and subordinate to one another various branches of scientific knowledge in the conduct of any concrete research, and to ascertain and give effect to the practical nature of fundamental research in science and bring them into practice in mass production. Such, in the ideal, should be the thinking of the scientists of today, in keeping with the tasks and nature of the present-day scientific and technological revolution.

Conclusion: we have given consideration to the question of scientific revolutions from the angle of a general criterion for them, and their specific criteria in respect of each of their four fundamental types. The question of the social conditionedness both of scientific revolutions themselves and of their specific criteria, as well as the question of the various ways in which they proceed in countries with differing socio-political and economic structures calls for special examination. In just the same way, special consideration should be given to an analysis of the question of scientific revolutions and their criteria from the angle of the interlink between philosophy and natural science, on the historical plane.

NOTES

[1] V.I.Lenin, Collected Works, Moscow, Vol.14, p. 262.

COMPARATIVE TABLE OF CRITERIA OF SCIENTIFIC REVOLUTIONS

All the above can be summed up in the following table:

Types / Stages	Criteria C	Mechanism M
	General C	General M
	(-): a radical breakdown in the former mode of thinking and the corresponding system of old concepts; destruction of faith in the hitherto accepted explanation of phenomena; (+): evolution of a new mode of thinking and a corresponding system of new notions; establishment of an essentially new explanation of phenomena.	Transition from the previous predominant and restricted mode of thinking, not simply to some new one in general but to a diametrically opposite mode, from the naive contemplative to the scientific, from one based on sensually visible models to one based on mathematical abstractions, from the metaphysical to the dialectical (conversion into its opposite).
	Specific C	Specific M
I C_I	(-): collapse of faith in immediate semblance; (+): recognition of the invisible (concealed from sight) essence of things and phenomena.	M_I overturning of previous representations; their placement from head onto feet; transition from the naively contemplative mode of thinking to the scientific.
II C_{II}	(-): collapse of faith in absolute immutability and mutual isolation; (+): recognition of the universal mutability and interconnection of things and phenomena.	M_{II} conversion of things previously considered permanent and their relationship to fluid ones; "molten" scientific concepts, i.e., their loss of their previous petrification, the onset of the transition from the metaphysical mode of thinking to the dialectical.
III C_{III}	(-): collapse of faith in the qualitative identity of macro-objects;	M_{III} the continuing transition from the metaphysical mode of thinking to the dialectical.

Types	Stages				
			(+): recognition of qualitative distinctions between them and the impossibility of reducing the law-governed patterns of micro-phenomena to the pattern of macro-phenomena.		
	1	C_{III_1}	(-): collapse of faith in the absolute elementariness (simplicity, exhaustibility) of "ultimate" particles of matter; (+): recognition of their inexhaustibility and of the infinity of matter in depth.	M_{III_1}	transition from a recognition of the finity and exhaustibility of forms of matter to a recognition of their infinity and inexhaustibility, i.e., to diametrically opposite views.
	2	C_{III_2}	(-): collapse of faith in the possibility of expressing the specific features in micro-phenomena with the aid of sensually visual mechanical models; (+): recognition of the need to express that with the aid of mathematical abstractions.	M_{III_2}	transition from a mode of thinking with the aid of mechanical images to a mode of thinking through operating with mathematical abstractions.
	3	C_{III_3}	(-): collapse of faith in obligatory junctapositions of particles of matter; (+): recognition of the virtual nature of particles and their ability to be born under definite circumstances.	M_{III_3}	transition to an understanding of the structure of microparticles from the demand for their presence in a ready state to a recognition of the reality of the possibility of their appearing in given conditions.
IV		C_{IV}	(-): collapse of faith in the possibility of the development of "pure" science wholly divorced from the	M_{IV}	transition from representations on the disunity between theory and practice to a recognition of their indivisible

demand of practice. (+): recognition of the necessity of an organic fusion of science, technology and production.	integrity.

Legend: C—criterion of the scientific revolution; M—its mechanism understood as the relation between the former and destroyed ideas and those which have nearly arisen. Indices with C and M, the Roman numerals indicate the type of scientific revolution and the Arabic--its stage. The signs (-) and (+) denote the respective negative (destructive) and the positive (constructive) aspects of tasks of the scientific revolution.

INTENSIVE AND EXTENSIVE DEVELOPMENT OF SCIENTIFIC KNOWLEDGE

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The idea of intensive and extensive development of knowledge is among the most general results of the theoretical study of the history of science. Indeed, when we consider any important step in scientific thought and review the destinies of various scientific disciplines, theories and conceptions we find they have intensive and extensive phases, i.e., phases of an essential deepening of knowledge leading it to new achievements, and phases of the expansion of attained knowledge accompanied by the application of the existing theoretical apparatus to new problems, tasks and facts. The intensive development of knowledge begins during its extensive development when the possibilities of applying what is known have been exhausted. In turn, extensive development is the direct continuation of intensive development and unfolds with the shaping of new scientific principles requiring verification of their capacity for work in broader application.

However, as any other strong generalisation the categories "intensive and extensive development of knowledge" must be specified in order to become effective instruments of methodological research. In this context it would be expedient to consider three levels of the methodological

analysis of scientific knowledge, i.e., to determine the categories "intensive and extensive development" for individual scientific concepts, for systems of scientific concepts (theories) and for supratheoretical systems of scientific knowledge consisting of several theories linked by a common idea. In literature there is a special designation for the latter: they are called conceptual systems.

Let us consider concepts. In this case intensive development coincides with the procedure for deepening the content of a concept, a procedure that has been dealt with in literature, while extensive development coincides with the procedure for increasing the volume of a concept; this has likewise been dealt with in literature. The intensive development of a concept thus means the specification of the information expressed in the concept, while extensive development means the enlargement of the set of objects designated by the concept.

Take, for instance, the concept of the chemical element. When we speak of the intensive development of this concept we must mention the transition from its empirical interpretation, which takes into account only its non-decomposability in the process of chemical conversion, to its theoretical interpretation, on the basis of the atomic-molecular theory and its subsequent modification that led to the present definition: "a kind of atom possessing a fixed charge of the nucleus". The extensive development of the concept of the chemical element means the extension of the set of objects designated by this concept, in other words, the detection of new chemical elements.

Needless to say, the intensive and extensive stages in the development of a concept are not independent of each other. Intensive development frequently superimposes itself on extensive development, and vice versa. For example, the discovery by Mendeleyev of the Periodic Law, which was an act of the intensive development of the concept of the chem-

ical element, proved to be accompanied by the prediction of still unknown elements, i.e., by the extensive development of this concept. Later, in the 20th century, the discovery of radioactive elements (extensive development of the concept "element") led to the discovery of the phenomenon of isotopy, and made it necessary to renounce determining the chemical element as a kind of atom with a fixed weight, in other words, it led to the intensive development of this concept.

What is meant by the intensive and extensive development of a scientific theory? The intensive development of a theory signifies its formation, which begins with the emergence of ideas that as yet do not fit into the pattern of established concepts, and the generalisation of facts that cannot be understood in the light of old theories. Intensive development ends when the core of a theory has taken shape, in other words, when the system of fundamental concepts representing the given theory's contribution to the world's scientific achievements has been formed.

The extensive development of a theory means the expansion of its sphere of application, in other words, the growth of the set of facts described, explained and forecast by the given theory.

Take, for instance, quantum mechanics. When we speak of this theory's intensive development, we must mention the emergence of the conception of the quantisation of the electronic oscillator, the idea of quanta of light, the formation of the so-called old quantum mechanics of Bohr-Sommerfeld, and the latter's evolution into the new quantum theory of Heisenberg-Schrödinger. In the case of the extensive development of quantum mechanics, note must be taken of the fact that initially this theory was applied chiefly to the problem of studying the absolutely black body, the interpretation of the line spectra of atoms, the explanation of the behaviour of the specific thermal capacity of solids. Sub-

sequently, the range of its application expanded considerably. This range covered, in particular, the theory of chemical bonds, the theory of the structure of solids, some branches of chemical kinetics and, lastly, some branches of biology.

The extensive development of quantum mechanics did not, needless to say, wait for the end of its intensive development: the area of the application of quantum mechanics expanded in the process of this theory's formation.

Let us consider the extensive development of a scientific theory in more detail. The tendency towards extensive development stems from the very nature of theoretical knowledge: a scientific theory is not simply a concise record of empirical facts. Theoretical principles have a certain content that cannot be reduced to facts, and this gives them the logical status of general assertions. At the same time, we must emphasise that the extensive development of a theory is development in the true sense of the word and not a simple extrapolation of "ready-made" principles. The extensive development of a theory is a "full-fledged" stage of scientific study, in the course of which new fragments of objective reality are cognised, hitherto unknown problems arise and methods for their solution are worked out.

So far we have spoken of intensive and extensive development of scientific knowledge, having in mind some single level of its methodological analysis, i.e., we have referred only either to concepts or to theories. Let us now consider inter-level relations: let us follow the behaviour of scientific concepts in the course of a theory's intensive and extensive development. We have already mentioned the core of a theory, in other words, the system of fundamental theoretical concepts. Naturally, during a theory's intensive development its conceptual core is likewise in the stage of intensive development, while in the course of a theory's extensive development its conceptual core is in the stage of

extensive development.

However, a theory consists not only of its core. In considering the structure of theoretical knowledge we must take into account the envelope of this core consisting of less general concepts that are the link between fundamental notions and empirical facts. If the core of a theory takes final shape with the completion of that theory's intensive development, the envelope continues to form in the course of the theory's extensive development as well. In other words, the extensive development of a theory is accompanied by the intensive development of the concepts forming its envelope.

Let us return to quantum mechanics. We have already noted that this theory's extensive development affected the problems of chemical bonds and of chemical interaction. It must be emphasised that the application of quantum mechanics to chemical problems was accompanied by the enrichment of the conceptual apparatus of this theory. The point is that the strict methods of quantum mechanics, involving the direct application of this theory's fundamental concepts, prove to be ineffective when the problem of computing the vast majority of chemical objects arise. For "chemical purposes" a wide set of approximate methods using concepts that do not spring directly from the fundamental propositions of this theory was developed in quantum mechanics. The computation of the simplest chemical system (the hydrogen molecule), made in 1927 by Heitler and London, was linked with the introduction of concepts such as "exchange interaction" and "quantum-mechanical resonance". Concepts such as "atomic and molecular orbitals", "state of pure valency", "electron correlation" subsequently appeared in the quantum-mechanical theory of the structure of molecules and chemical bonds.[1]

In the literature on the methodology of science, the development of theory is frequently discussed from the standpoint of tenets of deductive logic. In this connection men-

tion must be made of the conception of the hypothetico-deductive organisation of knowledge, according to which theory consists of a set of hypotheses, in which it is possible to distinguish fundamental, i.e., the most common hypotheses based on direct generalisations of experimental data. The development of knowledge within the framework of the hypothetico-deductive approach may be described as the build-up of some additional hypotheses with whose aid new empirically tested effects are brought to light.

The hypothetico-deductive approach unquestionably proved to be extremely effective in the elaboration of some methodological problems, particularly problems concerning the correlation between explanation and prediction, the corroboration of theoretical principles, and so on. At the same time, we must agree with the criticism of the excessively broad interpretation of this approach.[2] However, the hypothetico-deductive approach proves to be inadequately effective in the case of important stages of the development of scientific knowledge. We have just noted that this approach links the development of a scientific theory with the advancement of some additional hypotheses. Nevertheless, the arsenal of deductive logic does not have effective means for controlling the ways these hypotheses are advanced and their correlation with theoretical concepts and experiment.

In the context of intensive and extensive development of a scientific theory we should like to draw attention to another approach to the structure of theoretical knowledge that may be considered as "additional" to the deductive approach. We have in mind the presentation of a scientific theory in the form of a hierarchy of models of reality, in which the "upper levels" are occupied by the most fundamental models relating to the core of the theoretical system, while the "lower levels" consist of ancillary, "working" models relating to its envelope. Here the fundamental models prove also to be the most abstract reflections of reality.

It is natural to believe that a theory's intensive development leads to the formation of theoretical models. The models of the "lower levels" continue to form also in the course of the theory's extensive development. Two requirements must be met by these models. First, they must represent the objective reality described by the theory more specifically (in detail) and, second, they must be built along the same principles as fundamental models, i.e., they must serve as the prototypes of these models.

Take quantum mechanics again. The fundamental propositions of this theory form an extremely abstract model of objective reality. By applying the principles of quantum mechanics alone it is impossible even to introduce an idea of the state of an individual electron in an atom or molecule that would be desirable for the discussion of various chemical and physico-chemical problems. This gap is compensated in the course of the extensive development of quantum mechanics. The concept of the state of an individual electron appears at the level of the approximate methods of this theory, which more directly model atomic-molecular reality. For instance, according to the Hartree-Fock scheme, the wave function of an atom or molecule is the product of the wave functions of individual electrons with due regard for the requirements of the Pouli principle. The behaviour of electrons in a many-electron system is described by the Hartree-Fock equations, which, as in the case of the Schrödinger equation (the fundamental equation of quantum mechanics), may be obtained with the aid of the variational principle.[3]

Let us now consider the third level of the methodological analysis of scientific knowledge, namely, the conceptual systems. At first glance, the intensive and extensive stages of the development of conceptual systems follow the same pattern as the corresponding stages of the development of scientific theories. The intensive development of a conceptual system means the formation of its core, i.e., the sum-total of its fundamental propositions, while extensive

development means the expansion of the sphere of its application.

However, this is not so simple in reality. A conceptual system is the largest unit of scientific knowledge revealed by its methodological analysis. The relationship between conceptual systems is in fact not within the competence of natural scientific knowledge. Whereas the correlation between scientific theories is shown within the framework of conceptual systems with the aid of more general theoretical constructions, the relationship between conceptual systems belongs to the sphere of philosophical knowledge.

Take modern theoretical physics. In his analysis of the structure of this science W.Heisenberg distinguished four conceptual systems, each of which is based on one extremely general theory.[4] The first conceptual system is founded on classical mechanics (in addition to this theory, it includes acoustics, aerodynamics and hydrodynamics); the second conceptual system is based on statistical mechanics, and alongside this theory mention must be made of thermodynamics; the third conceptual system is based on the special theory of relativity and includes electrodynamics, optics and the theory of magnetism; and, lastly, the fourth conceptual system, which is based on quantum mechanics, includes nuclear physics, chemistry and the theory of ferromagnetism.[5]

What is the correlation between the above-mentioned conceptual systems? In considering this question I.Kuznetsov writes of the reciprocal negation and reciprocal presumption of conceptual systems.[6] Let us first deal with reciprocal negation. Each new conceptual system is an uncompromising antagonist of the old, for it brings a different and sometimes diametrically opposite view of the world. Classical mechanics held that there was single-valued causal relationship between events. However, in quantum mechanics, accord-

ing to Bohr and Heisenberg, the causal description complements the spatial-temporal description. In classical mechanics, the concepts of the particle (corpuscle) and the wave were regarded as mutually exclusive. In quantum mechanics, on the other hand, the corpuscular description of any phenomenon must be a wave description, and, conversely, wave description must be corpuscular.

We have noted that, like the intensive development of individual theories, the intensive development of conceptual systems leads to the formation of the fundamental ideas about nature. At this point we should like to emphasise that the appearance of each new conceptual system signifies a revolution, a leap, a break in the gradualness of scientific development. "Fundamentality" is a relative notion. One can speak of fundamentality in a branch of science or in science as a whole. The intensive development of conceptual systems is accompanied by the formation of concepts belonging to the forefront of scientific development, i.e., found on the boundary of what has been cognised by man. These are the most profound and most daring concepts, which reveal hitherto unknown structural levels of objective reality.

More than that. The intensive development of conceptual systems is accompanied, not only by the appearance of new profound natural scientific concepts, but also by the formation of new methodological generalisations relating to the scientific picture of the world and the structure and functions of theoretical knowledge. These methodological generalisations have a larger sphere of application than the fundamental notions of conceptual systems.

For instance, the appearance of the first (according to the Heisenberg classification) conceptual system—based on classical mechanics—was linked with the appearance of the Newtonian world outlook that was predominant throughout almost the entire 18th century. The Newtonian picture of

the world used the notion of an absolute system of reference (absolute space and absolute time), of the possibility of long-range action and so on. These notions were applied outside mechanics proper, namely, in chemistry,[7] the theory of electricity and so on.

Let us move to the 20th century. The appearance of quantum mechanics, which may be regarded as a component of the latest revolution in natural science, was likewise accompanied by new philosophical generalisations. These include the principle of complementarity, the concept of corpuscular-wave dualism and the conformity principle. The appearance of quantum mechanics changed the ideas about the role of mathematics and graphic illustration in natural science.[8]

The methodological generalisations we have mentioned are finding wider application than the principles of quantum mechanics as a concrete physical theory. For instance, by including chemistry in the fourth conceptual system (according to the Heisenberg classification) we do not have in mind that all chemical facts stem from quantum mechanics. The essential point here is that beginning from the second third of the 20th century quantum-mechanical methodology, notably complementarity and corpuscular-wave dualism, was widely applied in chemistry. Linked with these conceptions are such important novelties in chemistry as the interpretation of the electron as a particle and a "charge cloud", the distinction of individual and collective properties of the electrons of an atom or molecule, the ideas about the delocalisation of electrons and the hydrogen bond.

We have mentioned the reciprocal negation of conceptual systems, which underlies the discrete intermittent development of science. However, reciprocal negation cannot be separated from reciprocal presumption. While they radically differ from each other, the conceptual systems have innumerable points of contact. The discrete intermittent

development of science does not rule out continuity between old and new views.

We have counterposed quantum theory to classical mechanics. However, these conceptual systems have a number of elements in common. These are not only the conformity principle, according to which the equations of classical mechanics may be regarded as a limit particular case of the equations of quantum mechanics. The relationship between the quantum theory and classical mechanics is much stronger. "Quantum mechanics holds a very unique position among physical theories: it includes classical mechanics as its limit case and, at the same time, needs this limit case for its own substantiation."[9]

Let us now consider the inter-revolutionary stages of the development of science, which in effect coincide with the phases of the extensive development of conceptual systems. In literature these phases are sometimes counterposed to revolutionary stages much too sharply and linked with algorithmic, normalised activity that does not renew science's conceptual apparatus to any considerable extent. Our position on this question is different. The extensive development of a conceptual system witnesses not only the expansion of its sphere of application but also the intensive development of the elements of this conceptual system, in other words, the formation of new concepts and new theories.

Once again take the conceptual system based on quantum mechanics. We have noted that the extensive development of quantum mechanics is accompanied by the appearance of concepts that do not spring from the principles of this theory. Today we can say more. The extensive development of quantum mechanics led to the elaboration of a new theoretical system: quantum chemistry, which is, of course, part of the conceptual system based on quantum mechanics. However, the appearance of quantum chemistry meant the intensive development of chemistry, for it was linked with the integration

of physical ideas and traditional chemical ideas.

Further, it must be noted that the reduction of inter-revolutionary periods in the development of science to the algorithmicised solution of theoretical and practical problems makes it difficult to understand scientific revolutions themselves, because the question of the origin of new ideas remains vague. Scientific revolutions are inconceivable without preparatory work during the extensive development of conceptual systems. The history of science shows that in the formation of new conceptual systems decisive significance is very frequently acquired by ideas appearing during the extensive development of the already established scientific theories. For instance, in the modern quantum field theory, the idea of secondary quantisation, obtained in 1927-1928 as a derivative result of quantum mechanics, acquires fundamental importance.

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We have thus considered the question of the intensive and extensive development of scientific knowledge on three levels, namely: individual concepts, scientific theories and conceptual systems, which are the largest units of scientific knowledge. We have noted that the intensive development of conceptual systems spells out the revolutionary reshaping of scientific knowledge. The question of the nature of scientific revolutions is by no means resolved solely by methodological analysis. Sociological and psychological problems arise. However, a study of the intensive and extensive development of knowledge allows shedding light on the inner mechanisms of revolutionary transformations in science.

NOTES

[1] V.Fock, "Fundamental Significance of Approximate Methods in Theoretical Physics", Uspekhi fizicheskikh nauk, 1936, Vol.16, Issue 8, p.1070.

[2] V.Sadovsky, "The Deductive Method as a Problem of the Logic of Science", Problems of the Logic of Scientific Knowledge, Moscow, 1964, pp. 195-197 (in Russian); A.Uyemov, "The Intentional Interpretation of the Conclusions of a Given Experiment", Logic and Empirical Knowledge, Moscow, 1972 (in Russian).

[3] V.Fock, op.cit.

[4] W.Heisenberg, Physik und Philosophie, Stuttgart, 1959.

[5] Heisenberg writes of yet another conceptual system—the general theory of relativity. However, he does not bracket this system with the others because, as he puts it, it has not yet reached its consummation.

[6] I.Kuznetsov, Continuity, Unity and Minimisation of Knowledge—the Fundamental Features of the Scientific Method. Materialist Dialectics and the Methods of Natural Science, Moscow, 1968, p.329 (in Russian).

[7] In this context note should be made of a paper by S.Vavilov, in which he wrote of the Newtonian programme for the substantiation of chemistry. S.Vavilov, "Physics in the Scientific Work of Dmitry Mendeleyev", Transactions of the Jubilee Mendeleyev Congress, Moscow-Leningrad, 1936, Vol.2 (in Russian).

[8] Methodological Principles of Physics, Moscow, 1975, pp. 26, 204, 385 (in Russian).

[9] L.Landau, Y.Lifshits, Quantum Mechanics, Moscow-Leningrad, 1948, p.13 (in Russian).

SCIENTIFIC COGNITION AND HUMANISTIC IDEALS (SOCIO-ETHICAL REGULATION OF SCIENCE)

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The humanist significance of scientific and technological progress and its orientation towards man have confronted scientists with new questions pertaining to the sociology and ethics of science, in particular, the question of the blending of the research and the value approaches, and the subordination of scientific cognition to humanist ideals. These questions are being ever more widely discussed, not only by today's scientists but also among the general public, inasmuch as science has acquired a mass character in specific activities therein and in its consequences, its influence on human life.

The very nature of scientific work has changed, with the figure of the solitary scientist restricted to his narrow guild interests long receding into the past. The cell-like structure of scientific activities and their sporadic contacts with society and its needs, an external (and, of course, ultimately illusory) independence of them, and, in that sense, freedom of the choice of problems and lines of research characteristic of past stages in the development of science—all these have remained for all the time merely rose-coloured reminiscences of youth.

The assertion that objective cognition possesses absolute value as the sole source of genuine truth, and the scientistic super-optimism that found its extreme expression in Laplace's idea of Universal Reason precluded any need for science to be given some external appraisal. Consequently, no special ethics for science could be spoken of: such ethics were expelled from the realm of knowledge, since it allegedly did not possess the attributes of objectivity. Any humanist appraisal of scientific knowledge became meaningless, as lying beyond the borders of the necessary. Kant's attempt to moderate the claims of scientism and to show the boundaries of theoretical reason and the need for it to be supplemented with a moral principle independent of it, i.e., the Categorical Imperative, which proceeded from benefit to mankind, turned out to be so much abstract moralising, a striving to create a problem where it did not actually exist, at least in the acute forms in which Kant revealed it.

The collapse of these illusions, which was merely accelerated by Hiroshima and Nagasaki, led to thousands of private tragedies and forced many scientists to realise the social and moral situation they had found themselves in. Dealing with the subject in his book My Life and Views, Max Born noted that while, from the personal point of view, his scientific vocation was a source of joy and satisfaction, science and its ethics had, objectively speaking, undergone changes which made it impossible to preserve the old ideal of service to knowledge for its own sake, an ideal his generation had been raised on. That generation, M.Born went on to say, believed that such service would never turn into evil inasmuch as the search for truth was a virtue in itself. All that however had been a wonderful dream from which scientists had been awakened by the course of world events.

It is now clear that the significance of the factors determining the humanist essence of scientific and technological progress and comprising the content of science as a

social institution is ever mounting; without detriment to science and mankind, those factors cannot be separated from the very process of cognition as such. This refers in particular to the situation that has developed at the new stage of the scientific and technological revolution, in which man himself, in the unity of the biological and social aspects of his nature, is becoming the object of science. That is why the range of the social, philosophical, world-outlook and ethical problems in scientific cognition has acquired such importance today and is destined to play an ever more decisive role with the advance of scientific and technological knowledge into the "age of biology".

This refers not only to problems relating to human genetics but in general to everything that pertains to experiments on man, which are constantly growing in volume and the degree of risk, and call, not simply for purely ethical control but also for more rigorous and differentiated legal regulation in individual countries and on a world-wide scale. It is not fortuitous that many scientists consider that, in this area, we shall come up against moral, ethical, psychological and political problems, in comparison with which the problems that engage the minds of nuclear scientists will seem mere child's play. The reference here is to the global danger threatening man and mankind from biological means of warfare, the use of drugs affecting the mind and the transplantation of organs, which, besides everything else, pose the complex question of the "individual's nature".

We must be prepared to reply to these questions in accordance with the humanist mission of science, and our world outlook and morality.

The reply can be found only in a fusion of science and humanism, by subordinating scientific cognition to lofty social and humanist ends. The realisation of this is today

penetrating ever deeper into the thinking of scientists, who are engaged in lively discussions of questions bearing upon the social and ethical problems of scientific seekings. This refers in particular to problems of genetic engineering, i.e., active and purposeful intervention in human heredity, the "re-designing" of human organs according to preset aims.

What does this mean, and what does it hold in store for man and mankind? Many scientists think that genetic engineering is the future of molecular biology, that it provides for its extensive application in practice. At the same time, genetic engineering is a kind of Pandora's box, inasmuch as it contains a number of threats to mankind. On the one hand, as is common knowledge, genetic engineering will enable mankind, in the not too distant future, to obtain unlimited quantities of medicines that are hard to produce today, for instance insulin, the human growth hormone, and many antibiotics; the methods of genetic engineering will bring about realisation of what many plant-growers have always dreamt of—imparting to agricultural plants such qualities as resistance to diseases and parasites, to cold and drought, and to obtain nitrogen from the atmosphere, thus obviating the use of oil and natural gas for the production of expensive nitro-fertilisers. Finally, it is from genetic engineering that we can expect mankind to cast off inherited diseases by replacing pathological genes with normal ones.

On the other hand, since the procedures used in genetic engineering affect the inner mechanisms of self-regulating genetic processes and, in the long run, life itself, it is obvious that molecular biology has reached the brink of the experimental precipice which may ultimately prove more frightful than the one into which atomic physicists peered on the eve of the creation of a nuclear bomb. Even mere negligence on the part of the experimenter, or shortcomings in safety measures may lead to irreparable consequences and create a

threat to all mankind. Even greater harm can be created if these methods are used by various evil-doers or for military ends. The global nature of the possible dangers is conditioned in the first place, by the fact that the organisms on which experiments are most often conducted, are very widespread in nature and possess the capacity of exchanging genetic information with their "untamed" relatives. This problem acquires fresh aspects in the light of the possible emergence of organisms created as a result of such procedures, with new genetic qualities unknown in nature and not conditioned evolutionarily. It is impossible to foretell what consequences such experiments may lead up to.

All this has given rise to grave concern among progressive scientists and has led to lively discussions on the possibilities and conditions of experiments in the area of genetic engineering. These discussions have yielded certain results but, in their turn, they also pose fresh problems (including those of a socio-philosophical and ethical nature) bearing upon the very foundations of present-day science and its prospects in connection with human development.

It is common knowledge that in July 1974, a group of researchers engaged in pioneer work in genetic engineering and working under P.Berg, Professor of Stanford University, appealed to scientists of the world to impose a kind of moratorium on research in two of the more dangerous fields, until the holding of a world conference. The reference was to such experiments as: 1) on the introduction of genes of animal carcinogenic viruses and toxins into bacteria; 2) the creation of clonus effects, or shot-gun experiments, in genes of higher organisms, in bacteria. This was the first determined appeal to the scientific community on questions of the self-regulation of scientific activities since the 1940s, when physicists collectively decided to deny Germany access to nuclear information. The appeal issued by the Berg Commission was supported by many scientists throughout the world.

The moratorium was observed almost universally for eight months until the end of February 1975 when an international conference was held in Asilomar (Pacific Grove, USA). Attended by 140 scientists from 17 countries the Conference summed up the achievements in research on recombinant DNA molecules and discussed the social and ethical aspects of experiments in genetic engineering, ways of averting the potential biological dangers connected with such work, and the conditions for cancelling the moratorium on two types of especially dangerous experiments.

The Summary Statement of the Asilomar Conference on Recombinant DNA Molecules[1] declared that it had been called with the aim of examining scientific progress in research on recombinant DNA molecules and discussing the necessary measures to avert the potential biological dangers implicit in such work. Impressive scientific achievements had been made in this area, the methods used opening up excellent opportunities for a deeper understanding of the fundamental biochemical processes in procaryotic and eucaryotic cells. The methods used in work on recombinant DNA molecules hold out the promise of a revolution in the practice of molecular biochemistry. Although these new methods had not yet found practical application, there are grounds to believe that they will show their tremendous usefulness in the future.

The conferees showed particular interest in the question whether certain researches in this area might be resumed, a moratorium on which had been called for by the Committee on Recombinant DNA Molecules of the National Academy of Sciences of the USA in a letter published in July 1974; if so, how was scientific work to be conducted with minimum risk to laboratory personnel, the population at large and the species of animals and plants inhabiting our ecosystems.

The Summary Statement of the Asilomar Conference goes on to say that the new methods, which permit a blending of genetic information in organisms greatly differing from

each other leads us into the sphere of a biology with many unknown quantities. Even with the current and more limited level of research in this area, it has proved very difficult to appraise potential biological dangers. It is this ignorance that has made us come to the conclusion that considerable caution should be displayed in the course of such research. Nevertheless, the conferees agreed that the greater part of the work on the construction of recombinant DNA molecules may be conducted, if sufficient measures of caution are taken, mainly the establishment of biological and physical barriers that will make it possible to maintain newly created organisms. Moreover, the standards of caution should be still more rigorous at the initial stage of research, and be modified as the methodology improves and appraisals of possible risks change. Further, agreement was reached on the existence of certain experiments in which the potential risks are so grave that such experiments should not be conducted under the precautionary measures available today. Serious problems may arise in the more distant future in connection with the extensive use of this methodology in industry, medicine and agriculture. At the same time, it was recognised that future research and the experience amassed may show that many of the potential biological dangers are less grave and/or less probable than is suspected today.

The Asilomar Conference formulated several principles on which recommendations and conclusions have been based. The principles are as follows: 1) it is vitally important to consider questions of precautions when experiments are planned; 2) the efficacy of precautions should correspond as close as possible to evolution of the risk that may be incurred. In keeping with this, an appropriate scale of precautions should be evolved inasmuch as agreement will be reached on the degree of risk. The means of appraising and countering risk according to precautionary levels should be revised from time to time. It is to be hoped, the Summary

Statement points out, that, through formal and informal channels of information within nations and among the nations of the world a stable way will be evolved of comparing potential biological dangers and levels of precaution.

The Asilomar Conference divided permissible experiments into three categories of risk, ranging from experiments with minimum risk to those presenting extreme danger. Another group was specially singled out, referring to experiments presenting such grave danger today that they should not be undertaken in general until measures of precaution are evolved in keeping with the degree of risk presented. The main ways of preventing existing and possible dangers were seen by the conferees in the genetic designing of new bacteria and carriers that would have limited possibilities to multiply outside laboratories. The Summary Statement also devoted much attention to the question of getting all personnel engaged in any experiments fully informed of the degree of risk attending such experiments, as well as to careful preparation and training of personnel in the use of safety measures necessary in experiments of a given degree of risk.

All this is merely the beginning of the work, as was acknowledged by the Asilomar conferees. What is important is that the work is underway, so that the principles proposed by the Asilomar Conference have become a basis for the drawing up by the Consultative Committee of the National Health Institutes of acceptable instructions with the aim of controlling the methods used in manipulating the genes of living organisms.[2]

This question becomes particularly acute when the methods of genetic engineering are used directly on man. This is a prospect that does not appear too distant and has given rise to concern, not only in scientists but in broad public circles, creating as it does an atmosphere in which all kinds of myths and utopias become possible.

"The sleep of reason engenders monsters"—these words of Francisco Goya can be applied to many "scientific monsters", and to the neo-eugenic ideas in the first place, attempts to revive which are being made with reference to the possible outcome of the application of genetic engineering to man. Neo-eugenics, as is common knowledge, proceeds from the allegation that "genetic disaster" awaits man, an escape from which can be provided only by evolving a "new breed" of man through purely biological and genetic methods. It is our duty to reveal the untenability of neo-eugenic utopias, in the first place on the scientific and theoretical plane, their viciousness on the social plane and their misguided essence on the philosophical plane—that of world-outlook and methodology. The same can also be done on humanist, moral and ethical ground.

In rejecting neo-eugenics, we see at the same time the actual prospects that open up, in particular, in connection with research into problems of human and medical genetics, which have developed intensively of late, and the new possibilities that have appeared in recent years as a result of the successes scored in genetic engineering. Such research has nothing in common with neo-eugenics, but pose social, philosophical and ethical problems that are no less or perhaps even more complex and refined, problems that have become subjects of heated discussion in world science.

This refers, first and foremost, to the social and ethical regulation of research in this area, problems of the ethics of genetic control. Scientists are giving ever more thought to such questions as: is science capable of self-regulation? Can ethical norms, if divorced from the social, be the main regulator in the science that studies man's biology and genetics? This concern has found expression, in particular, in discussions at various international forums on genetics, and in numerous articles and books on the ethics of genetic control, as well as in the unprecedented movement involving scientists who are demanding the estab-

lishment of a moratorium on a number of experiments in the field of genetic engineering.

It should be noted in this connection that discussions centering on problems of genetic engineering have, as I see it, posed the cardinal question, not only of man's future but of the science that serves him. These discussions are ever more revealing dissatisfaction with the century-old concept of science as a self-sufficient and absolute value, a sphere of "pure" cognition independent of all the rest of mankind's values and standing above them, as it were. It is becoming ever more obvious that science cannot develop in a social vacuum, in a divorcement from its social, philosophical and ethical foundations. These are part of the very make-up of science, and not something standing outside it. The extreme school of "science for science's sake", with its emphasis on "pure" research, is revealing its bankruptcy and ever more leaving the historical scene.

The unshakable fact is becoming ever more distinctly realised that mankind and science itself will be unable to develop even in arithmetic progression unless the social responsibility of scientists, the role of the ethical principle in science progresses in geometrical progression. The ethics of science is being realised as a vital condition for the efficatious functioning of scientific cognition with a humanist orientation. What is particularly essential today, many scientists think, is a system of international agreements regulating the biological (genetic, medical, etc.) cognition of man.

In this connection, the question is being widely discussed of the permissibility of various experimental manipulation of man, the criteria of permissibility or impermissibility being defined according to the various kinds of understanding of the initial principles of ethics and humanism. Most scientists are agreed that such principles should be observed from the very commencement of preparations for an experiment. Even if it produces important

results, research conducted with infringement of those principles cannot be ethically justified after the fact. The post hoc approach can never be ethical, and in this sense the end can never justify the means in a biological experiment on humans, just as it cannot do so anywhere else.

A clear-cut recognition is essential of the uniqueness and freedom of each human individual, as assured by moral and legislative norms and actions by society as a whole; also standing in need of such recognition is the principle of the free development,—in the conditions of the observance of the above-mentioned norms—of cognition and practice, which are equally necessary for the common weal and are, therefore, fully encouraged morally and legislatively by society. In this sense, of course, any experimenting on man signifies a partial invasion of those inalienable human freedoms and rights, but it can be restricted sufficiently to be in keeping with the system of society's moral and other values and can be a consequence of freely taken decisions.

However, a more general question arises in this connection: can science be regulated only on the ethical level? Is it capable of ethical self-regulation? Even given the application of the scientific principles of ethics as actually conditioned by a concrete understanding of man's weal, it is still questionable how the "feed-back" and verification of the observance of such principles will operate and be assured. It is quite obvious that anything connected with the implementation and, in essence, with the evolving of the ethical principles of science and its orientation in terms of values—including the ethical ones—is determined by social factors, which should serve history's "end-in-itself"—man's free and allround development.

In this, decisive significance attaches to the kind of society practicing the social and ethical regulation of research, in particular in the field of genetic control.

Under socialism, where social control of scientific, including genetic, research is effected in fact and in various forms both by the state and the general public, extensive research is developing into problems of human genetics and medical genetics with the aim of the treatment and prevention of man's hereditary ailments, and a network of medico-genetic consultative institutions is being built, and experiments are being conducted in the area of genetic engineering, with due account, of course, for the prospects of its application to man. Under socialism, however, the aims of research and the means of its implementation are profoundly humanist in nature and are subordinated to the supreme principle of socialism—its main social goal—man's welfare, and his free and allround development.

Under socialism, the harmony between scientific and social aims and the means of their achievement also ensures the coincidence of the research and ethical aspirations of scientists, the dialectical interlink between freedom of research and social responsibility, which are sundered in capitalist society and often emerge as an antagonism which is a source of torment to the scientists and danger to society. Thus the social and ethical regulators of scientific research are seen by scientists of the socialist countries, not as a kind of "external control" but as something inherent as a social institution in socialist society.

In essence, ethical problems are not thereby cancelled for scientists, but a real foundation is provided for their proper solution. This harmony of scientific and social aims and means opens up boundless possibilities also for genetic research on man, which however can be conducted only by gradual degrees, as science and socialist society itself develop, and a new type of citizen is moulded with ever greater culture and self-awareness in both the social and ethical areas, in everyday life, in his family relations and so on.

The above can be briefly summed up as follows: 1) present-day science is not an isolated sphere of "pure" cogni-

tion but is a special kind of social institution essentially designed to serve man, his free and allround development, as history's "end-in-itself". The link between present-day science and man's life and labour, his prospects as a bio-social being, and the humanist significance of scientific and technological progress—these are among the fundamental and global philosophical problems of our age.

2) Since man is ever more becoming not only a subject but also the main object of science and its applications, special urgency attaches to questions of the ethics of the scientific cognition of man, the moral criteria of scientific research, social control and regulation of scientific research in areas affecting mankind's vital interests and its future as a biological species. These questions have acquired special urgency today, especially in discussions on the ethics of genetic control and on the question of permissibility or impermissibility of various experimental manipulations with man and of neo-eugenic projects, and finally in the unprecedented movement that scientists have launched for moratorium on a number of experiments in genetic engineering.

3) The ethics of science are being established as a vitally essential condition for the efficacious functioning of cognition with a humanist orientation. However, the answers to such questions as to whether science can be regulated only on the ethical level and it is capable of ethical self-regulation will evidently be only negative if the ethical principles of science are examined in isolation from the other forms of its orientation in terms of values—the social factors in the first place. Besides, there exists today the need for a clear-cut system of international legal agreements regulating the scientific cognition of man.

NOTES

[1] See The Proceedings of the National Academy of Sciences of the United States of America, Vol.72, No.6, pp.1981-1984, June 1975.

[2] Nature, Vol.258, Dec. 18, 1975.

PERIODISATION OF THE HISTORY OF NATURAL SCIENCE

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The question of identifying the various stages of the development of one field of knowledge or another usually arises when the history of science is studied. This is not a formal question. It is of fundamental significance for an overall assessment of events of the past. However, the pattern of the stages of the history of science compiled by various authors is by no means always similar. This is due to the fact that the principles for periodisation differ because no common view exists on what indicators define the substance of each period. The differences in the approach to and in distinguishing periods, and in the obtained results are evidence that the methodology of historical analysis has as yet been inadequately elaborated. This article is an attempt to show the criteria, which, we feel, ensure uniformity in considering the complex process of the development of natural science and, particularly, in periodising this process. We shall make the reservation, however, that this article examines the features of the history of only some areas of natural science, namely, geology, biology and chemistry.[1]

Geology

Geological knowledge has its roots in deep antiquity. In the Early Paleolithic, when man made his first implements, he empirically learned the properties of the stones used by him. In those distant times he evidently observed and in one way or another tried to understand geological phenomena such as earthquakes, volcanic activity, tides and so forth. But these fragmented elements of geological knowledge were only the prehistory of science. The beginning of geology as we understand it today dates from the 18th century.

Period of great expeditions (18th century). The rudiments of many ideas and orientations that continue to be developed to this day appeared in that period under the impact of the raw materials requirements of the metallurgical, porcelain, ceramics and building industries.

The belief that nature is immutable was predominant in the theories about the natural sciences. But a breakthrough was made in geology and the idea that the organic and inorganic worlds were changing constantly began to take shape through the efforts of the outstanding scientists Immanuel Kant, Mikhail Lomonosov and Georges Buffon. The resultant theory of development contributed greatly to the promotion of geology.

The purposeful accumulation of a vast number of facts was another circumstance that gave impetus to the development of geology in the 18th century. This allowed laying the foundation for research and theories in various spheres of geology. The collection of hitherto unknown data was made possible by the innumerable expeditions embracing all the continents of the world. These expeditions, which followed the most diverse routes extending over thousands of kilometres, resulted in the elaboration of the method of small-scale geological studies of large territories.

The motivations for progress in the 18th century were thus the demands of material production and they led to the appearance of ideas about the development of nature and the method of small-scale studies of large regions that became the main feature of that period.

The period of the struggle between catastrophism and uniformism (first half of the 19th century). This period witnessed the appearance of basic spheres of modern geological science such as stratigraphy, lithology, tectonics, mineralogy and so forth. Among the contradictory theoretical schools such as neptunism, plutonism, catastrophism, uniformism, creationism and transformism, which were prominent at this phase, the leading place was held in the history of geology by the uniformist doctrine. This conception ensured the elaboration and broad application of comparative-historical (actualistic) methods of research in natural science, and showed that it was possible to read the geological chronicle recorded in outcrops of rocks. It allowed adopting a sure approach to the solution of the problem of the genesis of various natural combinations and helped to resolve some other geological problems.

Among the many methods of study used in geology in that period the decisive role was played by the paleontological method, whose elaboration and application resulted in strikingly rapid progress in stratigraphy, the formulation of the method of geological charting, the accumulation of a large arsenal of primary data for the development of the theory of evolution and the creation of paleogeographical reconstructions that made it possible to show the specific features of the history of the Earth's geological development.

Period of historism (latter half of the 19th century). This period witnessed a more profound study of rocks and the conditions of their formation. Descriptive mineralogy, which at the close of this period ceded its place to the

genetic school in the science of natural combinations, reached the zenith of its success (early in this period); natural radioactivity was discovered. The evolutionary theory, which spread quickly in the natural sciences, including geology, became predominant. Universal recognition was won by the theories that there were changes in time in the geological conditions of the formation and transformation of rocks, that the paleogeographical situation was not constant and that the changes in the Earth and its crust followed a definite pattern. Evolutionary paleontology, historical geology, the theory of geographical cycles, historical mineralogy and other trends appeared.

The latter half of the 19th century witnessed rapid progress in the entire range of geological sciences studying the material composition of rocks. In the development of the sciences of this cycle the decisive role was played by the microscopic method of studying rocks and minerals. In addition, the first major step was taken in studying large structures of the Earth's crust (geosynclines and platforms), but this trend came to the fore in geology only at the next phase.

Period of the geosynclinal theory (first half of the 20th century). This period saw the continued differentiation of geological knowledge and the appearance of new trends and branches: biogeochemistry, radiogeology, absolute geochronology, seismotectonics, the theories of overthrust, depth fractures, fixism, mobilism and so forth. But the theory of geosynclines and platforms was the most important in this period. It became the leading trend in geology. This theory, which aims to show the interdependence between all the geological phenomena taking place in the Earth's crust has been successfully tested in practice.

New methods of investigation were worked out. These include a group of geophysical and geochemical methods, specific methods of Quaternary geology, lithology, stratigraphy

and so on. A large contribution to the development of geology at this phase was made through the application of the paleogeographical method for general geological and spectral sciences, for sciences studying the composition of rocks and minerals.

Period of global and cosmic geology (latter half of the 20th century). This period is characterised by unprecedentedly swift progress in all branches of science and technology and this required a cardinal reconsideration of many long-standing theoretical propositions. The striving to gain a knowledge of the deep-lying layers of the Earth and of the composition and structure of the substances in these layers and of the nature of the processes taking place in them has become particularly marked in geology. In addition, geologists have turned their gaze beyond the Earth and begun to devote increasing attention to studying the composition and structure of other celestial bodies, chiefly with the purpose of deciphering our planet's ancient history.

The latest scientific and technological achievements have taken many areas of geology to an entirely new phase of scientific knowledge. Many extremely complex problems of geophysics, geochemistry, the geology of rare and dispersed elements and the physics of materials have begun to be successfully studied; new trends have appeared—cosmogeology and shelf geology; the fundamentals of the geosynclinal theory are being re-evaluated; the theory of the rift zones of the Earth's crust has appeared; theoretical propositions on new global tectonics have been put forward. The key feature of present-day geology is the idea that there is a close relation between depth and subsurface geological processes and the idea that the Earth is part of the surrounding cosmic space and, in this context, that geological events are linked with processes taking place outside our planet.

Biology

Biology as we know it today began to take shape in the 18th century.[2] The direct threshold to it was the preceding century, when the microscope was invented and opened for researchers a new world of hitherto unknown phenomena and facts. Scientists discovered the cellular and fibre structure of plants, the movement of blood along capillaries, the existence of sex cells in plants and animals, and so forth. Analyses of the vast array of facts accumulated during the latter half of the 17th century served as the foundation for important theoretical conclusions that ushered in scientific biology.

Period of the creation of a scientific system (18th century). Carolus Linnaeus' classification of organic substance given in Systema naturae (1737) and based on the idea of the universe's absolute immutability contributed greatly to the science of the organic world at this stage. The morphological (formal-descriptive) method was used to characterise individual organisms, while the introduction of a binary nomenclature (genus and species) helped to create an improved classification.

In contrast to the system evolved by Linnaeus, whose theory was founded on the immutability of organisms, Georges Buffon wrote about the origin of some species from others, thereby accentuating the absence of sharply defined boundaries between forms and, consequently, the artificiality of any classification. A struggle raged between the epigeneticists and the preformists over the cardinal issues of the biological theory of individual development, and this prepared the soil for the appearance of experimental embriology.

Many major discoveries and theoretical generalisations were made in different branches of biology during the 18th century. But the main factor behind the principal achieve-

ments of this period was the idea that systematic categories of the organic world were real. This made it possible to compile a classification of living organisms. Another important circumstance that helped to promote biology during this phase was the gradual formation of the experimental method.

Period of catastrophism—creationism (end of the 18th and first half of the 19th century). Experimental studies continued during this phase with the purpose of bringing to light the fine structure of the functioning of living matter. Investigations were conducted into the cellular structure and an impetus was given to the theory of embrionic forms, the theory of the parallelism between ontogenesis and philogenesis, the foundations of physiology, the chemical structure of animals and plants, and so forth. It was established that ancient organisms did not differ fundamentally in structure from modern organisms. Paleontology, comparative anatomy (with its rule of correlation of organs), relative embriology and other branches were given shape. The immutable species were recognised as the lower subdivision of the organic world. Paleontological data on the replacement of animals and plants in time were explained from the angle of the theory of catastrophes (Georges Cuvier). The appearance of new species was regarded as the result of acts of creation (creationism).

To sum up the features of this second period, it must be noted that the theory of the immutability of species continued to be predominant. This "fixation" of species gave rise to a strict morphological approach. From the very outset of the 19th century, when these theories were accepted by most scientists, Jean Baptiste Lamarck and some other naturalists proposed transformative theories. The dominant comparative-morphological method of research made the largest contribution to the development of anatomy, embriology and paleontology.

Period of the assertion of the theory of evolution (latter half of the 19th century). Research into the system of life continued to expand in breadth and depth; physiology and the higher nervous system were studied; the mechanism of metabolism was discovered; microbiology appeared; and it was proved that there could be no self-conception. An outstanding event in theoretical biology was Darwin's elaboration of the theory of evolution (1859), which brought with it new ideas and methods that changed the orientation of research not only in sciences treating of the organic world, but also in natural science as a whole. The former classifications based on the principle that the species are immutable were replaced by the theory of phylogenetic systematisation. During the last quarter of the 19th century Darwinism permeated almost the entire spectrum of biological sciences.

During the third period the theory of evolution was thus the predominant school of thought, and the historical method prevailed over all others.

Period of the crisis of classical Darwinism; struggle between organicism and reductionism (first half of the 20th century). This period may be divided into two stages. The first, covering the initial quarter of the 20th century, was characterised by the rise of genetics. Variability and heredity were studied intensively; the theory of mutation and the chromosome theory were originally based on the autogenetic conception of the development of organisms, which clashed with the theory of natural selection. A crisis gripped Darwinism.

The fine structure of cells and features of the individual development of organisms were studied during these years. This led to the establishment of complex morphological and biochemical reductions, which chemistry could hardly explain in those years. For that reason allowence again was made for non-material factors (entelechy, "vitality", psy-

choids, and so on) governing vital processes.

At the second stage (second quarter of the century) investigations of the chromosome structure led to the establishment of the basic features of the biochemical process, of the features linked with the mechanism of heredity. This made it possible to end the crisis of Darwinism and led to the fusion of the theory of natural selection with genetics. During these years prominence was commanded by the controversy between the proponents of the autogenetic theory (organism) and those of the theory of reduction, who tried to explain biological processes from the standpoint of the physico-chemical laws known at the time. This controversy stimulated a more profound study of the biochemical and physical processes in living matter. This helped to elaborate the theory of open systems and the thermodynamics of the irreversible processes in the organic world, the mechanisms of which were discovered later (1950s-1970s).

During the first stage of the fourth period the leading role was thus played by the autogenetic theory. The second stage was characterised by the appearance of the ideas of evolutionary genetics. Experimental methods were introduced into different branches of biology, the cardinal method being genetical analysis.

Period of the development of the theories of micro- and macro-evolution and of the theories about the organisational levels of the organic world (second half of the 20th century). The further development of the theories of the organism's interaction with its environment (ecological trend) led to the appearance of the theory of populations as primary units of the evolutionary process. The idea of macro-evolution was also propounded. According to that idea the taxons of the higher species develop in keeping with their own laws.

Perfection of the methods used in biology—mathematical (cybernetics, etc.), physical (roentgeno-structural analysis, electronic microscopy, tracer atoms, etc.) and biochemical

(synthesis of organic polymers, etc.)—facilitated the understanding of the fine structure of viruses and cells, and also the mechanisms regulating the functioning of living matter. The theory of the "self-assembly" of organic polymers was proposed; molecular biology appeared and began to develop rapidly. Considerable headway was made by biophysics, biochemistry, cytology, histology, embryology and other branches of biology. Important achievements were scored in genetics: the concept of a heredity code recorded in DNA molecules was worked out, and the nucleproteid structure of the chromosome was established.

Diverse theories and principles applied in modern biology were united in the general idea that living matter consists of hierarchically co-subordinated structural levels of organisation. Modelling increasingly became the principal method used by researchers in their attempts to reproduce living processes experimentally.

Chemistry

The first steps in this area of natural science were made in remote antiquity. However, as a science chemistry began to take shape only at the close of the 17th century, when the notions of the alchemists were rejected and the works of Robert Boyle laid the beginning for the theory of chemical elements.[3] Chemistry's further history is divided into several stages.

Period of the development of the theory of the composition of bodies and of the chemico-analytical method of experimentation (end of the 17th and the 18th century). This period falls distinctly into two stages united by one and the same method of studying the element composition of bodies.

The first stage may be called the epoch of the phlogiston theory, which held that all inflammable substances contained a combustible element. The phlogiston quest was the

stimulant in all investigations of the chemical composition of natural substances. This contributed to the intensive elaboration of the experimental-analytical method. The second stage began in the 1760 s. In those years the phlogiston idea, which had played an essentially positive role, was completely rejected and replaced with the oxygen theory of combustion (Antoine Lavoisier).

The empirico-analytical method was improved, and analytical chemistry took shape as a science of chemical elements and their compounds.

Period of the appearance of structural chemistry and organic synthesis (first three quarters of the 19th century). The idea that atoms are the smallest particles of substances retaining all the properties of substances began to be developed at the beginning of the 19th century (John Dalton). The concept of atomic weight appeared, and chemical elements were given a quantitative characteristic. This was followed somewhat later by the concept of a molecule. It was found that the qualities and properties of bodies depended on their composition and structure.

In 1861, Alexander Butlerov proposed the theory of chemical structure that became the basis of organic synthesis. Chemistry began to be converted from a predominantly analytical science into mainly a synthetic science. In 1869, Dmitri Mendeleyev evolved the periodic law of chemical elements that allowed establishing the natural link between individual elements and predicting the properties of elements not yet discovered.

The main developments of this period that fostered progress in chemistry in the 19th century were the appearance of the theory of the common nature of organic and inorganic substances and also of the periodic natural recurrence of properties and structures of chemical elements.

Period of theories about chemical processes (end of the 19th and first half of the 20th century). In this period

chemistry developed under the impact of notions about the dependence of the properties of substances not only on composition and structure but also on the thermodynamic conditions of the environment, on the nature of co-reagents, on the walls of the reaction vessel, on admixtures and so on. These notions underlay many theories not only of chemical kinetics but also of chemical links, the structure of giant molecules and the modes of the redistribution of link electrons.

Period of evolutionary chemistry (third quarter of the 20th century). The present stage of the development of all branches of chemistry witnesses the broad utilisation of physical methods: roentgeno-structural and quantitative spectral analyses, and so on. The biological chemistry of complex natural substances is developing, and new branches have appeared: chemistry of high molecular and that of element-organic compounds.

The factors stimulating the development of modern chemistry are the need for the maximum conversion of primary materials, the development of substances with programmed properties and the liquidation of production waste. All this is leading to the rise of evolutionary chemistry based on the study of living nature's catalytic experience.

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This brief review of the history of geology, biology and chemistry enables us to draw some conclusions:

1. Scientific development proceeds unevenly. This and the fact earlier noted were underscored by T.S.Kuhn, who distinguished the epoch of the gradual accumulation of new data and the epoch of the revolutionary replacement of established theories. The structure of science, which Kuhn calls a paradigm[4], is changing.

Writing of the development of science, S.Mikulinsky notes that this is a stepped process, which is uneven and

is characterised by stages or levels. Each successive stage represents a higher level of knowledge.[5]

2. The development of the natural sciences is closely linked with human history, with the replacement of one socio-economic formation by another ushering in a new stage in the development of these sciences.[6] As a result of the close reciprocal influence between the socio-economic situation, technology and the natural sciences conditions arise that ensure the coincidence of the boundaries of important generalised periods of the history of the natural sciences with the periods of the socio-economic history of mankind.

3. The individual major areas into which natural science is divided (biology, geography, geology, physics and chemistry) likewise develop under the impact of socio-economic factors. Each new social formation sets the different branches of natural science various tasks and changes the conditions under which research is conducted. A new period begins in the history of each branch of natural science when fundamentally new demands are made of it, mainly by production. In a broad context the boundaries between the individual periods distinguished in different sciences are quite close to each other but do not entirely coincide, and in this we see the relative independence of the development of the different branches of natural science.

4. The periodisation applied in the course of historical study must not be an artificial method. It must be the reflection of objective reality conditioned by the uneven development of science and based on the stages of development.

5. Each period of the history of an individual science or of a major branch has features of its own that distinguish it from other periods. This applies, above all, to the scientific conception or theory holding the predominant position in the given period and ensuring the solution of the basic problems that production sets the relevant branch

of natural science. The leading method of study in solving the problems of the relevant science is likewise an important feature of the given period.

These features determine the characteristics of each major stage of the history of each natural science. When these stages are distinguished it becomes possible to periodise the history of natural science as a hierarchy of successive levels of scientific knowledge.

NOTES

[1] For details, see V.V.Tichomirov, "Über die wichtigsten Etappen und Faktoren in der Entwicklungsgeschichte der Geologie", Ber. Deutsch. Ges. Geol. Wiss., 1969, Ed.414, No.6, pp.693-704.

[2] This is dealt with at length in A History of Biology From Ancient Times to the Beginning of the 20th Century, Moscow, Nauka Publishers, 1972, 563 pp.; A History of Biology From the Beginning of the 20th Century to Our Day, Moscow, Nauka Publishers, 1975, 660 pp. (both in Russian).

[3] See N.Figurovsky, An Essay on the General History of Chemistry. From Ancient Times to the Beginning of the 19th Century, Moscow, Nauka Publishers, 1969, p.156 (in Russian).

[4] T.S.Kuhn, The Structure of Scientific Revolutions, Chicago, 1962, 172 pp.

[5] S.Mikulinsky, "Methodological Problems of the History of Biology", Voprosy filosofii, 1964, No.9, pp.32-42.

[6] B.Kedrov, "On the Question of the Principles for Periodising the History of the Natural Sciences", Proceedings of a Conference on the History of Natural Science, Moscow, 1948, pp.17-57 (in Russian).

SCIENTIFIC SCHOOLS AS MODELS OF COLLECTIVE CREATIVITY

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The advance of ideas is most fully recorded in the chronicles of science, and it is a favourite subject of historico-scientific research to analyse this advance, moving from one set of theories and discoveries to another. Since ancient times, information about individuals dedicated to the service of scientific truths has also been recorded, and this determines the second traditional topic favoured by historians, namely, the recreation by means of the biographical method of "works and days", mode of thinking and action, the psychological characteristics of the outstanding representatives of the scientific world. The diversity of socio-creative links between scientists has been much less studied. The important of these forms of links are schools in science, which have a two-fold function to perform: the educational (instruction in creativity), and the research function proper. Without these schools, the powerful relay—the transfer, from one generation to the next, of the achievements, rules and values of the scientific community—would have been cut short.

Consideration of such schools, on the one hand, modifies the historian's angle of vision, and on the other, introduces new realia into the sphere of his interests. It is true that historians always took note of the existence of such schools, but they have always considered the

phenomenon from the viewpoint of the two above-mentioned approaches: they either specified these schools according to work, adding the portrait of the head of the school surrounded by his loyal followers. The fact is that scientific schools are a special object which cannot be reconstructed within the system of these two coordinates. They require a study of scientific intercourse as a creative process, to show behind each new movement of thought in the mind of the individual not his subconscious associations but the intricate system of inter-individual relations rooted in the specifically organised activity in the joint comprehension of the nature of things. With the development of the science of science, which treats science as a special social institution, the various forms of scientific ties, associations and organisations have come to the fore. Initially, two main programmes for studying scientific associations took shape: "scientists in organisations" and "invisible colleges". At present, efforts are being made to analyse associations of the "discipline", "specialty" and other types. In this series, "scientific schools" have a special place and require a special programme of study.

Recourse to the historical tradition leaves no doubt about the fact that in the real activity and self-consciousness of the scientific community, schools invariably appear as phenomena exerting either a positive or a negative influence on the production of knowledge. Affiliation with a school helps to explain both the achievements and the failures of individual researchers. The establishment of a school of one's own ranks high on the list of merits, because it is in itself an indication that the obtaining of scientific truth is not confined to the "subject of creativity—analysed object" relationship, but includes as a factor the dependence of that subject's efficiency of action also on the school.

Since the term "scientific school" is associated with the most diverse sets of notions, it is well worth while to

try to bring out within the great diversity of scientific associations designated by the term some of the typological forms, among them: a) science-education school; b)research-group school; c) the school as a direction which under definite socio-historical conditions acquires a national and even an international character.

The difficulties of drawing a distinction between these various socio-scientific forms spring from the fact that, first, one and the same scientist may head all three types of school, and second, that as in any other typology, "pure" forms are extremely rare, the mixed type being the most common.

The first type—science-educational schools—means "initiation into science", the learning of its conceptions and methods, value orientations and categorial systems. Science and its logic, communion with which helps to shape the creative personality, does not exist either in the form of Popper's subjectless "third world", or in the form of Kuhn's universal paradigm, like the paradigms of declension, or conjugation in grammar. Science is always personified in concrete individuals and their groups, in the process of intercourse with whom the future scientist takes shape. Through these persons he obtains socio-historical experience and nurtures the hope of becoming famous through a contribution of his own. It is true that intercourse between neophytes and men of science may be either direct or mediated by publications, but even the most impassive and precise text is not an array of "recorded judgements", as the positivists would have us believe. In rolled-up form it contains the impression both of the author's activity and personality, and of relations between individuals.

From this standpoint, the school must be seen as a form through which the individual comes in touch with the activity in the production and consumption of knowledge in the context of definite inter-individual relations. The individual researcher frequently passes through several

schools, and has many teachers, while the "courses" he has learned differ in "class". All of this tends to converge and mould his cast of mind, creating the wealth of "personal knowledge" without which creativity is impossible.

The influence of the science-educational school may spread to the creative effort of the scientist who subsequently has to work (and even sets up his own school) in another field than that which his teacher in that school represented. Thus, many of Sechenov's students became prominent researchers not in physiology, which he had taught them, but in other fields of science. They learned Sechenov's approach to vital phenomena, to physiological functions, and Sechenov's style of thinking did not, of course, fail to exert an influence on their study of the problems they had to tackle in other fields of biology and medicine. These pupils, who did not work directly under Sechenov's guidance and under his own programmes, should be distinguished from others who helped to set up the type of school which we have designated as the research-group school. Let us note its distinctive features:

a) a single research programme on whose realisation the members of the school have concentrated their efforts;

b) the cohesion and intensity of cooperation induced by the programme among the members of the group-school who are held together by a common inner-motivation;

c) the existence of a head of the school who is not only the leader in ideas but also the organiser of the attendant activity.

Each such school is a microsocial structure constituting a peculiar and unique entity. Their emergence and disappearance poses special problems before students of science which would not have existed if instruction and research in the various schools did not differ among each other to such an extent that entire periods in the evolution of some disciplines turned out to be shot through with the antago-

nisms of schools. This situation may appear to be paradoxical, considering that the whole point of scientific activity is to achieve the most objective ideas of reality, free from personal or group bias. This has frequently led to negative assessments of the role of schools in the advance of knowledge. Science is based on facts, and schools on dogmas, was Francis Bacon's firm assertion.

The school is contrasted to "normal science" also in Kuhn's well-known concept of the paradigm as the basis for the cohesion of the scientific community. According to Kuhn, schools are symptoms of the immaturity of science. They disappear with the establishment of a generally accepted model of scientific activity (paradigm) and re-emerge in periods of crisis, when the once united community breaks up into groups separated with a great number of logico-psychological barriers. This view of schools sharpened interest in a question which remains in the background when the concept of schools in science is limited to such features as: a) instruction in creativity and b)elaboration of their own conceptions.

The fundamentally new and important feature, which we are here considering, bears on the relation of schools to the common store of knowledge, to the generally accepted models of activity, to the logic in the development of science, which is independent not only of the intellectual bias and principles of individuals, but also of their groups.

In analysing the cognitive, (rational, logical) aspect of scientific activity, historians are influenced by the notions induced in their minds by traditional logic that only the characteristics of thought which are effective for all periods and objects may be forms of thought (in contrast to the endless succession of contents which pass through these allegedly everlasting forms). This approach cuts off the historical "reference point" which alone can help to determine the advantages of one set of

"contents" (elaborated by the given school) over the others, and to evaluate the school's accomplishments.

The vital need to take account of the objective-historical substance of the structures of scientific cognition (and not only of its contents) which traditional logic has always ignored, has been expressed in the adoption of such concepts as "style of thinking", "paradigm", and "research programme" (in the sense with which this term has been invested by Lakatos). These concepts were put forward for the purpose of reconstructing various stages or epochs in the history of scientific knowledge. However, each of these stages not only has distinctive features which are common to all the researchers and scientific associations representing it, for they have peculiar logico-subject-matter characteristics which distinguish them from each other. The historian is faced with the task of "bridging" the intellectual forms characteristic of the given school (or trend), and the developing logical, categorial system of the common store of scientific knowledge. Only through orientation upon that store is it possible to determine the real value of the contribution made by a school. This does not eliminate the problem of the school's conceptual face (its "style of thinking", etc.), but includes it within a new context in which the logical-subject-matter system of the scientific discipline is related with the school's research programme, and in which the components of the programme which secure for that school (or fail to secure for it) the role of advancing scientific knowledge are brought out.

In elaborating the conceptions of the cognitive logical-subject-matter aspect of a school's activity there is need for orientation upon a specific line of analysis implying that the advance of ideas has a definite logic. We have to multiply the already abundant multiplicity of meanings of the term "logic" for lack of another that is more akin to the meaning of the matter under consideration.

However wide the views of the logical ground of knowledge may diverge, the adherents of any type of logic assume that they have to deal with the structures or forms of thinking in contrast to purely substantive descriptions. The problem of the transformation of these structures in the course of man's real and historically variable quest for the truth establishes a special angle of vision of the structural-dynamic properties of scientific knowledge. Advance in this problem constitutes a new trend, and because it differs substantially from other vectors of logical analysis, it has to be separated from them in terminology as well. In the science of science it is usually called science-development logic, which is taken to mean (like the other logics) the properties of cognition per se, and their theoretical reconstruction.[1]

Those who regard "logic" as signifying only the universal characteristics of thought may suspect that I have rashly included the content of thought in the ambit of logic, despite the fact that the former does change, in contrast to its forms, and not only on the scale of the epochs but before our very eyes. This makes it necessary to give a reminder that what I mean is the logic underlying the development of science which cannot be otherwise than historical subject-matter logic, which means, first, that it must be substantive, and second, that it must deal with the various intellectual formations. Such an approach does not mean any confusion of the formal aspects with the content, but impels a new approach in treating the problem of forms and structures of thought. These must be extracted from the content as its invariants.

Thus, for instance, none of the particular (substantive) propositions formulated by Descartes relating to the activity of the brain has stood the test of time or was even accepted by the naturalists of his age. But the basic determinist idea about the brain operating like a machine has provided the lodestar for research into the

nervous system for centuries. Are we to regard this idea as form or content of scientific thought? It is formal in the sense of its being an invariant, a component of a great number of research programmes which filled it with diverse content from the period of Descartes to that of Sechenov. It is substantive because it relates to a concrete fragment of reality, which is of no interest at all for the formal logical study of thought.

The categorial system of science is a dynamic system of its historical subject-matter substantive forms. The extent of the advance in this system (that is, the character of the enrichment of scientific categories) helps to determine the value of each particular research programme which serves as the basis for consolidating a scientific school.

Thus, confining ourselves to this example, we find that the category of reflex as imprinted in the Cartesian scheme, was elaborated in neuromuscular physiology over the centuries in the most diverse individual and collective programmes, among which some major ones stand out as milestones in the shaping of the categorial system of science. In order to "weigh" the value of these programmes these must be related to the level of development of the given object category by the historical period in which these took shape. That is the only way to determine the length of the stride which a given school has made along the highroad of advancing knowledge.

According to historical scientific data, adherence to a school is not confined to the knowledge component. We constantly find various other components, such as the cooperation of those who make up this peculiar collective (as a whole which cannot be reduced to its parts) and the individual claims of its various members, each of whom expects, in accordance with the code of science, to make a unique contribution. In other words, to the knowledge (logical subject-matter) component is added the inter-personal individual component.

The value of a school in scientific progress is determined by the scale of the advance within the system of categories and not by indicators like the number of adherents, institutions, publications, quotation references, or expansion in space and time. The experience of scientific associations which have generated entire trends and disciplines (cybernetics, molecular biology) indicates that the categorial advance takes place in the process of collective creative effort by a small but well-knit group of researchers, which may have a very small specific weight in the scientific community in quantitative terms, but may subsequently exert a tremendous influence. To this should be added the relatively short period of its existence. The experience in the emergence of such groups (research-group schools) is of especial value in understanding the factors which determine the intensity of the research effort.

The head of the school, who has both research (logical subject-matter) and organisational (socio-psychological) functions has an important role to play in generating and realising the research programme. At the same time, there have been great scientists in the history of science who have not won fame as founders of schools. Helmholtz, whose works brought about a revolution in physiology, had no school, while Ludwig or Foster, whose individual contributions to science were very much smaller than those of Helmholtz, had an outstanding role to play in science because they helped to found powerful physiological schools.

Three categories of researchers could be identified. One group had no scientific school and fulfilled their research programmes, whatever their number, individually. A second group, by contrast, always had a need for pupils and followers (usually beginners) and for their part acted as a centre of attraction for young scientists. Among them were Ludwig, Pavlov and Hull. Finally, the third group consists of scientists round whom a scientific school (as a research group-school) takes shape only in one period of

their creative lifetime on the basis of one programme, while the other programmes are drawn up by them individually. That was the case of Sechenov and Wundt. An analysis of their activity is of especial interest because it helps to trace the dependence of the formation of a school on the requirements of the logic in the development of science under whose pressure researchers who had not founded schools under other circumstances became founders and heads of schools for the duration of the programme, whereupon they reverted to their individual activity.

The head of a scientific school exerts an influence on those who are concentrated round him in all the aspects of their personality. The scientist has the function not only of fostering the young minds or of acting as a "programmer" who is capable of fulfilling on his own the programme he has conceived, but also as the organiser of the research group-school. It is up to him to allocate the assignments, to regulate the scientific intercourse, to compare the results, and to evaluate and generalise these. Like all other organisational activity, this must also be motivated. A bird's-eye view of the programme will show that it consists of a series of steps which is alienated from the subject, leading to the realisation of the scheme. But as I have already said, the programme contains both logical subject-matter and personal-individual components, and that it is an embodiment of the claims conceived by the researcher to a unique contribution of his own. If these are to be shared with others, there must be an imperative to do so.

At the same time, there must also be due motivation for those who seek to join the new programme. After all, each of them, for his part, expects to make a unique contribution of his own to the general advance of knowledge, thereby expressing himself as a personality and a man of science.

From this it follows that one of the most important functions of the leader of a school is to produce among his pupils a form of motivation, which I have designated as inner motivation, a term which evidently becomes meaningful only when compared with "external" motivation. What then is the content of these two terms?

Inner motivation originates in the context of cooperation among the objective historical requirements of logic underlying the development of science and the subject's readiness to realise these. These requirements need to be formulated, and the subject's readiness formed. Neither is achieved through the individual efforts of the subject on his own, but in dynamic cooperation with the socium in which he is integrated, and more immediately by the microsocium (notably, the school) which has invested one of its members with the functions of teacher, leader and guide.

Whatever the motivation which induces one (frequently with tremendous force) to stand up for cherished but dead-end ideas, it is ultimately bound to develop from an inner into an external motivation, because lack of prospect means the inability of thought to make headway in the subject-matter content, and to obtain new knowledge assimilated by the system of science.

But then it becomes obvious that the energy being put into the promotion of a thought which is no longer workable must be obtained not from contact with the subject-matter but from other sources, namely, the urge to maintain one's positions, prestige and so on. And, by definition, this is external motivation. What is it external to? It is external to the developing subject-matter of knowledge. When the programme on which the school is based exhausts itself, and the school may for various reasons (for instance, the leader's claims) seek to maintain itself, it inevitably becomes a drag on scientific progress because its members lack inner motivation. Indeed, the breakup of such a school is a premise for progress. A scientific school can flourish only

if there is a collective motivation rooted in a common and developing programme of activity.

In this age of the rapid quantitative growth of science along every parameter, the problem of intensifying research has become especially acute. The elaboration of this problem implies a close study of historical experience showing that under definite curcumstances the schools become the centres of the most intensive concentration of intellectual energy and exert the most active influence on scientific progress. It is this that induces one to take a fresh look at the ancient phenomenon of the scientific school and to study it as a special systemic object providing an informative model for collective creative effort.

NOTE

[1] Just as the term "grammar" means both the system of a language, and its theory.

OBJECTIVE AND SUBJECTIVE ASPECTS OF CONTINUITY

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In the historical development of science in general and of physical science in particular there is an inherent continuity between the old and the new. This means that every stride forward rests on the earlier results and appears to be an elaboration or a modification of what is known, has been tested and used. However fundamental the changes in science, the wealth of ideas accumulated in the past cannot be entirely discarded. The newly formulated conceptions, ideas and notions are connected with the earlier ones through a multiplicity of channels.

Continuity between the various physical views is interpreted very broadly in methodological terms.

First, there is the continuity in periods of relatively quiet development of science, when the existing theories and notions simply become overgrown with new information which does not affect the basic principles of physics as a whole or any of its individual areas. The new propositions fit very well within the overall framework of the existing conceptions and notions and do not undermine but confirm these and provide additional concretisation for them.

Second, there is the continuity in periods of scientific revolutions, when the old physical conceptions and notions are broken up. Here, continuity is expressed either in the transition of some of the earlier established laws of physical phenomena to new theories without change, or in some of the old laws beginning to appear as roughly true, as particular and marginal cases of new and more profound laws, or in the old laws and conceptions being clothed in a new form, acquiring another meaning, without being entirely discarded.

Finally, third, one has to consider the continuity of scientific ideas between periods of history which are chronologically remote from each other and which are not directly adjacent to each other. Ideas and notions expressed very long ago may well be resurrected for a new life in new theories. This is frequently accompanied with some transformation of the face of the old ideas, so that a superficial view does not all at once reveal the existence of continuity. One should also take into account that the earlier ideas absorbed by the new theories frequently belong to very different departments of physical science or have even been borrowed from other sciences.

Consequently, continuity in the development of physical science, as of all science in general, may be expressed in diverse forms, regarded from different angles and may have different aspects. Without considering the problem of continuity as a whole in any great detail here, we intend to deal with one relevant problem which is formulated as the problem of the objective or the subjective character of its particular manifestations.

What do we have in mind when we consider the objective and subjective aspects or manifestations of continuity?

In identifying the objective aspect of continuity the latter is regarded in purely logical terms, in abstraction from the real features of the complex historical process of

the accumulation of knowledge. In this case, continuity is revealed by means of a comparison of the content of consistently emerging notions. We have to deal here with objective laws being realised in the development of science and independent of the acts or desires of individuals. Here physical science appears as being relatively isolated from the surroundings, developing along its way in accordance with its own laws, and being analysed in its general self-movement.

By contrast, identification of the subjective aspects of continuity entails a study of the development of physical views in fully concrete terms. Here we no longer abstract ourselves from the specific features of the activity of individual scientists, from the concrete historical situation engendering the various studies, or from the actual course of the latter. We make a study of all the twists and turns in the shaping of theories, asking ourselves these questions: Under the influence of which factor did this or that scientist achieve his results? What were the motive forces impelling his reason to perform the various acts? What was the impact on these acts from the individual traits of the founder of the new theory? and so on.

The existance of the two given aspects of continuity in the development of physical science—the objective and the subjective—is a direct expression of the general propositions of dialectical materialism concerning the categories of the logical and the historical. The historical is advance in all its diversity, with a great number of details and specific features. The logical is the historical but stripped of the casual factors and concrete features, retaining the most general, typical, law-governed and necessary elements. Because these are characteristic of development as a whole, they are also inherent in continuity, an important aspect which is being considered.

A study of both aspects of continuity is of substantial importance for the history of science. An analysis of the

objective aspect of continuity is closely bound up with one of the fundamental tasks in the history of science, namely, the task of showing the general and particular laws in the advance of knowledge. In addition, let us point to a narrower but highly interesting methodological problem, which cannot be solved otherwise than by relying on the objective aspects in the continuity of views. We have in mind the problem of revealing, typification and systematisation of the individual forms (or varieties) of continuity-link characteristic of the given science or of the science as a whole. Thus, among the forms of continuity typical of physics there are: the link in accordance with the conformity principle, the link in the successive development of the qualitative and quantitative content of theories, the link within the framework of the "Erlangen concept", and so on.

An analysis of the subjective aspect of continuity makes it possible to establish in every detail the concrete influence exerted on the development of science by production, the social system, philosophy, other sciences, and so on. In the light of this, there is a need to find out why a theory produced by this or that scientist has come too early on the scene, has not merged with the overall tide of ideas, has been forgotten, and has been revived only some time later. Finally, consideration of the subjective aspect of continuity is important for showing the internal laws of the individual creativity of the scientist, that which is called the psychology of scientific creativity.

There must be a conscious distinction between the aspects of continuity, an independent study of each of them with an analysis of all the possible modes of their real correlation and interaction. Let us note, nonetheless, that the two given aspects of continuity are not always easily distinguished, and are now and again simply confused, which results in conclusions that are historically invalid. Thus, now and again there is a wrong presentation in physical

and even in historico-physical writings of Max Planck's discovery of the law of the distribution of energy within the black body spectrum. This was already remarked upon by L.Polak, who wrote: "Many books on physics and even historical surveys frequently say that Planck initially obtained his law by interpolating between Wien's law and Rayleigh-Jeans' law. Actually, this was not quite so."[1] This mistake has been repeated again and again to this very day, and the incorrect presentation of the history of this question has also led to incorrect general conclusions about the character of the development of knowledge.

Natural interest attaches to the question of how the given aspects of continuity correspond each other, whether they diverge and how frequently, and how essential their divergence is.

There have been frequent cases in the practice of historical study when both these aspects of continuity have approximated each other, with the concrete historical emergence of a theory and its author's thinking coinciding with the logical course of the overall elaboration of the given question or department of physics.

An example is offered by the continuity between Faraday and Maxwell in the elaboration of the electromagnetic-field theory. Faraday laid the foundations of near-action electrodynamics, and the further shaping of the theory ran a strictly logical course. Maxwell's works on the electromagnetic-field theory were an elaboration of Faraday's ideas in the logical plane. The subjective aspect of continuity indicates the same lines of connection, because Maxwell repeatedly said that he was fulfilling the task of translating Faraday's ideas into mathematical language. Indeed, he gave a strict mathematical meaning to Faraday's ideas about electrotonic state, his notions of lines of force, and so on.

A later example of the coincidence of the objective

and the subjective aspects of physical research is offered by the works of Sakata on the theory of elementary particles. In 1956, he put forward the idea of a composite structure of elementary particles, taking nucleons and lambda-hyperons as the basic particles. This allowed him to explain the existence of the experimentally established set of relations between spin, isospin and "strangeness". Sakata's notions of the structure of elementary particles on the basis of the nucleon-hyperon model are objectively comparable in terms of ideas with the views of the structure of the atomic nucleus earlier propounded by D.Ivanenko and W.Heisenberg on the basis of the nucleon model. Consequently, we find here the existence of the objective aspect of continuity but there is also the subjective aspect here, and this was established by Sakata himself when he said that he got his idea of the nucleon-hyperon model of elementary particles under the influence of the idea of the nucleon model of the nucleus.[2]

However, the history of physical science also provides opposite examples, when the logical and the historical in development do not coincide, with the objective and subjective aspects greatly diverging, the personal aspirations of the scientists failing to fit within the dominant trends, and so on.

To bear out what has been said above let us mention the relationship between Faraday's views and the physical notions of his immediate predecessors and contemporaries. Let us recall that Faraday was quite alone in advancing the theory of near-action to explain electric and magnetic phenomena, having advanced a number of new and brilliant ideas. But all of these were somewhat premature and were not accepted by his contemporaries. Here, while there is the subjective aspect of the connection—because Faraday undoubtedly relied on what was known in science—the objective aspect of continuity is absent. Faraday's views were too far outside the framework of the objective development of the theo-

ry of electromagnetic phenomena at the time. Faraday's individual approach, and the subjective aspects of his creative activity sprang from the specific path he followed in science and a number of other concrete factors.

The same is true of Lomonosov's ideas. In his lifetime physics followed its own objective laws of development, while the departure of Lomonosov's personal aspirations from the overall tendency was subjective. His ideas about the nature of light, heat, electric and magnetic phenomena went beyond the prevailing views and were well ahead of his day, reaching out into the 19th century, when the objective requirements emerged for the elaboration of the kinetic theory of heat, the electromagnetic field theory, and so on. The subjective features and distinctions of Lomonosov's views from those of his predecessors and contemporaries were also due to the specific features of his biography, his way to science, conditions of activity and so on.

Now and again, situations arise in the history of physics in the consideration of which it is hard to establish the interconnection between the subjective and the objective aspects of continuity in the development of this or that theory, and this frequently leads to uncoordinated conclusions, and diverging views and appreciations of the achievements of various scientists.

That is exactly what happened with the discovery of the special theory of relativity.

Objectively and in logical terms, it is quite natural here to consider in definite succession the continuity between Lorentz, Poincaré and Einstein. But Lorentz's theory, subsequently elaborated by Poincaré, sprang from an analysis of experiments of the type of Michelson's ("second-order experiments"). Consequently, logically the following chain stands out quite clearly: Michelson's experiment, Lorentz's theory, generalisation of the theory by Poincaré, and finally, the appearance of Einstein's theory of relativity.

That this scheme appears to be very natural will be seen from the fact that various monographs, articles and manuals on the theory of relativity present the history of the latter according to this scheme (it is true that Poincaré's contribution is not always mentioned) unless these confine themselves to axiomatic expositions of the theory. In a number of his works, Einstein himself set forth the history of the theory of relativity in the same vein.

However, the actual shaping of the theory of relativity ran a much more intricate and confused course. One could assume that historically this process did not coincide entirely with the logic of the emergence of the given theory as it is presented above. To this very day there is no consensus on the extent to which Michelson, Lorentz and Poincaré are Einstein's predecessors in his formulation of the special theory of relativity.

In a fundamental work in 1905, in which Einstein first formulated the principles of the special theory of relativity, he makes no mention at all of his predecessors. He says nothing either about Michelson's experiment or of Lorentz's work or of Poincaré's. Without a knowledge of the history of electrodynamics of bodies in motion, one could assume that Einstein had started from scratch, arriving at his special theory of relativity in his own entirely original way, being completely unaware of the works of his predecessors. But this is apparently not quite so. Einstein undoubtedly must have known something of the works of Lorentz, Poincaré and others.

The question of what Einstein knew of the works of his predecessors is being vigorously discussed in historico-physical writings, and there are various views on this point. Quite naturally, researchers turn to Einstein's own reminiscences, and here we discover that they contain some contradictions. Thus, in 1950, Einstein declared that he had no knowledge of Michelson's experiment when formulating his theory of relativity, as otherwise he would have mentioned

it in his article. But on the other hand, C.Sellig, one of Einstein's biographers, wrote that according to Einstein himself he knew Lorentz's fundamental work, which was written in 1895, and which also sets forth Michelson's experiment, and the contraction hypothesis, although Lorentz still makes use of approximated transformations of coordinates, time and field intensity. There is a somewhat more definite answer to the question of whether Einstein had knowledge of Lorentz's 1904 work, in which the latter gave correct relativistic transformations: he probably did not know about it, even though the opposite view is sometimes advanced.

Consequently, the Michelson-Lorentz-Einstein continuity to some extent fails to accord with the actual development of the theory of relativity.

The question of the Poincaré-Einstein continuity is even more obscure. One could accept that Einstein had no knowledge of Poincaré's 1905 work, which was published in the French journal Comptes rendues (140, pp.1504, 1905) almost simultaneously with Einstein's work.[3] Both formulated correct formulas of Lorentz's transformations, having corrected some of his errors on the strength of the relativity principle. But Poincaré had expressed the relativity principle as a universal law of nature, which was true not only for mechanics but also for electrodynamics, even earlier.[4] Besides, Poincaré developed the idea before Einstein did about the need to draw attention to the problem of the simultaneity of events at remote points of space and proposed the use of light signals for synchronising clocks.

What did Einstein know about these works, and what he did not? For the time being, this question appears to be an open one. Einstein himself never said anything about whether Poincaré's ideas had influenced him or not. This state of things gives rise to discussions and different views.

So, in this instance, the objective and the subjective aspects of continuity do not coincide, but to what extent still remains to be clarified.

Apart from the hushing up or denial of continuity, facts which arouse some mistrust, there are also equally problematic assertions as regards the existence of continuity, which also arouse definite doubts.

Let us turn to Einstein's work, the process of his discovery of the general theory of relativity, where one finds a line of continuity between Ernst Mach and Einstein. The latter himself emphasised the existence of this line of continuity. However, there is no evidence anywhere of Mach's influence on the beginning of Einstein's work (what we have in mind is Mach's principle). Einstein himself began to recall Mach's ideas later, when he had already produced his own ideas about the basic principles of the new theory. We feel that despite the relevant statements by Einstein, Mach's ideas had no significant role to play in his approach to the basic ideas of the general theory of relativity.

These examples well illustrate the state of things one frequently finds in the history of science. While the objective aspect of continuity may be unequivocally established through methodological analysis, things are not quite so simple with the subjective aspect, for there is a need to turn to the evidence and statements of various scientists, but even these cannot always be entirely reliable. Despite such difficulties, joint analysis and comparison of both aspects of continuity make a positive contribution both to the analysis of the general laws underlying the development of science and to the study of the individual features of scientific creativity.

NOTES

[1] L.Polak, "Quantum Physics from Max Planck to Niels Bohr", in the collection Max Planck, Moscow, 1958, p.153 (in Russian).

[2] See S.Sakata, Progress of Theoretical Physics, 16, 1956, p.686.

[3] See Annalen der Physik, 17, 1905, p.891.

[4] See Rapports du Congrès de Physique, Paris, 1, 1900, p.22.

ON THE ROAD TO THE RELATIVITY THEORY OF GRAVITATION (1900-1911)

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The study of the mechanism of the appearance of scientific knowledge is one of the cardinal tasks of historico-scientific research. The general theory of relativity, which is the foundation of the modern theory of gravitation, is unquestionably among the most outstanding achievements of the human intellect. How was the gigantic leap from the firmly established simple and reliable Newtonian theory of gravitation to the mathematically intricate and physically paradoxical theory of Einstein made possible?

A close study of the problem of gravitation in the period preceding the evolution of the general theory of relativity (1911-1915) brings to light the preconditions, ways and means that made this leap possible.

A situation close to a crisis arose in the sphere of gravitation towards the beginning of the 20th century. For half a century the Newtonian theory of gravitation could not remove the small, but, against the background of its impressive successes, extremely disappointing discrepancy with astronomical observations, namely, the anomalous displacement of Mercury's perihelion. Among the empirical difficulties of the theory there were essentially smaller, than in the case of Mercury, anomalies in the movement of Mars, Venus, the Moon and Encke's comet.

Difficulties of a logico-theoretical order proved to be even more considerable. They became particularly acute in view of the immense progress made by physics and mathematics in the latter half of the 19th century.

Logico-Theoretical Shortcomings of Newton's Theory

The chief of these were phenomenologism, which was not balanced by an atomistic conception of the type of kinetics theory; isolationism (absence of links with other interactions in both experimental and the theoretical respects); instantism (instant long-range action); geometrical apriorism (logically unjustified accentuation of the Euclidean geometry of space); geometrical absolutism (use of absolute space and time lacking operational-measurement substantiation); finitism (gravitational paradox); and empiricism, due mainly to the inexplicable accidental fact of equality between inert and gravitational mass.

At the close of the 19th and the beginning of the 20th century many of the scientists studying gravitation were aware of these shortcomings of the classical theory of gravitation. In order to remove them they put forward many different ideas and theoretical schemes within the framework of the classical mechanical programme (with and without modifications of the Newtonian law) of gravitation. Attempts were made to go beyond this programme. However, although they partially removed one or several of the above-mentioned difficulties, all these innovations either came into conflict with experiment or did not fit into the law of the concervation of energy, or contained many ad hoc hypotheses and arbitrary constants, and thus failed to stand up to the Newtonian theory.

Electromagnetic Conception of Gravitation

Theories based on Maxwell's electrodynamics, particularly on the Lorentz electromagnetic theory (1900), were the most serious rivals of the classical theory of gravitation at the beginning of the 20th century. The Lorentz

theory was then developed by W.Wien, J.J.Tomson and other scientists and was supported by Langevin and Poincaré. This theory was the direct result of the expansion of the electromagnetic conception of physics (a school of which Lorentz was one of the leaders) and led to a generalisation of the law of gravitation. This gave rise to the vector field theory of gravitation, with the intensity of the gravitational field described, as in the case of the magnetic field, with a pair of vectors. The movement of gravitating bodies gave rise to additional terms in the law of gravitation, depending on the ratio of the square of the speeds of the bodies to the square of the speed of light with which, according to this theory, gravitation also spread. The new theory led to a reduction of the Mercury anomaly, but not more than by 7" instead of 40". Wien's modification of this scheme gave the Mercury anomaly as being equal to 14".

It seemed that the Lorentz-Wien electromagnetic theory removed instantism, and also the phenomenologism and isolationism inherent in the Newtonian theory. Moreover, it seemed to provide the key to explaining the equality between the inert and the gravitational mass, since both these masses proved to be proportional to the number of charged particles forming the interacting bodies. At last there was hope that the Mercury anomaly would be solved. However, the removal of these shortcomings entailed additional difficulties.

First, the existence of a "magnetic" component of the gravitational force could not be verified experimentally, because it was included in the expression for the force with a coefficient proportional to $\frac{v^2}{c^2}$.

Second, as was noted somewhat later by R.Gans and M.Abraham, the quasi-electromagnetic nature of gravitation must lead to a certain analogue of electromagnetic induction, which would make any equilibrium of masses unstable. With

this was linked yet another major shortcoming of the electromagnetic theory of gravitation, that was noted by Maxwell: the negative energy density of the gravitational field. This means that the energy of the gravitational field spreads in a direction opposite to the spread of the field itself. Lastly, these theories used, as a rule, ethereal and model notions (concerning the structure of substances), which caused new difficulties.

Relativistic Programme and the Lorentz-Covariant Theories of Gravitation

The situation was further complicated by the fact that the dependence of the mass of moving bodies on their velocity was established as a result of the development of the electrodynamics of moving media and the electron theory. This brought the special theory of relativity into being. Shortly before this, the German theorist Wilkens tried to take this dependence into account when computing the displacement of Mercury's perihelion, which made up 7.2" per century. Soon after the special theory of relativity was evolved, Wacker obtained an analogous result by a somewhat more correct method.

This period (1905-1907) witnessed the shaping of a new research programme in opposition to the classical mechanical programme and resting on the special theory of relativity (relativist programme). It required the restructuring of all physical theories in accordance with the Lorentz-covariant principle, provided they coincided with the classical analogues within the limit of low velocities (compared with the velicity of light).

The first theory that formally satisfied the requirements of the relativist programme was worked out by Poincaré (1906). He gave two variants of the Lorentz-covariant generalisation of Newton's law. Two years later a similar theory was constructed by H.Minkowski, who used graphic geometrical considerations. Both stressed that their

modifications of the gravitation law developed by them did not conflict with the well-known celestial-mechanical observations to the same extent as the classical theory. In 1910 Sommerfeld showed that the Minkowski theory coincided with one of Poincaré's formulations. The subsequent researches made in this direction by Lorentz, de Sitter and others did not contribute anything fundamentally new to the solution of the problem, while the most correct computation of the Mercury anomaly (7.15") did not in fact differ from the magnitude obtained by Wilkens and Wacker.

The Lorentz-covariant generalisations of Newton's law in the spirit of Poincaré and Minkowsky were thus unable to remove the main empirical difficulty of the theory of gravitation. While partially removing isolationism, instantism and geometrical absolutism, they contained all the other shortcomings, notably empiricism. Despite the existence of the finite velocity of the spread of gravitation, postulated by the Lorentz-covariant theories, they did not resolve the problem of instantism radically, because they were based not on the differential equations for the gravitational field but on the elementary law of interaction, which was not deduced from similar field equations. The situation thus remained the same as in the pre-Maxwellian long-range action electrodynamics of Weber and Neumann.

The shortcomings of the special theories of relativity, including the ambiguity of the possible Lorentz-covariant generalisation of Newton's law, were realised by the authors of these theories. For example, in discussing the problem of gravitation in 1908, Poincaré considered the Lorentz electromagnetic theory in detail and made only passing mention of the Lorentz-covariant generalisation of the law of gravitation.[1] This may be explained by the fact that Poincaré was an adherent of the electromagnetic conception of nature rather than of the relativistic programme, which he helped to work out. For some opponents of the special theory of relativity, the failure to apply the relativistic

programme directly to the problem of gravitation was a further argument against that programme. This stand was adopted, for example, by W.Ritz, who suggested his own variant for solving the gravitational problem on the basis of his emission electrodynamics and highly special assumptions about the structure of matter, a variant that would explain the Mercury anomaly.

Nevertheless, the Lorentz-covariant theories of the Poincaré-Minkowski type were not only the natural but also the positive element on the road to the consistent relative field theory of gravitation. First, they showed that it was possible to conform gravitation without contradiction to the principle of relativity and the finite velocity of its propagation equal to the velocity of light. Not being field theories, they circumvented the difficulties arising from the negative energy density. Second, the failure to explain the Mercury anomaly and the continued existence of some of the logico-theoretical shortcomings typical of the classics (above all, empiricism), in combination with the non-field character of gravitational interaction stimulated the further elaboration of the problem of gravitation.

Principle of Equivalence, 1907

At first Einstein evidently also tried to construct the Lorentz-covariant theory of gravitation in such a way as to explain the Mercury anomaly. This is evidenced by his letter to C.Habicht in December 1907.[2] Concentrated study brought him to a way of applying the relativistic programme less formally to the problem of gravitation. This involved using this programme in such a manner as would take into account the fundamental fact of the equality of the inert and gravitational mass from the very outset. This approach led Einstein to the principle of equivalence, which radically changed the stand of the relativistic programme as regards gravitation.

It may be assumed that a certain role in shaping the principle of equivalence was played by Planck's famous work,[3] to which, true in a different connection, Einstein referred in the same article in which he formulated the principle of equivalence for the first time.[4] Planck, in particular, had drawn attention to the fact that the gravitational mass of a physical system must be determined by its total energy.

There is every reason to believe that in 1907 Einstein endeavoured to construct the Lorentz-covariant theory of gravitation in a manner other than Poincaré and Minkowski. This concerns the relativistic generalisation of the Poisson equation, i.e., a field theory of the type proposed by Nordström in 1912. However, as it seemed at the time to Einstein, in theories of the Nordström type the acceleration of free fall proved to be dependent on the body's internal energy, which inevitably violated the identity of the inert and gravitational mass. He could not allow this because, as he recalled later, he did not doubt the absolute strictness of the equation $m_r = m_{in}$, although he did not as yet know of the extremely accurate experiments of R.Eötvös. After having noted this remarkable identity, Einstein could no longer ignore it when working on the relativistic theory of gravitation.

One of the most characteristic features of the methodology used by the founder of relativity was his quick perception of various non-symmetries in the problem situations studied by him and also his conviction that symmetry on the level of phenomena must be mirrored on the theoretical level. For that reason the theory of gravitation had to be relativistic and, in addition, it had to take into account such a fundamental symmetry as the identity of the inert and gravitational mass. Einstein was helped to achieve this by relativistic methodology, that, in addition to the relativistic programme, included the method of mental experiment in combination with the operational-measurement approach,

in particular, his mastery operation with reference systems, clocks, rulers and so on. This was yet another feature of Einstein's creative thinking—a method of converting propositions subject to explanation by the theory under construction, into an heuristic postulate effectively used for the construction of that theory.

It seemed that a new fruitful way had now been opened for constructing the relativistic theory of gravitation, a way that involved the application of the principle of equivalence to arbitrary gravitational fields and the corresponding extension of the special theory of relativity. However, although the problem of gravitation attracted the attention of many theorists, in fact nobody appreciated the possibilities indicated by Einstein. As a matter of fact, this was quite natural in 1907-1908, when physicists were only beginning to master the special theory of relativity and the relativistic programme, which seemed to be promising as applied to the solution of the problem of gravitation as well. On the other hand, the programme, linked as it was with the electromagnetic conception of physics, indicated its own way for solving the problem (electro-magnetic theories of gravitation).

At first glance, a more puzzling circumstance is that Einstein himself, who had in 1907 proposed the principle of equivalence and thereby an extended relativistic programme for constructing the gravitational theory, published nothing on gravitation until 1911. A possible explanation is above all that the application of the principle of equivalence to the systematic construction of a general gravitational field theory encountered some fundamental difficulties, mainly of a physical nature.

First, the need for going beyond the class of inertial reference systems and the special principle of relativity undermined the very foundations of the relativistic programme. So powerful a heuristic principle as Lorentz-covariance was vanishing. Second, the inclusion of non-inertial

reference systems among the permissible systems of reference made it no longer possible to require that the difference between the coordinates should be the direct result of measurements made with the aid of ideal rulers and clocks. Third, the principle of equivalence directly concerned only homogeneous fields of gravitation, while its extension to any heterogeneous fields was extremely problematic. Lastly, although the remarkable results obtained by Einstein from the principle of equivalence were in principle observable, he felt they could not be verified experimentally because of their insignificance. These reasons were quite sufficient to delay progress towards the theory of gravitation linked with the principle of equivalence.

The Einstein Programme of an Integral Field and Gravitation Theory (1908-1910)

A blanket feature of Einstein's creative thinking was the striving for a synthesis of different and contradictory physical conceptions, towards the construction of an integral physical theory. This feature manifested itself at the very outset of his career, when along with his work on the theory of relativity he worked with similar success on problems of the theory of quanta. The conception of the field which was fundamental to the theory of relativity and gravitation, and the equally fundamental conception of quanta, which gave the key for understanding an entire class of physical phenomena, polar in their essence, did not fit into the integral picture of physical reality. Not later than 1908 Einstein made determined attempts to synthetise these opposing aspects on the basis of a single field theory. In tackling this new problem he drew up a programme broader than the relativistic programme. To some extent it anticipated the famous programme of the integral geometricised field theory on which Einstein worked during the last 30 years of his life. Basing himself on the principle of relativistic invariance and the character of solutions (electro-

magnetic and gravitational fields, quanta and electrons), he endeavoured to work out differential equatious that could yield the necessary solutions.

Naturally, the solution of this global problem should have led to the solution of the problem of gravitation or, at least, indicated additional means of attaining that goal. Einstein's papers on the theory of quanta and, particularly, his correspondence with Lorentz show that in the period from 1908 to 1910 he worked intensively in this direction.[5] This quest for an integral theory was not successful. More, there was hardly a trace of it in Einstein's scientific publications. Nevertheless, it evidently played a certain role in the subsequent development of the idea that led to the general theory of relativity. The point is not only in the fact that having tried this road Einstein realised that it was premature and found himself compelled to return to a study of more specific problems. The experience gained by him in his work on an integral field theory--recognition of the fundamental importance of the conception of the field, the idea of non-linearity of field equations, the idea of deducing the motion equations from the equations of the field, and so on--was useful, of course, in his further work on the construction of the general theory of relativity.

Principle of Equivalence (1911)

In June 1911 Einstein completed a paper[6] devoted entirely to the principle of equivalence and an analysis of the consequences flowing from it, i.e., in effect, he repeated the results of the corresponding part of the work accomplished by him in 1907. From this time onwards Einstein and other physicists had been working on the problem of gravitation, and this work had ultimately led to the construction of the consistent relativistic theory of gravitation that is justifiably associated with Einstein's name.

Resumption of work on the gravitational problem and the return to the principle of equivalence were due to

Einstein's disappointment with the programme for an integral field theory. It may be assumed that there were other strong motivations. First, by that time the special relativist theories of the Poincaré-Minkowsky type had been totally discredited. Second, in the spring of 1911 Einstein moved to Prague, where he established contact with the mathematician Pieck and was in correspondence with Ehrenfest. A detailed analysis shows that these factors proved to be extremely stimulating. Third, by that time Einstein had realised that the effect of the distortion of the light rays in the field of the Sun could be checked experimentally by astronomical observations. This radically changed the situation and created a powerful incentive for constructing the theory of gravitation on the basis of the principle of equivalence, although the main difficulties standing in the way (violation of Lorentz-covariance, loss by the coordinates of the direct metric sense and the fact that the application of the principle to heterogeneous fields was problematic remained unsurmouted.

While demonstrating that the road of knowledge is far from being smooth, the fragment of the history of the theory of relativity we have just dealt with is evidence of the fruitfulness of such methodological abstractions as the conceptions of "logico-theoretical difficulties" and "research programme". By revealing the mechanism of the genesis of a scientific theory we penetrate into the creative laboratory of scientists and are thus able to obtain a more profound understanding of the emergence and restructuring of scientific knowledge.

NOTES

[1] H.Poincaré, "La dynamique de l'électron", Revue gén. sci.pur.et.appl., 1908, Vol.19, pp.386-402.

[2] S.Sellig, Albert Einstein, London, 1956, p.76.

[3] M.Planck, Zur Dynamik bewegter Systeme, Sitzungsber. Akad.Wiss. Berlin, 1907, 542-570, p.543.

[4] A.Einstein, "Ueber des Relativitaetsprinzip und die aus demselben gezogenen Folgerungen", Jahrbuch d.Rad.u.Elektr., 1907/8, Vol.4, 411-462, p.454.

[5] R.McCormmach, Einstein, "Lorentz and the Electron Theory", Hist.Stud.Pys.Sci. Vol.2, Philadelphia, 1970, pp,41-88.

[6] A.Einstein, "Ueber den Einfluss der Schwerkraft auf dies Ausbreitung des Lichtes", Ann.Phys.,1911, Vol.35, pp.898-908.

INTERCONNECTION BETWEEN MECHANICS AND MATHEMATICS

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Progress in mechanics (as in any other scientific discipline) is due, on the one hand, to external factors primarily depending on the level of development of the allied sciences, and, on the other hand, to the logic of development of mechanics itself. This process of the interaction, interconnection, interpenetration, differentiation and integration of sciences is highly complicated, and in a whole number of cases it is difficult and even impossible to single out the main factor which has influenced one or another discovery in mechanics.

Among the sciences which are developing in the closest and most organic interconnection with mechanics, mathematics holds a special place. Without the formalism of infinitesimal calculus, for instance, mechanics could not have emerged as a science. On the other hand, the rapid development of mechanics on the basis of mathematical analysis in the works of Euler had, in turn, exerted an enormous and, perhaps, decisive influence on the further development of the mathematics of that time. A similar situation was observed in the period when relativistic mechanics took shape in the works of Einstein and his predecessors and contemporaries: that was only possible on the basis of tensor cal-

culus which at the turn of the 20th century was detailed in the works of Ricci and Levi-Civita.

There are, perhaps, few branches in mathematics which are not connected with mechanics in one way or another or find no reflection in the development of its various fields. Mathematical formalism is a means by which one formulates problems of mechanics, improves its axioms and methods of solving relevant problems, establishes analogies in some regularities relating to phenomena of a different physical nature, records experimental data and draws conclusions as regards the accuracy of adopted models; it is a language which makes it possible, by way of concise formulas, to convey a large volume of information, to register the behaviour of mechanical systems in the past, to investigate their movement at present and to foresee it in the future.

As is known, classical mechanics is based on Newton s laws, and the method of working out an appropriate system of ordinary differential equations of the second order with their subsequent integration under given initial conditions is therefore the principal mathematical method of setting out questions of the mechanics of a discrete system of material points and an absolute solid. In their general form these equations are non-linear with regards to their first derivatives and hardly lend themselves to precise integration. It seems rational (so as to facilitate the working out of equations, to achieve their greatest compactness, to reduce their number as far as possible and to continue their investigation) to refer Newton's equations to generalised coordinates and give the equations of the movement of a discrete material system in the form of Lagrange's equations.

Lagrange's equations of the second kind (the number of these equations is equal to the number of the system's degrees of freedom) are characterised, in particular, by the fact that their left-hand parts (lagrangians) reflect the material structure of the system and its inertial pro-

perties, while their right-hand parts (generalised forces) describe the character of the external force field in its action on the material points of the system.

It is a striking feature that all lagrangians are expressed by way of one scalar function—the system's kinetic energy which in its general form consists of three components: generalised velocities in the zero, the first and the second power respectively, generalised coordinates (in any combination and form), and time (in explicit form). In the event of stationary linkages, kinetic energy is the homogeneous quadratic function of generalised velocities, which depends on the generalised coordinates and does not contain time explicity. Generalised forces are characterised by the work of the force field performed during the system's possible displacements. Thus, in Lagrange's equations of the second kind the kinetic energy of the system and the action of the force field around the moving material system acquire exceptional importance.

Of special interest is the movement of a material system in a potential force field, a phenomenon frequently observable in nature and in technology. This case is remarkable for the fact that the generalised forces are expressed with the aid of one scalar function—the force function of the system, which depends on generalised coordinates (and explicitly on time if the force field is not stationary). Thus, as regards the highly widespread case of the movement of a material system in a potential force field the dynamic equations can be expressed by means of two scalar functions —kinetic energy and the force function (potential energy), or with the aid of Lagrange's function (kinetic potential) alone. These specifics of Lagrange's equations of the second kind make them indispensable in mathematical research on problems of mechanics. It should be added that a system of such equations is autonomous and does not depend on holonomic linkage equations, if such linkages are imposed on the system. Generalised coordinates, generalised velocities

and time are called Lagrange's variables. In their general form the kinetic energy and generalised forces of a system are the functions of these variables.

Lagrange's equations of the second kind can be given in the form of Gibbs-Appell's equations whose left-hand parts are expressed through the function of accelerations which, like the generalised forces figuring in the right-hand parts of these equations, depend on Lagrange's variables and generalised accelerations, i.e., are second-order differential expressions.

Lagrange's equations of the second kind can also be given in the form of Hamilton's equations (canonical form). Canonical equations in mechanics represent a system of ordinary differential equations of the first order, which describe the movement of a holonomic system in a potential force field. In its general form Hamilton's function, which takes the place of the lagrangian in these equations, is expressed by means of generalised coordinates, generalised impulses and time (Hamilton's variables or canonical variables). The number of these equations is equal to the doubled number of the system's degrees of freedom.

Lagrangian dynamics is equivalent to Hamiltonian dynamics. The general dynamic theory operates with various parameters: generalised coordinates (configuration space), generalised coordinates and time (event space), generalised impulses and Hamilton's function (impulse and energy space), generalised coordinates and impulses (phase space), Hamilton's variables (state space), Hamilton's variables and functions (state and energy space). The dynamic theories expressed in the above-said mathematical spaces (notion spaces), like Lagrangian and Hamiltonian dynamics, are equivalent. It turns out that classical dynamics can also be based on a partial differential equation of the first order (the Hamilton-Jacobi-Ostrogradsky equation); so the kinetic equations in mechanics and the Hamilton-Jacobi-Ostrogradsky

equation are equivalent.

If the movement of a material system is restricted by non-holonomic linkages, then in the movement differential equations, as compared with Lagrange's equations of the second kind, there appear additional (correcting) additive terms, these dynamic equations comprising an aggregate system of differential equations and non-holonomic linkage differential equations. Present-day mathematical researchers show that classical mechanics is thus connected with differential geometry and tensor analysis and that differential geometry can develop as a basis for classical mechanics.

A synthesis of the methods of non-holonomic mechanics, tensor analysis and modern differential geometry is of great importance for the development of classical mechanics. In the 1940s W.Wagner showed that first-order non-linear non-holonomic mechanics, too, can be developed on the basis of the formalisms of differential geometry and tensor analysis. For the complete solution of the converse problem of dynamics it is necessary to integrate the differential equations of the movement of a material system or of an absolute solid body under given initial conditions. Consequently, one can apply here all the methods of accurate and approximate integration known from the theory of ordinary differential equations, including the methods of numerical integration on a computer.

In solving the Hamilton-Jacobi-Ostrogradsky equation and its relevant particular cases so as to find their total integral one can use Voronets' or variable-separating method. A particular solution of this equation can be illustrated geometrically in accordance with an optico-mechanical analogy. Here one can see once again the close connection between dynamics and geometry: dynamics problems can be formulated in geometrical images if an appropriate differential form of metric geometry is brought in correspondence with a given mechanics problem. In this case Riemann-

ian geometry is not the only possible form of metric geometry. As regards the general case of a mechanical system's movement such geometry will be non-Riemannian geometry and we shall have to consider event space (i.e., a configuration space also includes time along with generalised coordinates). Mechanical trajectories are the shortest (geodesic) lines of this variety.

Consequently, the solution of dynamic equations is equivalent to the finding of a geodesic on a definite (in the general case, non-Riemannian) variety: that is how classical mechanics and differential geometry are connected (geometrisation of dynamics). On the other hand, the solution of problems of classical dynamics is closely linked with the theory of transformation groups. It is therefore necessary to find such a canonical transformation of Hamilton's variables given which the system of Hamilton's equations allows of the first integral.

Emmy Noether showed that the various conservation laws (the momentum conservation law, the angular momentum conservation law, the kinetic energy conservation law and so on) are particular cases of one general theorem: to any one-parameter group of diffeomorphisms of the Lagrangian system's configuration variety, which retain Lagrange's function, corresponds the first integral of the movement equations. Under definite conditions, problems in the field of classical mechanics can be solved with the aid of the basic theorems of dynamics which follow from the differential equations of the movement of a material system. These theorems can also be expressed by means of first-order differential equations relative to the generalised velocities (or point velocities) of the system.

Lagrange devised one more method of solving dynamics problems. In literature this method is referred to as Lagrange's equations of the first kind. It is a system of second-order differential equations relative to the Cartesian

coordinates of a system's points, which contains additive unknowns—linkage factors. The additive terms in Lagrange's equations of the first kind are components of the interaction of the linkages (holonomic or non-holonomic) restricting the movement of the system. Let us note that in a number of cases it is useful to operate with excess coordinates. This circumstance counts in the extra additive terms of Lagrange's equations of the first or the second kind. In a number of cases it is rational to relate the movement of an object to a mobile coordinate system, which causes the appearance of inertia terms (transmissible and Coriolis inertial forces of the system's points or generalised inertial forces) in the dynamic equations of the movement. In a whole number of cases, when the differential equations of the movement of a mechanical system do not lend themselves to precise integration, one has to use mathematical methods of the qualitative theory of differential equations, which make it possible to judge of many regularities in the movement of the system by the very character of the equations without resorting to their integration.

Finally, let us note that the variational principles of mechanics (the Lagrange, D'Alembert-Lagrange, Gauss, Hamilton-Ostrogradsky and other principles), which are concretisations of the theorems of variational calculus as applied to classical mechanics, are at the same time effective methods for solving problems in the fields of statics and dynamics. Moreover, it should be borne in mind that problems of mechanics call for the finding of the stationary values, and not necessarily the extremum, of a given functional. Lagrange's equations of the second kind can be regarded as the necessary and sufficient conditions of the stationary nature of action according to Hamilton.

Now let us consider the basic mathematical methods used in the mechanics of continuous systems—the mechanics of a deformable solid body and the mechanics of liquid and gaseous bodies.

As in the mechanics of discrete mechanical systems and unchangeable solid bodies, in the mathematical description of the mechanics of deformable solid bodies the central place is held by the theory of linear and non-linear differential equations. For instance, to describe the movement of an elastic body in general, it is necessary to work out a system of 15 partial non-linear differential equations with 15 unknown functions (three displacement components, six tension components and six deformation components). Such a complicated system of equations does not lend itself to an exact analytical solution, and it is therefore necessary to introduce various particular mechanical models corresponding to some or other simplifying assumptions as regards the geometrical and physical characteristics of the solid body. If, for example, one adopts some additional hypotheses as concerns elongations, shifts and turning angles and also about the physical properties of the material, then in the case of a wide range of problems one can, with a degree of accuracy sufficient for practical purposes, linearise the equations and thereby simplify their solution.

The equations of the classical theory of elasticity can be obtained from the general elasticity theory if one takes into account Hook's law, i.e., the existence of linear dependence between tensions and deformations, and ignores all non-linear terms in the formulas for deformation components and in the equations for the equilibrium of a volumetric element of the body. As is known, the former simplification is permissible for most materials within a sufficiently narrow region of elongations and shifts, while the latter simplification is allowable when the elongations, shifts and turning angles are much less than unity, and the squares and products of the turning angles are small second-order magnitudes relative to the elongations and shifts.

The linearised equations admit of further simplifications if one imposes additional conditions on the nature of loading and the geometry of the body. Kirchhoff-Love's hypo-

theses in the theory of thin plates, for instance, make it possible to reduce three-dimensional problems to two-dimensional ones. If tensions are evenly distributed throughout the thickness of a plate, then in the differential equations one can strike out the momentums (momentumless theory) thereby reducing the order of the system of equations. The differential equations can also be simplified when the forces, momentums, deformation and displacements rapidly attenuate as the distance from the line of distortion increases (simple boundary effect). Some values in the equations become very small for gently sloping plates and also for cylindrical enveloping surfaces of great and medium reduced length. The equations of enveloping surface theory can be simplified in the event the stressed condition of the surfaces greatly change. For the integration of approximate linearised equations describing thin plates one can use the methods of surface theory, the theory of complex variable functions, the theory of generalised analytical and other special functions, the methods of asymptotic integration and so on.

Solution of differential equations in the field of the non-linear theory of thin plates is connected with the use of methods of small parameter successive approximations, variational and numerical methods, including those with the employment of computers. The convergence of the process of obtaining solutions on the basis of these methods and the theorems of the existence and uniqueness of solutions can be substantiated with the aid of functional analysis. The method of working out differential equations with their subsequent integration is one of the principal methods of the statics of elastically plastic bodies, the theory of viscoplastic incompressible flow, the study of elastic system stability beyond the elasticity bounds, the theory of wave propagation in elastic and elastically plastic media and all the other branches of the mechanics of deformable solid bodies.

The mechanics of liquid and gaseous bodies is based on the appropriate differential equations of equilibrium and motion. The equations of stressed continuum dynamics, the energy balance equation and general equilibrium equations are partial differential equations of the first order. The basic ideal liquid and gas equations (Euler-Lagrange's equations), mathematical expressions for the general theorems of dynamics as applied to continuum, and continuity equations are partial differential equations of the first order, which in their general form are non-linear equations. The general equations of viscouse liquid motion (Navier-Stokes's equations), dynamic equations and energy balance equation are partial non-linear differential equations of a complicated structure. Thus, the methods of the theory of partial differential equations are central in all branches of the mechanics of continuous systems.

The solution of many problems in the field of the mechanics of continuous systems, however, can be reduced to a system of ordinary differential equations. This is chiefly connected with the introduction of additional simplifying hypotheses and the presentation of the solution sought in the form of series and also takes place in special cases of continuum automodel motion and equilibrium. If we examine, for instance, the flutter of an aircraft wing (combination of torsional and bending vibrations of the wing, rudder and other elements of the aircraft extremely dangerous for its construction) on a wing model moving in the air flow of a wind tunnel in the presence of elastic coupling and a dry friction damper, we shall obtain an ordinary linear differential equation of the second order with constant coefficients. The problem of a viscoplastic rod's impact on a fixed obstacle is also reduced to an ordinary differential equation in an approximate presentation.

Of great importance for research on problems in the field of the mechanics of continuous systems are the methods of integral and integro-differential equations. The equa-

tions of the first and the second boundary-value problem of the elasticity theory are integral equations. Integral equation methods find wide application in demonstrating the theorems of the existence and uniqueness of solutions to Euler-Lagrange's dynamic equations for an ideal liquid and also in solving streamline body and viscouse liquid problems.

Integral and integro-differential equations prove highly effective in the fields of thin plate statics and dynamics, the dynamics of a not quite elastic thread of a variable length and in solving many problems as concerns wave propagation in an elastic medium.

The use of the Cauchy integral has made it possible to reduce the plane problem of elasticity theory to Fredholm's integral equation of the second kind for whose solution there are well-developed approximate methods. In some particular cases it is possible to obtain for this equation even an exact solution, for instance, for a disc with an elliptic hole.

The methods of the theory of analytical functions have an important part to play in the mechanics of continuous systems. They were used primarily in investigating the plane problem of the mechanics of elastic bodies. The methods of the theory of complex variable functions were successfully used in solving plane problems of elasticity theory for one-link regions (including angle point regions of plane problems involving elastic body vibrations and elastic plate deformation) and also problems as regards the determination of tension concentration around the holes in isotropic and anisotropic plates. Thanks to the introduction of complex variable functions of a special structure (in the form of power series) and various modifications of perturbation theory and the reduction of boundary-value problems to infinite systems of algebraic equations, effective approximate methods have been devised for the solution of problems con-

cerning tension concentration around the holes in layers and plates.

In investigating spatial problems in the field of elasticity theory great impetus has been given to Fourier's method and the theory of generalised analytical functions. The theory of analytical functions finds wide application in hydroaeromechanics. As regards continuum plane motions with a velocity potential and ideal liquid jet motions, for instance, the theory of complex variable functions has produced substantial results. On the other hand, such applications have stimulated the development of function theory methods. In connection with problems of hydroaeromechanics substantial progress has been achieved, for instance, in the development of variational methods in the theory of complex variable functions and also of conformal mapping theory.

Variational principles and the variational methods corresponding thereto play an important role in the development of the mechanics of continuous systems. In a number of cases these methods make it possible, without resorting to differential equations (as a rule, non-linear equations) of a system's motion or equilibrium, to demonstrate the relevant theorems concerning particular problems of the mechanics of deformable solid bodies and hydroaeromechanics. Numerous approximate analytical and numerical methods of mathematical analysis have been established in investigating problems of mechanics.

The methods of tensor calculus, differential geometry and functional analysis may prove useful in studying the mechanics of continuous systems. The modern dislocation theory has been developed in close connection with images of analytical spaces and tensor analysis. The deformation of a continuous system's element, for example, can be regarded as the result of a non-holonomic transformation of metric tensor components. Development of the theory of dislocation led to the evolution of the theory of non-Riemannian space.

A close connection can be established between mechanics and functional analysis: the theory of rotating liquid equilibrium figures, the theory of heavy liquid surface waves, the theory of dynamic systems, the theory of bifurcation points, the theory of ideal and viscouse liquid nonstationary motion, the substantiation of vibration theory methods, the theory of plates and enveloping surfaces—such is the far from complete list of objects of functional analysis in mechanics.

The foregoing convinces us of the fact that owing to the interconnection and interpenetration of the various branches and methods of mechanics and mathematics over the last three centuries these two sciences have mutually enriched themselves, thereby serving as an important factor of scientific and technological progress as a whole.

A NEW READING OF A PAGE FROM THE HISTORY OF SCIENCE

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"As science progresses many of the facts known earlier are seen in a new light.... The history of science is read anew with every new major stage in its development", Corresponding Member of the USSR Academy of Sciences S.Mikulinsky wrote.[1] This is a legitimate general principle. In effect it is one of the regularities of the historiography of science. Indeed, do we not regard the classical mechanics of Newton from the angle of quantum mechanics, or the old ideas of affinity in the light of modern chemistry?

But special interest centres on pages from the history of science whose new reading is usually an essential re-evaluation of scientific ideas and discoveries that had been the subject of broad and sharp polemics. The factors determining this interest are, first, the outstanding qualities not only of those ideas that had won a hard victory but also of those that had been rejected in the course of polemics but proved to be not so fallacious after all, and second, the profound philosophical significance of the very tournament of scientific ideas.

Recently we encountered striking examples of such a new reading of pages of the past when the famous polemic between Berzelius and Justus von Liebig and between Joseph Proust and Claude Berthollet were analysed from the angle

of present-day knowledge. It turned out that the scientists who had been defeated in the polemic had propounded such far-reaching ideas that today they are and, in the immediate future at least, will continue to be the lodestar in the study of substance.

In this article we shall consider, in the light of the latest achievements of catalytic chemistry and molecular biology, an extremely interesting page from the history of science linked with the problem of fermentative catalysis that had been the subject of a long polemic between Louis Pasteur and his opponents in the 19th century. On the basis of historical facts we shall try to determine Pasteur's natural scientific and philosophical stand in this polemic and establish to what it essentially boiled down and how one can explain Pasteur's phenomenal firmness in upholding his views despite the opposition of extremely powerful opponents.

First and foremost, it must be recalled that this was not only a natural scientific polemic. It was also a philosophical polemic illustrating the long struggle between the materialistic and the idealistic world outlook, between the dialectical and the mechanistical modes of thought. It is only on this basis that one can explain the tense atmosphere and the impassioned arguments that involved such outstanding representatives of mid-19th-century natural science as Louis Pasteur, Theodor Schwann, Claude Bernard, Louis Thénard, Hermann Helmholtz, Eilhard Mitscherlich, Jöns Berzelius, Justus von Liebig, Marcelin Berthelot and other leading figures in chemistry and biology.

Although the subject was quite concrete and, it would seem, narrow, the polemic itself proceeded in three interrelated aspects: natural scientific, methodological and philosophical, each of which was clearly manifested in the stance of the scientists involved. This mutli-aspect character of the polemic on the problem of biocatalysis was the circumstance that led to the profound distinctions in

grasping and assessing the essence of one and the same natural scientific fact.

Moreover, the historical fact of the discussion of a natural scientific problem in these three aspects was further convincing evidence of the justification of the thesis that philosophy and natural science are not autonomous and independent of each other, that they are profoundly interrelated aspects of society's intellectual life. It is thus obvious that a re-evaluation of the history of the study of some problems of chemistry and biology, including the one we are considering, is primarily an analysis of the philosophical attitudes of the opposing sides, the topicality of which in our day is due to the need for a critique of the mechanistic and idealistic speculations arising over unresolved problems of science.

Let us now recall what the polemic formally boiled down to and what were the actual arguments of the opposing sides.

In the 1830s the biological doctrine of fermentation began to take shape mainly as a result of the works of Jean-Baptiste Desmazières, Charles Cagniard-de-Latour, Theodor Schwann and Friedrich Kützing. Kützing's definition that fermentation is a chemical process stemming from the vital process (Lebensprocess) of an organised body[2] mirrored the conclusion that was arrived at independently by several researchers. However, due to the absence of adequate empirical foundations, this definition did not receive universal recognition. More, its proclamation evoked criticism from two sides simultaneously: from Berzelius and Mitscherlich and from Liebig.

In 1835 Berzelius, who had for a long time followed the experiments of many chemists in the sphere of catalysis, formulated his basic ideas of the essence of catalysis, advancing the idea that the living organism was a laboratory in which thousands of catalytical processes were taking place. He reduced the latter to electro-chemical

relations of matter and thereby gave a general foundation for non-organic catalysis and biocatalysis.[3]

For his part, Mitscherlich did not in general see any distinction between any "contact" inorganic matter and a ferment. Liebig's criticism of the biological doctrine of fermentation was likewise founded on his generalisations in the sphere of catalysis. He reduced the essence of a catalytic act to the shattering of the forces of chemical affinity by contact between a substance and a catalyst, which he regarded as a disintegrating or generally extremely unstable body. It is indicative that he propounded his ideas on catalysis in 1839 in an article in which he strove, in particular, to prove that fermentation was a common chemical process.

In 1857, Pasteur published his famous Memoir on So-called Lactic Fermentation,[4] in which he developed the idea, first stated by him in a letter to Jean Baptiste Biot, that "all fermentations are phenomena related to the life of a globule, a plant of the mycodermic type developing during fermentation..."[5] In the same year, 1857, Berthelot proposed his theory of the fermentive conditionality of the phenomenon of fermentation, which he formulated as follows: "The development of organised bodies... is not strictly necessary. Consequently, the cause of fermentation evidently lies in the chemical nature of special bodies playing the role of ferments. The action of living yeasts is conditioned not by their organised structure but by their chemical nature and is similar to the action of almond emulsion on almond, of diastase on starch, of pancreatic juice on fats."[6] In a paper written in 1859[7] he characterised Pasteur's stand as typically vitalistic, and opposed the theory of the physiological causal conditionality of fermentation with a hypothesis, according to which the chemical process of the disintegration of sugar could be separated from the living organism as a component from the sum of functioning parts.

This fundamental point evidently did not escape Pasteur's notice. Rejecting this easy division of an integral organism into components, he wrote in reply to Berthelot's paper: "I am inclined to regard the process of alcoholic fermentation as a simple, unique and, at the same time, complex phenomenon such as may only be a phenomenon closely linked with life."[8]

However, in view of the profound chemical transformations of matter as a result of fermentation, Pasteur allowed for the formation of ferments in the yeast cell. He assessed the discovery of the ferment mechanism of fermentation as a "remarkable fact", emphasising, however, that "my researches...have unquestionably established that there is a profound difference between fermentations, which I call such in the proper meaning of the word, and phenomena caused by soluble substances".[9] He was aware of the role of ferments in the physiological process and tried to separate an "alcoholic" ferment by grinding frozen yeast cells.

However, evidently convinced that the chemical process evoked by autonomous isolated ferments was by no means identical in nature to a physiological process, that it was only an artificial and transient model of the latter, Pasteur wrote: "At present I see no necessity for the existence of these ferments, nor the utility of their influence on fermentations of this kind. Way confuse the action of diastase, which is nothing more than phenomenon of hydration, with the action of organised ferments, and vice versa? I cannot see what can be changed in the conclusions of my works by the presence, if such is proved, of these soluble substances".[10]

The polemic became sharp and went on for more than 20 years. It was joined by other biologists and chemists, who, in the long run, did not make their point to each other. This is not surprising: the further development of biochemistry and microbiology proved that in <u>their own way</u> both sides were correct. Ferments were isolated and studied.

They proved to be complex organic compounds capable of evoking fermentation also outside the cells of an organism. That was the triumph of the chemical conception. Further, it was proved that fermentation takes place not in the way the chemists supposed, that it proceeds as a result of the combined action of innumerable ferments and is a complex process consisting of many parallel and consecutive reactions. To some extent, this indicated that Pasteur and his supporters were right.

But only to some extent, for the fermentive part was separated from the whole and began to function. The separation of zymase—a complex of ferments causing extra-cellular fermentation—from yeast cells by Eduard and Hans Buchner in 1897 was called by K.Timiryazev "one of the key triumphs of the strictly scientific view over the so-called vitalist one".[11] This meant that those who had, for various reasons, accused Pasteur of vitalism, now had the support of immaculate experimental facts that were unknown to Pasteur (he died in 1895).

For that reason, although in the polemic most of the naturalists were inclined to side with the biological theory of fermentation, subsequently it proved to be in a worse position. This circumstance, too, was of course one of the foundations for supporting Berthelot in his charge that Pasteur's theory was of a vitalist character. Support for and even the development of this thesis was promoted, naturally, mainly by chemists. For instance, in his A History of Organic Chemistry Carl Graebe[12] devoted an entire chapter to Pasteur's "vitalist theory of fermentation". Strange as it may seem, from time to time efforts are still made to interpret Pasteur's stand as vitalist. As a matter of fact, this was the impetus for this article.

How can we assess Pasteur's views on the above problem from the standpoint of modern natural science, to be more exact, from the standpoint of two of its branches—molecular biology and catalytic chemistry? In what light do we

today see Pasteur's "vitalism" and what developments associated with his name must remain immutable in the history of science?

Let us begin with what the modern theory of catalysis says on this issue.

Given the entire diversity of the many modern theories of catalysis, the teaching on catalysis is, as a whole, based on only a few fundamental postulates, the sources of which are to be found in the works of Berzelius and Liebig. These scientists were the first to indicate that the essence of catalysis is due to the weakening of the primary chemical links between the atoms of a molecule when it comes into contact with a catalyst that remains chemically unchanged. This proposition was subsequently specified through the elucidation of the mechanism by which a catalyst acts, and today there are scores, if not hundreds, of rules indicating the role of geometrical, energy, electron and other factors ensuring the extension of the potential barrier of reaction. However, the classical teaching on catalysis is nearing its limit. It has been established that the best catalytic systems are those in which the systematic destruction and the self-regeneration of catalysts take place as a result of the interaction with reagents, in which catalysts are adapted to the requirements of the basic reaction through a change in composition and structure, in other words, systems that are analogous to the fermentive systems of living organisms.

In this context two independent tasks were placed on the agenda: 1) the extraction from living organisms and identification of fermentive systems and 2) the modelling of biocatalysts. It did not prove to be simple to accomplish these tasks. The first can, in principle, be accomplished by very few ferments, in particular, the ferments of the process of fermentation. Even if they are extracted from the cells of an organism, the more complex fermentive systems quickly lose their vigour, disintegrate after they

join in a reaction and, losing their apparatus of inner-cellular self-regeneration, become waste.[13] Let us recall that in connection with a similar phenomenon Pasteur wrote the following: "as it develops, yeast forms a substance similar to pepsin that acts on sugar and then, becoming exhausted, disappears, because no similar substance can be found in liquids."[14] The second task can, in principle, be accomplished by all biocatalysts. But after achieving the activity of the original during the first moments of reaction, even models of biocatalysts quickly break down and, naturally, cannot self-regenerate. This gives rise to a third task: in order to assimilate the catalytic experience of living nature it is necessary to model not only biocatalysts proper but also the entire range of the biopolymers and bioregulators of which the organism as a whole consists. In other words, it is necessary to model the apparatus of metabolism and, consequently, know what life is, how life is born on the basis of abiogenic forms.[15]

The fulfilment of this third task may be described in more detail, but even without this it is quite clear that the very fact it has been set requires a return to the ideas of Pasteur.

Moreover, a re-assessment of Pasteur's view is required by the latest advances in molecular biology that have virtually upset the earlier prevailing views about the specific nature of the living world and about the forms of the links between the inorganic and organic worlds. A study of the structural and functional regularities of the molecular level of living organisms led to two quite incontestable and outwardly alternative conclusions.

It was found that the composition and structure of biopolymeral molecules represented a single standardised set for all living organisms, beginning with procariots and ending with higher species of animals. The mechanism of the processes of vital activity likewise proved to be amazingly universal. The structure and functions of all key

molecules of biopolymers and bioregulators are, for that reason more or less standard for all organisms and quite accessible for study by physical and chemical methods. This conclusion thus points to unity of the physico-chemical laws governing the abiogenous processes and those of vital activity, i.e., to what is common to all these processes.

In addition, the highly specific nature of the living was demonstrated. This is manifested not only at the higher levels of organisation—at the level of cells or the entire organism. It is also manifested in the behaviour of fragments of living systems at the molecular level, where the laws of other levels are mirrored.

This specific nature of the molecular level of the living is manifested concretely in many astonishing facts that are essentially alien to common, or classical, chemical thought. Today these facts are described in textbooks. First, it has been established that as distinct from catalysts that possess functional selectivity of action, i.e., the ability to accelerate the conversion of many substrata with a definite functional group (OH, CO, COOH, C=C, etc.), ferments possess absolute substratum selectivity, i.e., the ability to convert only one substratum. Second, it has been shown that the active catalytic centre in the globule of a ferment "is ostensibly submerged in a special solvent, whose composition has nothing in common with the composition of the aquatic environment of the globule of the ferment... The immediate environment of the active centre formed by various aminoacid remnants of the polypeptide chain arranges itself at distances and in conformations that are atypical for free molecules in liquids".[16] In view of the fact that the primary structure of the polypeptide chain is determined solely by the genetic code, "no thermodynamic restrictions are imposed on it".[17] Lastly, there is the totally unusual fact that many chemical reactions of oxidation-restoration in the living cell "may take place without direct contact between reacting molecules".[18]

All this, as Academician V.Engelgardt noted, indicates that "types of chemical conversions take place in living systems that have never been observed in non-living nature".[19] It is highly noteworthy that this is shown precisely by molecular biology that studies the organisms at the level of chemism. The living is not "merely a complex combination of trivial physico-chemical processes".[20]

Pasteur's assertions have thus proved to be trustworthy, while the accusation of vitalism was ephemeral. Today we must draw attention not only to the fact that Pasteur eventually proved to be right in his polemic with his opponents. Much more important and interesting is the prospect held out by Pasteur's theory, or by his scientific programme in the methodological aspect depicted in Lakatos' conception of the development of science.[21] This programme was formulated by Pasteur during the period of his crystallographical researches. "Is it not necessary and enough to surmise", he wrote, "that there is a dissymetrical force at the moment various combinations form in the vegetable organism... force that is absent or exercises no influence whatever on reactions taking place in laboratories?"[22] This is the first proportion of his programme.

He maintained that the living had a unique specific nature and put forward the next proposition of his programme: "...soluble ferments form only as a result of vital activity. The cell must be in an active state in order to form a diastase, pepsin and emulsin. The fermentive processes that may take place in a dead plant or a cadaver must be short because these powerful and mysterious agents are not renewed."[23]

The third proposition of Pasteur's programme was his assertion that the structural-functional changes of chemical objects differ from the behaviour of an "organised being"— his concept of organisation."The organisation of beer ferments is by no means a difficulty for the theory of fermen-

tation", he wrote, polemising with chemists. "On the contrary, precisely for this reason yeast is included in the general law and can serve as an example of all true ferments... True ferments have always been organised beings".[24]

The fourth proposition of the Pasteur programme—"fermentation always manifests itself in connection with life, with organisation... and not in connection with death... Fermentation is not a contact process, in which the conversion of sugar takes place in the presence of a ferment, giving it nothing and taking nothing from it"[25]—was, essentially speaking, directed against the metaphysical interpretation of the essence of life, against the absolute counterposing of the object to the process, of the part to the whole, of the cause to the effect.

And, lastly, the fifth proposition of the Pasteur programme boiled down to a clearly expressed historical approach to the problem of the emergence of the specific features of the living. "Living cells", he wrote, "have a vital potential... I would say, that the evolutionary ability of the embryo develops in the sphere of a new determinism of phenomena and naturally leads to particular results, among which the processes of fermentation are to be observed."[26] Two attributes of the living—organisation and development—were regarded by Pasteur not in isolation but in close interaction, and he considered the specific nature of the living not as a result of a simple composition but as a "vital potential" that took shape through evolution.

To this day Pateur's programme for the study of the living is as topical as the programme for the study of the inorganic world, proposed by Bertholet at the very beginning of the 19th century.

NOTES

[1] S.Mikulinsky, A History of Biology from Ancient Times to the Beginning of the 20th Century, Moscow, 1972, p.5 (in Russian).

[2] See F.Kützing, "Mikroskopische Untersuchungen über die Hefe und Essigmutter, nebst mehreren anderen dazugehörigen Vegetablischen Gebilden", J.prakt.Chem., 1837, No.11, p.408.

[3] See J.Berzelius, Berz.Jahresberichte, 1834/1836, No.15, p.234.

[4] L.Pasteur, "Mémoire sur la fermentation apelée lactique (Extrait par l'auteur), C.r.Acad.Sci., 1857, No.45, pp.913-916.

[5] L.Pasteur, Correspondance,1840-1895. Vol.1, Paris, 1940, pp.426-427.

[6] M.Berthelot, "Sur la fermentation alcoolique", C.r.Acad.Sci., 1857, No.44, p.704.

[7] M.Berthelot, "Remarques sur la fermentation alcoolique de la levûre die bière", C.r.Acad.Sci., 1859, No.48, p.691.

[8] Oeuvres de Pasteur, Vol.II, Paris, 1922, p.76.

[9] Ibid., Vol.V, Paris, 1928, pp.251-252.

[10] R.Vallery-Radot, La vie de Pasteur, Paris, 1941, pp.376-377.

[11] K.Timiryazev, Works, Vol.8, Moscow, 1939, p.488 (in Russian).

[12] C.Graebe, Geschichte der organischen Chemie, Berlin, Springervelog, 1920.

[13] O.Poltorak, E.Chukhrai, Physico-Chemical Foundations of Fermentive Catalysis, Moscow, 1971 (in Russian).

[14] Oeuvres de Pasteur, Vol.II, p.77.

[15] L.Nikolayev, Biocatalysts and Their Models, Moscow, 1968 (in Russian).

[16] O.Poltorak, E.Chukhrai, op.cit., p.281.

[17] Ibidem.

[18] N.Semenov, Some Problems of Chemical Kinetics and Reaction Capability, Moscow, 1958, p.307 (in Russian). (in Russian).

[19] V.Engelgardt, "The Problem of Life in Modern Natural Science", Lenin and Modern Natural Science, Moscow, 1969, p.271.

[20] See Voprosy filosofii, 1959, No.10, p.95.

[21] I.Lakatos, "History of Science and Its Rational Reconstruction", Boston Studies in the Philosophy of Science, Vol.VIII, Dordrecht, Holland, 1971, p.91.

[22] Oeuvres de Pasteur, Vol.I, pp.341-342.

[23] Ibid., Vol.II, p.533.

[24] Ibid., p.224.

[25] Ibid., p.13.

[26] Ibid., p.539.

ON THE ORIGIN OF ATOMISTICS

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The origin of the atomistic doctrine remains a perpetual mystery in the history of science. In this sense, there is a fundamental distinction between cosmology and atomistics, the two pillars of natural science in antiquity. The genesis of cosmological systems of the earlier Greek thinkers is clear, for there are obvious traces of the ties connecting these systems with the cosmogonic myth-making of the pre-scientific period. Things are different with atomistics, because neither the Greek nor any other mythology contains anything that could be related to the direct sources of atomistic notions.

Ancient sources, notably Aristotle, confirm the assumption that atomistics originated as an attempt to tackle certain theoretical problems which beset human thought at the early stages in the development of science in antiquity. According to Aristotle's account, the founder of the atomistic doctrine, Leucippus, developed his conception in an effort to overcome the difficulties which arose in connection with Parmenides's analysis of the concept of Being. If Being is everlasting and invariable, and can neither originate nor be destroyed, and always remains equivalent to itself, how are we to accord this view with the evidence of our sense organs?

This can be done by assuming that Being is not uniform, but consists of a great number of bodies or figures separated by a void, which, contrary to Parmenides, does exist, although it cannot be regarded as Being in the proper sense of the word. These figures, which apart from the properties of Parmenides's Being—eternity, immutability, uniformity, etc—also had, according to Leucippus, the property of perpetual motion, and were subsequently named "atoms", that is, indivisibles (or to be more precise, uncuttables). As they rushed about in the void, atoms collided with and influenced each other. As they linked up and formed more or less stable combinations, they produced the things we see around us.

The similarity between the atomistics of antiquity and that of the New Period is purely superficial, being largely determined by the common term "atom", which is used in both instances to designate concepts that are, in effect, fundamentally distinct. The roots of the atomistics of Leucippus and Democritus have nothing in common with the considerations which have led science to develop the atomic theory in its present form.

This view is shared by many researchers and at first sight appears to be convincing, but a closer look shows that it is a dubious one. First of all, it fails to explain the role which the atomistic conception has had to play throughout the long history of European culture. Even in the epoch of Leucippus and Democritus the beginnings of atomistic concepts, which originated parallel with and independently of each other, will be found in the teachings of Empedocles and apparently also in the Pythagorean school, where they no longer had any direct connection with Permenides's teaching of Being.

In Plato's The Timeus, we find a well-elaborated atomistic conception which essentially differs from that produced by Democritus. Even in the period of antiquity, Democritus's atomistic theory had a revival, having become the theoretical

basis for Epicureanism, one of the most influential and popular trends in the Hellenic period. By then, the problems raised by Parmenides had already become less meaningful and other philosophical systems (Anaxagoras and Empedocles) which originated simultaneously with that of Leucippus, were taken over by doxographers, while atomistics continued to develop, being enriched with new motivations and substantiations, as we discover, for instance, from the famous poem by Lucretius.

Centuries later, in the epoch of the late Middle Ages, and at the beginning of the New Period, the emergence of new progressive trends in science inevitably went hand in hand with a consideration of atomistics. Giordano Bruno, Gassendi, Boyle, Newton, Lomonosov and Boscovich developed and modified the atomistic teaching, doing this in each instance in the light of the tasks and requirements of their day, and doing all this long before the existence of atoms had become an experimentally proved fact.

But the most amazing thing in the history of atomistics was perhaps the fact that Greece was not at all alone in being considered the homeland of atomistics: the origination of similar notions will be discovered in several cultural areas of the globe, and in their most elaborate form they were found, apart from Greece, in some philosophical systems of ancient India. Together with some features of unexpected similarity, we find in Indian and Greek atomistics some characteristic distinctions as well, and in the light of the problem being considered here what was especially substantive was that the spiritual trends which led to the emergence of such systems in India did not in any way remind one of the situation which arose in Greek philosophy about the middle of the 5th century B.C. Any efforts to explain the parallel origination of atomistic teachings in these two countries by referring to the existence of direct or indirect cultural influences have been unsuccessful.

The main difficulty may be summed up as follows. Atomistic conceptions were created in various periods and in different conditions for the solution of dissimilar theoretical problems. Despite the distinction and specific character (in each case) of these problems, they were tackled with the use of notions which had some fundamentals in common. Why was this so? Perhaps the notion that things consist of the tiniest indivisible particles which our sense organs cannot perceive is some kind of archetype of scientific thinking. Or perhaps the experience gained by man over the centuries helped to engender definite psychological premises which made it easier for these notions to originate. Are there perhaps some linguistic data that would help to shed light on this problem?

Indeed, the languages of all the peoples of the world contain words serving to designate concepts like dust and ashes, each of which is of a collective nature, being necessarily connected with the notion of an immense number of tiny particles (specks of dust, motes,etc.). Consequently, each of these consists of two opposite and interrelated aspects: the aspect of an immense number which defies reckoning, and the aspect of the exceptional smallness of these particles, which verges on the infinitesimal. In effect, the tiniest speck of dust or ashes was the smallest marginal object in mankind's experience prior to the invention of the magnifying glass or the microscope. Both these aspects are broadly reflected in folklore among the various nations, and there are many examples to illustrate this. Take Homer's "dust and sand" metaphor, which Achilles uses to denote an immense host. On the other hand, the idea of small specks of dust was used to emphasise the insignificance and infinitesimal character of things, as in this passage from The Book of Isaiah (40, 15):

> "Lo! the nations are like a drop from a bucket,
> Like fine dust in the scales are they counted.
> Lo! the coast lands weigh no more than a grain"...

The notion of dust or ashes is one which is most likely to produce the idea that things, including man himself, consist of the tiniest particles, which are hardly visible and frequently not visible at all. After all, dust and ashes are what all things ultimately become, as they waste away, or dry or burn up. That all the frail things of this earth are ultimately reduced to dust and ashes was not suggested by some speculative turn of the mind, but by man's experience over the millennia. Nor is the human body any exception in this sense: so long as it is animate, it appears to be whole and entire, but as soon as the soul departs, the body falls apart into its constituent particles and grains. This original dualism of soul and body, of the immortal and divine element and the frail flesh, consisting of dust, will be found in any religious creed, and this is based on man's daily experience.

There is some indication of the link between these primitive notions, on the one hand, and the atomistic conceptions of the early period, on the other, in the perceptible image of the specks of dust dancing in a ray of sunlight, which we find over and over again in the ancient authors who wrote about the atomistics of Leucippus and Democritus.

This image was the subject of a lively discussion by Aristotle's commentators, among them Simplicius, Themistius and Philoponus, who stressed that it was not the particles of dust that Democritus believed to be atoms, but even smaller invisible bodies which behaved like particles of dust. Consequently, the particles of dust dancing in the sunlight are a model of the motion of atoms in a void. It is true that some authors in the later period of antiquity (Theodoretus and St. Hieronymous) expressed a different view, claiming that Democritus identified dust particles and atoms.

It is a curious fact that the image of specks of dust in sunrays is also to be found in some Indian texts dealing with atomistics, and below I will quote one such text.

Of course, there could be no direct or immediate transition from the visual notions of dust and ashes and the perceptible image of specks of dust in the rays of the sun to the atomistic conception of the structure of a substance, for this transition could have been effected only with a sufficiently high level of theoretical thinking in an effort to solve some problems which were also theoretical. That required substantiation of propositions essential for any atomistic theory, like the idea that the tiniest structural units of corporal things were immutable and indivisible.

Everyone knows of the problems that the founders of classical Greek atomistics had to tackle. Indian thinkers elaborating their own atomistic conception faced a different set of problems. The earliest systematic expositions of Indian atomistics will be found in the vaiśeṣika sūtra, which is ascribed to the legendary sage Kanada, the founder of one of the six orthodox systems of Brahmanism, the vaiśeṣika system. We know nothing about the life and activity of Kanada himself, and most students of Indian philosophy date the origination of the vaiśeṣika sūtra to the 3rd-1st century B.C. But one must take into account that the Indian sūtras were not produced at once in their entirety, being improved and enlarged with the passage of time, so becoming the product of creative effort by many generations.

A study of the vaiśeṣika sūtra reveals three sets of ideas which must have been elaborated at different periods. These are: 1. The theory of categories; 2. The theory of elements; and 3. Atomistics in the proper sense of the word (I leave aside the ethical and theological aspects of the vaiśeṣika system). The notion of several elements on which the world of things is based was common to all the philosophical systems of ancient India and goes back to Upanishads. The differences on this matter boil down to the number of elements (from three to five), and their selec-

tion. The vaiśeṣika sūtra postulates the existence of five elements, falling within the category of substances or physical realities (dravya). Four of these have an atomistic structure. These are earth, water, fire and air (or wind). The fifth element (ākāśah), which is usually compared with ether, does not divide into atoms; it is an all-pervasive element, which continuously fills up the whole of space. Space itself and also time, the soul, and manas (reason) are the incorporeal substances.

The first thing that leaps to the eye is that the set of elements in the vaiśeṣika system outwardly coincides with Aristotle's. In both instances, the fifth element has a special role to play, although it is a different one in the two systems. But the main difference with Aristotle's physics is that the vaiśeṣika sūtra postulates the ultimate divisibility of the four traditional elements, with atoms (Sanskrit paramāṇu) being the ultimate limits of their divisibility. The sūtra itself does not substantiate in any way the existence of indivisible particles, and we find these in some of the later commentaries. Here is an example of this kind of substantiation, which we find in a commentary on nyāya sūtra (the nyāya teaching was linked mainly with the atomistic conception of vaiśeṣika):

"For example, if we divide a clod of earth into parts, then (these parts) will become smaller and smaller. And where this row of diminishing (parts) ends, because there can be nothing smaller, then this (smallest) is called the atom (paramāṇu). If the division into parts could have been continued endlessly, it would have followed that a sun speck of dust would have been immensely great in the number (of its component parts), in magnitude and in weight. It would then have been impossible to say: 'A sun speck of dust has such and such a magnitude, such and such a weight, and consists of a combination of so many atoms'. Why not? Just as the Himalayas consist of an accumulation of numerous atoms, being immense in the number (of these atoms), in magnitude

and weight, so with endless divisibility the same would be true of the sun speck of dust (Nyāyavārttikam, pp.510,5-15).

Thus, the assumption of endless divisibility necessarily leads to the recognition of the relativity of the big and the small. This conclusion, which in Greece was intrepidly accepted by Anaxagoras, appears to be unacceptable to the author of the commentary. This passage shows that the Indian thinkers based their idea of the atomistic structure of a substance on considerations which differed substantially from those of Leusippus, whose basic properties of atoms--indivisibility, immutability, lack of properties--sprang directly from Parmenides's teaching of Being.

Indian atomistics started from other premises. In particular, according to the vaiśeṣika teaching the atoms of the four elements were not in any sense without properties, for they had the same properties that were inherent in the corresponding elements. Thus, earth atoms, like earth itself, had four properties: smell, taste, colour and tangibility (the latter also included heat). Water had three properties: taste, colour and tangibility, fire, two: colour and tangibility, and finally, air had only one--tangibility. It is a curious fact that sound was not ascribed to any of the four elements, and was considered to be the exclusive attribute of the fifth, continuous element, akashi (ether). This element had no other properties to characterise it.

In contrast to the atoms of Leusippus and Democritus, the atoms in the vaiśeṣika teaching are not absolutely immutable, for while the atom of one element cannot pass into the atom of another, its properties can change within certain limits under the impact of external conditions. Indian texts offer an example of such change by pointing to the change in colour--from grey to red--as an earthen vessel is baked, which is said to be due to the change in the colour of the atoms of the earth under the influence of heat.

The Leucippus-Democritus teaching ascribes to each individual atom a definite and immutable geometrical form, only the atoms of fire being regarded as spherical, and the form of the other having no direct connection with the elements. Vaiśeṣika sūtra calls the atoms spherical (parimandalah), and while this was subsequently interpreted in the most diverse ways, it is quite clear, at any rate, that the form of the atoms was not a question that was essential in Indian atomistics. Furthermore, atoms made up a kind of molecule consisting of two or three atoms of different elements, so producing secondary, non-elementary substances.

Finally, in contrast to the Leucippus-Democritus atomistics, the vaiśeṣika teaching does not regard motion as an inherent property of atoms, which are in themselves passive and are set in motion under the influence of external, non-material factors.

From this it quite obviously follows that while there was no immediate connection in the Leucippus-Democritus atomistics with notions among the ancient Greeks about the elements, the vaiśeṣika atomistics can be regarded as an integral part and further development of the teaching of elements. That is why the view that the teaching of elements was the earliest component part of the vaiśeṣika system appears to be unconvincing. This teaching was subsequently supplemented with the atomistic conception whose beginnings we find in other philosophical systems of that period (ajjivaka, jaina), and the classification of the categories of Being was effected in the period of the final formalisation of the system.[1]

Let us now go back to Greece. In the light of what has been said, let us ask ourselves this question: Can we perhaps discover in Greece as well atomistic notions which developed, as they did in India, on the basis of a teaching of elements? Indeed, such notions can be discovered, although they have been pushed into the background by the Leucippus-Democritus teaching, which in the later period

came to be regarded as being virtually the only form of Greek atomistics. Let us enumerate the main points of which we are aware on this matter.

In its classical expression, the teaching of the four elements is represented in the philosophical system of Empedocles. These elements--fire, air, water and earth--are eternal and immutable, but they can move in space and enter into different combinations with each other. All things (substances) are combinations of these four elements in various proportions. Here and there, Empedocles indicates these proportions.

The question is: How are these elements combined with each other? Do such combinations entail absolute confluence and interpenetration of the elements, so that at any point in space, however small it may be, we shall always find the elements which are constituents of the combination? Or does each element consist of small and fully homogeneous particles, so that the mix of the elements is a mechanical mix of such particles, like a mix of grains of sand?

That the latter assumption is true is backed up with evidence to be found in Aristotle, Theophrastus, and other writers of antiquity, and also some passages in Empedocles himself. This is also borne out by the theory of "pores and effluents" by means of which Empedocles explained the mechanism of sensory perceptions and some physical phenomena. The effluents released by various bodies were treated by Empedocles as flows of particles which, generally speaking, were complex particles, being combinations of several elements. However that may be, Empedocles's system was infused with corpuscular notions although these notions cannot yet be regarded as atomistic in the strict sense of the word.[2] The question of the form and the limit of the divisibility of the elementary particles was apparently not considered by Empedocles, so that his teaching was a teaching of the four elements, which included only some rudiments of atomistics.

Another line in the development of atomistic notions in Greece was connected with the Pythagorean school. I say nothing about the so-called "mathematical atomism" of the Pythagoreans who claimed that all things consisted of a great number of point-units--atoms. This kind of atomism should be regarded as an invention of scientists in our own day. If the Pythagoreans did have any kind of rudiments of atomistic notions, these were connected, as they were in Empedocles's thinking, with the teaching of the elements.

The information we have at our disposal shows that the Pythagoreans of the 5th century B.C. had very definite notions of the elements. We are aware, for instance, that the Pythagorean Yon of Chios, who held that the number 3 was at the root of the whole of the universe, said that there were three elements: fire, air and earth. An extract from Philolaus says that there are five bodies (elements) in the world sphere, among which are designated fire, water, earth and air, and a fifth element which in translation appears as "a cargo vessel of the world sphere". By then the Pythagoreans must have compared the elements and regular polyhedrons, so that the "world sphere", that is, the universe, was seen as a dodecahedron.

According to Aetius, this kind of comparison was ascribed to Pythagoras himself, but we should not be put out by this: according to the tradition adopted in the Pythagorean school, all the important discoveries made in the school were ascribed to its founder. Does this mean, however, that the Pythagoreans had already elaborated an atomistic theory which was later set forth by Plato in his The Timeus? That is something we do not know.

Of definite interest in this context is the evidence we find in Aristotle's De Caeli. Considering the various views of the elements, Aristotle deals with the teaching which says that fire was the sole origin of all things. Some followers of this teaching, says Aristotle, assumed that

fire consisted of the tiniest particles which had the form of a pyramid (that is, tetrahedron).

In a commentary on this passage, Simplicius wonders: whom did Aristotle have in mind in that case? It is well known that Heraclitus held fire to be the sole principle of all things, but Heraclitus (according to Simplicius) did not believe that fire consisted of pyramids. On the other hand, Simplicius continues, the Pythagoreans believed that fire consisted of tiny pyramids, but according to their teaching there were several principles instead of one.

Despite the bewilderment of Simplicius, we could say that the teaching, which Aristotle considers, originated in the Pythagorean school. Thus, Hippasus of Metapontum followed Heraclitus in believing that fire was the only principle, and he was a member of the Pythagorean fraternity. The assumption that Aristotle had in mind Hippasus and his followers appears to be all the more warranted since the semilegendary stories of Hippasus suggest that he had an interest in geometry, notably the problem of regular polyhedrons.

However that may be, one could assume that the Pythagoreans had a scientific tradition connected with the conception of the four elements, and which was consummated in Plato's atomistic theory. Its specific feature was that, among other things, it did not regard the tiniest particles of the elements, which had the form of four regular polyhedrons, as being primitive and indivisible particles, but as consisting of even more elementary objects. This enable Plato, while remaining within the framework of the atomistic conception, on the one hand, to substantiate the possibility of the mutual transmutation of the elements, and on the other, to regard the elements not as being homogeneous substances always equivalent to themselves, but as classes of "fire-like", "earth-like", etc., substances. As a result, Plato's theory became flexible and highly productive, which was not duly realised because of definite historical conditions.

In regarding Plato's atomistics in the genetic plane, it should, like the Indian Vaiśeşika system, be classed in the category of atomistic teachings that were developed on the basis of notions about the four elements. That is the genesis of the atomistic doctrines which appears to be the most direct and natural. As for the Leucippus-Democritus atomistics, its origination was in a sense unique, but this does not, however, run counter to the great role which it had subsequently to play as the most consistent materialist doctrine in the history of the philosophical thinking of antiquity.

NOTES

[1] See: Erich Franwallner, Geschichte der indischen Philosophie, Vol. II, Die naturphilosophischen Schulen und das Vaiśeşika System, Salzburg, 1956.

[2] This is summed up in W. Kranz, Empedocles und Atomistik, Issue 1, pp. 18–42.

MATHEMATICS IN THE INDUS CIVILISATION

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There exists a considerable literature on the history of mathematics in India. All general writings on the histry of mathematics provide detailed accounts of the appearance of the decimal positional system of computation, and point out that arithmetic, a considerable part of algebra, and elements of trigonometry are of Indian origin. Finally, appraisal is usually given of the important part played by India in scientific contacts between ancient Greece, and mediaeval Arab and West European cultures.

These writings, however, are in the main devoted to the medieval period in the development of Indian mathematics, yet the earliest information regarding the Indians' knowledge of the natural sciences pertain to the epoch of the Indus civilisation, which refers to the middle of the third millennium B.C.

In the mid-twenties of our century, archeologists reported the amazing discovery of the ruins of Mohenjo-Daro and Harappa, two cities once located in the basin of the River Indus (hence the term Indus civilisation, or Indus Valley culture). No mathematical texts dating to that period have come down to us, and the inscriptions unearthed have not been deciphered, which is why a judgement of the level of such knowledge during that civilisation can be formed only indirectly, either through the results of excavations or by analogy with the knowledge other peoples

possessed in the field of the natural sciences. The relics of handicraftsmanship, and the shape of the artifacts and household articles found speak of the existence of cultural links between the Indus Valley and the areas lying westward in the Asian continent. Some links are traced to be with Elam, Egypt, Troy, Caucasia and even Europe, but primarily and quite intensively with Sumer. A number of common features have been noted in the material culture of Sumer and Mohenjo-Daro, the greatest closeness between these cultures finding expression in their writing systems.

The inscriptions pertaining to the Indus civilisation that have come down to us are very brief, being met only on seals on baked clay and on amulets, as well as, in rare instances, on tools and weapons. The writing on all these articles has the same appearance, irrespective of whether they have been found in the upper or lower layers in both cities. Another type of writing, closer to the manuscript, could have been used for daily needs, the absence of any longer texts giving grounds to think that bark, cotton fabric, leather or palm leaves were the most widespread materials used for written communication, perishable materials which have long rotten away in the moist soil of the area.

Thin clay tablets of rectangular form, with ears attached to one end could also have been used for writing. Such tablets were between ten to eighteen centimetres in length, and, like the wooden plates still used in India for the purpose, were covered with a smooth substance from which the writing could easily be washed off. Among other artifacts found was a small clay jar, probably an inkwell, since the ancient scribes used ink, including Indian ink, for writing.

The available evidence regarding the level of arithmetical knowledge during the Indus civilisation seems to indicate that the numeration system was decimal: this is borne out by the find of part of a ruler consisting of a

narrow strip of shell with nine division notches 6.7 millimetres in width. The error in these notches does not exceed an average of .07 millimetres, two different markings showing that this was part of a longer measuring instrument based on the decimal system. It is quite possible that, in its original condition, this ruler was made up of separate parts joined together by strips of metal. The choice of shell for the purpose was a good one, since this material does not warp, contract or expand with temperature changes.

During that period the decimal system of computation was also used beyond the confines of India: it is to be met in proto-Elam tables, as well as tables from Jemdet-Nasra in Mesopotamia.

Numbers were expressed in the first place through the use of notches, which had been found on the stone rings used to build columns supporting the roof tops of dwellings, Nine numbers used in this system have been discovered, viz., 1, 2, 3, 4, 5, 6, 7, and 9. The number 8 has not been found, and there are two ways of denoting six. The numbers from 1 to 4 consist of a single group of notches; the numbers 5, 6, 7 consist of two groups written either horizontally or vertically, while the number 9 consists of three vertical groups. Some horizontal and vertical lines were used in later Haroshti and Brahmi Indian systems of numeration.

Pictographic signs and symbols resembling numbers distinct from the notch system were incised on some tools found at Mohenjo-Daro. These were probably temple or state-owned property, the marks used indicating registration numbers.

The abacus, a special contrivance for calculation, could have been used for arithmetical operations. A brick was found at Mohenjo-Daro with three rows of oblongs cut out in it, four in each row. One of the hollows in it was

marked by intercepting lines, which gives reason to believe that the brick was a gameboard or part of a board, since it was found in a paved floor. Another brick was also found, with one end broken off. On one side there were hollowed out four rows of shallow depressions. The row best preserved contained 15 such hollows, each like the others, so that the brick reminds one of a playing board. Such or similar boards could also be used for the simplest arithmetical operations for which the small pebbles or beans found on the spot could well serve.

Some of the games popular in towns of the Indus Valley required the use of dice. The world's most ancient dice, unearthed during excavations there, are of baked clay or stone, cubic in form, and resemble those in use today, only much larger. Numbers ranging from one to six are indicated by little pits on each of their faces, this distinguishing them from present-day dice which require that the numbers on opposing faces should total seven. Another way of indicating the various faces consisted in the incising of different designs or hieroglyphics on each face, their significance still remaining unknown.

Stone weights made of highly polished shale were in wide use, most of them in the shape of cubes. Such weights ranged from the smallest to comparatively big ones with a maximum mass of 274,938 grammes. The next most widespread type of weights was globe-shaped with flat tops and bottoms, some of them fairly big in size. The third type, barrel-shaped, resemble weights found in Egypt, Sumer and Elam. Some of the heavier weights, one of which tipping the scales at 11 kilogrammes, is conical, with a hole bored through the top for a metal or thong ring for handling.

Research has shown that the unit of weight was .8565 grammes, the system of weights being based on the doubling of small units and on multiplication by 10 or 100 for larger weights, and the following proportions being observed: 1/3; 1; 2; 4; 8; 16; 32; 64; 160; 200; 320; 640;

1,600; 3,200; 6,400; 8,000; 12,800.

The system of weights used in ancient India had no features common with the Babylonian, both systems being regarded as quite independent.

The few scales found pertain to the usual system and consist of a bronze beam with copper pans. Scales with heavier beams had to be used for heavier masses. There is no evidence to show that the inhabitants of Mohenjo-Daro and Harappa had any knowledge of the steelyard.

A unit of length then in use—5.7 cm—is often to be met in the bricks that buildings were made of. All the bricks were strictly proportional, the face ratios being 1:2:4 or 1:3:9. The actual sizes range from 5.7x12.7x26 centimetres to 5.7x21.6x52 centimetres. When unbaked bricks were used they were larger in size than baked bricks, their dimensions ranging from 7.8x18.2x38 centimetres to 9x18.7x 35.3 centimetres. The 5.7-centimetre unit of length also denoted the step height in one of the wealthy houses.

Bricks of other shapes were used for special purposes. Thus, wedge-shaped bricks were used to line water wells. Ordinary bricks were often broken into smaller sizes— 5x11x24.2 cm for floors. Several columns of baked bricks were discovered, which supported roofs, among them a tapering pillar .28 sq metres at the bottom and .21 sq metres at the top. The other pillars were right-angled parallelepipeds with square or oblong bases.

While Sumerian excavations show that the round column was in common use in local architecture, it was unknown in architecture of the Indus civilisation, whose members were already conducting trade with Sumer in those ancient times. The wedge-shaped bricks used to line water wells could well have been employed in the construction of round columns. Incidentally, columns could have been built of limestone rings surrounding wooden pillars. Thus, stone rings with diameters between 42 and 48.5 centimetres and with heights

ranging from 25 to 28.4 centimetres have been found at Mohenjo-Daro. The small notches on them, probably their numeration, indicate the presence of two sets of rings, such numbers confirming the surmise that such rings were originally part of two columns used to support the portico of some buildings.

In speaking of the geometrical concepts of the ancient Indians, one should note that, from the very outset, the towns in the Indus Valley were planned according to a previously chosen geometrical scheme whose nature can be more easily understood from material provided by Mohenjo-Daro, which is in a better state of preservation than Harappa. At Mohenjo-Daro the streets follow parallel lines intercepting at right angles. The city itself was situated on a territory reminiscent of a trapezium, three angles of which can be fairly distinctly made out. This regular form of the city plan would suggest the existence of city walls.

Excavations have revealed a large number of various artifacts of regular geometrical shape, for instance, various metal cones and semi-spherical articles used for adornment. Among the utensils found is a cylindrical vessel. Two amulet seals found are also cylindrical in shape, though such artifacts are mostly either square or oblong. Small metal cones unearthed belonged to buried treasures at Mohenjo-Daro and Harappa. With an average height of six centimetres and a diametre of five centimetres, these cones are of gold, silver, copper or faience. The original hollow artifacts of semi-spherical or conic shape and made of two, three or even four pieces of shell were probably also used for adornment.

The ornamentation on ceramic artifacts was of abstract geometrical shape: it is to be found partly on ceramic artifacts in other countries of the ancient world and is partly peculiar to the Indus Valley. The most widespread ornament consists of circles superimposed on each other, a design that is not met on utensils of other ancient

cultures. In cases when squares were first imposed on the utensil for a correct design, the circles have been more carefully drawn. A widespread form of ornamentation reminds one of a large comb, to be met together with a solar disc and other emblems that are hard to determine. Another widespread design consisted of a black-and-red checker-board; triangular designs are in 1, 2, and, more rarely, 3 rows forming an attractive pattern. Hatching was widely used to separate triangles, squares or other motifs from each other.

A special instrument like present-day compasses seems to have been used to describe circles, while the construction of several similar geometrical patterns also called for the use of a special measuring instrument. The preparation of articles similar in form but differing in size also required a knowledge of principles of similarity, i.e., elementary, mostly empirical, data on the centre of similarity and the factor of proportionality.

Many elements of geometrical ornamentation were imposed on the inner (concave) or outer (convex) sides of vessels, this requiring a knowledge of projection.

A large number of weapons such as axes and pole-axes have come down to us as excellent models of axial symmetry in all three dimensions—in length, breadth and height. Examples of strictly axial symmetry are also provided by a number of artifacts made out of shell and evidently used for adornment.

In a number of cases, construction was impossible without a preliminary drawing which was later transferred to the shell used, this also requiring some idea of similarity and projection.

In their geometrical constructions, the ancient Indians had to solve a number of geometrical problems of construction and transformation: straight, curved, closed and broken lines; the construction of right angles and perpen-

diculars, as well as of squares, oblongs, circles and polygons; then there was also the construction of cubes and parallelepipeds; the division of a length into halves and equal parts, the division of a circle into halves; the division of a circle into four equal parts; the division of a sphere into halves; the construction of sectors and segments in a circle; the construction of concentric circles and parallel lines.

We do not know how such constructions were performed in most cases, since we possess only the final results. There are, however, some cases in which we can also judge of the methods used. Thus, to draw a line parallel to two given parallel straight lines, the ancient mathematician described parts of concentric and equidistant circles between the given parallel lines, for which he had to use, on the one hand, compasses and on the other, an instrument for the measurement of equal segments. Then he would draw a third line through the middle of these arcs, passing at equal distances between the two parallel straight lines, thus becoming parallel to them.

Construction on the spot called for the use of special instruments to draw straight lines, describe right, vertical and adjacent angles, and their measurement as well as the determination of distances between definite objects.

Many practical tasks called for a knowledge of the area and volume of the basic geometrical figures, though we do not know how they were calculated.

Amulet seals which, judging by the number of finds, were universally worn, are a supreme artistic achievement. Made invariably out of soapstone, such amulets vary from 3.2 to 16 sq centimetres, the most common dimensions being between 4.5 and 7.7 sq centimetres. There are two basic types of seals: square in shape with various depictions of animals and with inscriptions and, secondly, oblong in shape with a single inscription. The square-shaped amulets

have a small projection at the back with an orifice for a thong; the oblong-shaped amulets had a raised shape running vertically along the back, which is pierced from top to bottom.

Of considerable interest are the inscriptions on the seals, which have not yet been deciphered: the writing employed by the inhabitants of the Indus Valley consisted of syllabic symbols with ideograms and possibly also with determinants. Successful deciphering of this writing depends on the finding of bilingual inscriptions or at least several inscriptions of greater length than those at present in our possession.

Many features link the Indus civilisation with the ancient cultures of Egypt and Babylon which is why all three were confronted by similar mathematical problems stemming from the need for calculations in the constructions of palaces, temples, dwelling houses, granaries and fortifications, as well as in land surveying, the distribution of materials and products, trade, and navigation. We do not know how the Indus inhabitants coped with these tasks, but they did probably so in the same manner as the ancient Egyptians and Babylonians.

It may be confidently said that our information on the ancient Indians' knowledge of the natural sciences will be greatly expanded following the deciphering of the texts in our possession.

THE INTERACTION BETWEEN SCIENCE AND THE ECONOMY

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The development of the economy in the 20th century has in ever greater degree been determined by progress in science and technology. In its turn, scientific and technological progress has been fostered by the needs of the economy. Considerable interest in this respect is presented by the experience of economic development in the USSR.

The new social system that came into being in Russia in October 1917 ensured favourable conditions for the development of all branches of the economy, science and culture. Pre-revolutionary Russia's share of world industrial output was a little over four percent; today the Soviet Union, whose population is only six percent of the world total, accounts for twenty percent of the world's industrial output. The USSR tops all other countries in the extraction of oil, coal, and iron ores, iron and steel smelting, and production of tractors, electric locomotives, cement, mineral fertilisers, cotton, woollen fabrics, animal fats and a number of other products.

Sixty years ago, three-quarters of Russia's inhabitants were unlettered; today the USSR is a country with a high level of culture and 100 per cent literacy. About 77 per cent of the country's work force have gone through higher and secondary schools. Almost two million students are annually graduated from our higher and secondary specialised schools, this makes it possible to fully meet the country's need for fully trained experts.

There were only 298 science institutions in pre-revolutionary Russia, in the main small observatories, experimental stations and laboratories at higher schools. Today, over 5,300 science institutions and higher schools are operating in the USSR, their science personnel totalling over 1,200,000. State expenditures on the development of science are constantly rising: they totalled 300 million roubles in 1940; 6,900 million—in 1965; 17,500 million roubles—in 1975.

The rapid growth of the Soviet economy has resulted from the extensive organisational work of the Communist party and the Soviet state, and the efforts of millions of factory workers, peasants, and brain workers. Science and technology have also played a major part in the country's progress.

The Soviet Union has every reason to be proud of its scientists, who have blazed trails in space travel, won priority in the peaceful use of atomic energy, built unique equipment for the power industry, iron and steel production and machine building, and are successfully solving many important economic problems. Soviet science stands in the fore in a number of areas of world science; it is one of the major productive forces of the developed socialist society established in the USSR.

Lenin, the founder of the Soviet state, displayed constant concern for the development of science and the active involvement of scientists in the accomplishment of the urgent tasks confronting the development of the economy. In the "Draft Plan of Scientific and Technical Work", which he wrote in April 1918, Lenin mapped out a programme of the reconstruction of the entire economy on the foundation of the rational distribution of industry and the extensive utilisation of scientific achievements, with a major role given to the Academy of Sciences in dealing with the most complex problem of the country's development, that of the

possibility "to provide itself independently with all the chief items of raw materials".[1] The efforts of scientists were directed towards laying down the material foundation of industrial development, the surveying and exploitation of natural resources, the extensive use of electric energy and the efficacious utilisation of various kinds of fuel.

This programme met with a warm reception from scientists. Already in the first years of Soviet power, work began on a study of the Kursk Magnetic Anomaly (today a major source of iron ore in the USSR); utilisation of the chemical raw materials in the Kara Bogaz Gol Bay in the Caspian Sea; study of ways of obtaining radium from native ores, as well as of the Solikamsk potassium deposits and the apatite ores of the Kolsk Peninsula. It was in the first years of the Soviets that a network of important research institutes was set up, which was to become the foundation for the development of Soviet science and technology. In the years 1918-1919 alone, 33 major science institutes were organised, including the Optical and Physico-technical institutes in Petrograd (the Leningrad of today), the Central Aerohydrodynamics Institute (TsAGI) and the Institute of Physical Chemistry in Moscow, and a big Radio Laboratory in Nizhni-Novgorod (now Gorky).

It would be hard to overestimate the part played by scientists in the work done by the State Commission for the Electrification of Russia, which in 1920 drew up the GOELRO Plan, the country's first unified long-term plan of economic development on the basis of its electrification. Over two hundred leading experts in science and technology took part in drawing up the GOELRO Plan which was calculated for a period of ten to fifteen years, though it was fulfilled ahead of schedule. Beginning with the late twenties, the Soviet Union set about planning the development of the economy, science and culture in accordance with five-year plans, in whose drawing up and implementation Soviet scientists have played a most active part.

By special decree of the Soviet Government adopted in July 1925, the Academy of Sciences (now designated as the Academy of Sciences of the USSR) was recognised as the supreme scientific body in the Soviet State. To it was entrusted the highly responsible duty of uniting all the scientific forces of the country. In the late 1920s and early 1930s, the make-up of the Academy was supplemented by dozens of prominent figures in various branches of science and technology. All these measures helped to direct the Academy's activities towards careful planning of scientific research and its maximum approximation towards meeting the practical needs of the economy.

The Soviet Union was entering into a period of industrialisation at the time, the pressing need being to reorganise, within the shortest possible time limits, the country's economy on the basis of the development of a heavy industry capable of ensuring rapid progress in all the other branches of the economy. Construction was begun of new electric power stations, mines and factories, and new branches of industry came into being. Special attention was paid to the search for new sources of raw materials, and a rational system of geographical district division was introduced. Hundreds of geological expeditions were organised to study the natural wealth of the Urals and Siberia, the Volga Area and the Far East, Transcaucasia, Central Asia and Kazakhstan. Scientific bases were set up in all the Union and Autonomous Soviet Republics, soon to become branches of the USSR Academy of Sciences and providing the foundation for the subsequent organisation of Academies of Sciences in the Union Soviet Republics, and major science centres in a number of regions and territories.

Soviet science had become an important creative force in the years preceding the Second World War, scientists working on ever more large-scale scientific problems serving the practical needs of the economy. The natural wealth of the country's outlying areas was studied, industrial

centres were set up in the Volga Area, the Urals and Central Asia, the task of electrification was tackled in a big way, a scientific foundation was laid down for the further development of aerodynamics and rocketry, research was conducted to boost the productivity of agriculture, and so on and so forth.

Nazi Germany's attack on the Soviet Union in June 1941 confronted the Soviet people, including our scientists, with the task of the fullest possible mobilisation of all forces to curb the enemy, hurl him back and organise his defeat. The complex and responsible problems confronting science already in the early period of the war were of a complex nature as a rule, the most important scientific research being carried out by the united efforts of big scientific collectives often consisting of thousands of scientists and other experts. In those conditions, the best form of science organisation was presented by what were known as complex commissions, which not only worked on particular major scientific problems but rapidly ensured that the results of their research were given practical industrial implementation.

Already in August 1941, a commission was set up to mobilise the resources of the Urals for war needs, its activities soon involving Western Siberia and Kazakhstan. A similar commission of the Academy of Sciences was organised for the rapid mobilisation of the resources of the Central Volga Area and the basin of the Kama River. Other commissions were also set up to work on problems of physics, biology and medicine, their efforts being directed to the production of new types of military material, finding new sources of raw materials for industrial needs, new food resources for the population, and new medicaments and treatment methods for the sick and wounded.

The links between science and industry developed apace and grew ever stronger during the war, with the eco-

nomy constantly setting science ever new tasks. The work of research institutes, designing offices and higher schools became an important component of the efforts of the entire people for the early achievement of victory. The supply of strategic raw materials, the construction of advanced war materiel and work on highly productive industrial methods —all these resulted from the joint efforts of scientists and those working in the national economy, efforts which brought nearer the victory over fascism.

However, work on fundamental science was not discontinued even in the severe years of war. Theoretical work was carried on intensively to ensure an ever more rapid rate of development of science and technology after the war. Research into nuclear physics was resumed early in 1943, the study of the atomic nucleus and of the practical utilisation of atomic energy being the focus of the efforts of many science indtitutions. In 1946, the Soviet Union's first atomic reactor was launched, soon to be followed by the atomic bomb, this exerting a healthy influence on the world situation and ensuring conditions for the peaceful development of the USSR.

During the war years, much progress was made in dealing with many other important problems of science and technology. In 1944, the phenomenon of paramagnetic resonance was discovered, which laid the foundation for research into the structure of solids, liquids,and molecules, and provided the guidelines for magnetic-radio-spectroscopy, an important department of present-day physics. In the concluding years of the war, Soviet scientists evolved a new principle of accelerating elementary particles, thus making it possible to boost many times over the energy in a cyclotrone. Major successes were scored in research in other areas of fundamental science, this making it possible, even in the war years, to prepare the ground for the impending creation of nuclear power engineering, rocket and space equipment, electronics, present-day automation, semi-con-

ductor production,the production of new chemicals and other advances in science and technology in the second half of the 20th century.

With the victory over fascism ensuring peaceful creative work for the peoples of the USSR, our country set about intensively developing the socialist economy. To science, which was ever more becoming one of society's productive forces and a most important instrument in achieving technological progress, was set the task of designing new highly productive machinery and equipment, and new and improved industrial and economic management methods.

At the same time, Soviet scientists devoted prime attention to the development of theoretical research, to progress in fundamental areas of knowledge, on which the country's higher scientific potential, its immediate future, hinged first and foremost. In the years since the war, interest in scientific progress has grown throughout the world, and the question has already been posed of the onset of a new era in the development of science, the scientific and technological revolution of today, which is called upon to restructure the entire economy on the basis of the latest achievements in science and technology.

Soviet science has always developed hand in hand with the economy the practical needs of the country. Today, scientific achievements, including fundamental discoveries by scientists, are being given practical application at an ever faster rate. The growth and the constant improvement in all branches of industry, agriculture, transport, electrical and other communications, as well as the various areas of human activities, are simply inconceivable without the immediate impact of science, which is now confronted by responsible tasks involving higher efficiency, the concentration of efforts and close attention on the part of scientists in the areas of the most important and promising trends of scientific and technological progress.

Particular importance attaches in this respect to the development of fundamental problems of science. "It is the progress of fundamental knowledge," A.Alexandrov, President of the USSR Academy of Sciences, has said, "which is changing viewpoints in science that may have seemed established once and for all, revealing new vistas in science and technology, radically changing production methods, leading to the appearance of new kinds of material and opening up prospects of the utilisation of completely new and often unexpected phenomena in areas wholly unrelated to the initial field of research."[2]

Soviet scientists have endeavoured to accelerate in every possible way the introduction of scientific achievements into the economy, and to ensure the rapid translation of scientific schemes into practical implementation. This has entailed better interaction between research institutes and industry, with better results being achieved whenever schemes under way at academic institutions are ensured the early participation of specialised science institutions or factories with a considerable part of the efforts involved, including industrial implementation, being carried on jointly.

A variety of forms of interaction between science and industry are being successfully developed in the Soviet Union, these including numerous scientific-industrial associations, which bring into a single system major industrial enterprises, research institutes and works laboratories. A system of business contacts between research institutes and higher schools on the one hand, and various branches of industry and individual factories on the other, is becoming widespread. Scientists and industrial managers conclude contracts on joint creative work, this enabling them to cope with concrete tasks of scientific and technological progress.

Soviet scientists are also working on a number of major problems affecting the entire counrty and possessing

great economic importance. The power industry is one such area, whose further development presents a considerable and manifold problem, including the prospecting and extraction of natural energy resources as well as the system of transformation of energy into the forms required. The structure of our fuel and power resources must be gradually improved. The production of atomic energy must be expanded, thus making it possible to save on non-renewable kinds of raw material, such as petroleum and natural gas, which should be used for purposes of chemical synthesis. It is highly probable that the end of the present century will see the utilisation, in energy production, of thermal nuclear sources, magneto-hydrodynamic generators, and new methods of conveying energy. Thermo-nuclear electric power stations will probably have capacities of no less than 10 million kilowatts. Implementation of this State programme will naturally call for the joint efforts of large research collectives. At the Academy of Sciences, for instance, economists, geologists, nuclear scientists and systems planning experts have been drawn into work on this problem.

A reasonable blending of scientific and technological progress and measures to protect the environment is a most important and world-wide problem of our times. The more rational exploitation of Nature is not only a highly important scientific, technological and economic problem but one involving society as a whole. Mankind today as well as future generations have a vital interest, not only in protecting Nature and making rational use of its resources, but also in improving it. That is why the Soviet Union is actively participating in all international measures for Nature protection, and is taking all steps to prevent progress in science and technology from becoming a source of dangerous pollution of water resources and the atmosphere, and the exhaustion of the soil.

In the conditions of the planned development of the USSR's economy, scientific and technological progress has

always gone hand in hand with the country's economic needs. State strategy in this area has been directed towards the dynamic and proportional development of industry, this being targeted towards a constant rise in the standard of living. The results of the development of science and technology are to be seen in all branches of the Soviet economy, coal production providing a good illustration. During the past five years, coal extraction has gone up by over 70 million tons, though 140,000 fewer underground workers go down to the coal face as against the total number five years ago. More efficient machinery and automatic systems which substantially reduce manual labour are being put into operation in industry and agriculture.

The use of up-to-date industrial equipment and production methods has been greatly speeded up by the rapid development of such leading branches of industry as electric power engineering, the atomic power, oil and gas industries, the chemical and petrochemical industries, machine-building and radioelectronics. In 1975 these branches accounted for 37 per cent of the aggregate industrial output, this percentage to rise to 41 by 1980.

In accordance with the decisions of the CPSU's 25th Congress, a long-term plan for the development of the economy up to the year 1990 is being drawn up in the Soviet Union. Preliminary calculations show that material and financial resources will double in the next fifteen years as against the preceding. This will ensure a considerable acceleration of scientific progress, economic advance and the solution of major social problems.

The past few years have seen the establishment of trends in the USSR's scientific, technological and economic progress, which are gradually moulding the character of the productive forces of the communist society of the future. According to Academician P.Fedoseyev, the well-known Soviet scientist, the following departments can be mentioned among such trends:

the creation of fully mechanised and automated production methods that will ensure a higher productive level of socialised labour, enhance its attractiveness and creativity, and make for a solution of environmental protection problems;

the restructuring of the fuel, power and raw-material basis of the economy through the utilisation of new materials and energy sources, and less dependence on limited natural resources of fuel and raw material;

the full industrialisation of agriculture as a result of its complete mechanisation, and effective control of biological processes;

the development of the industrial infra-structure on the basis of a unified system of transport and a unified automated communications network;

higher efficiency and quality of output and radical improvements in management, with the use of computers and automatic systems of the storage, processing and transmission of information.

In the sixty years since the October Revolution, development of the economy and science in the Soviet Union has been marked by close interaction between these two spheres of human activities with a constant growth of the role played by science in the economic process.

NOTES

[1] V.I.Lenin, Collected Works, Moscow, Vol.27, p.320.

[2] Pravda, March 5, 1976.

SCIENCE ORGANISATION IN THE USSR: PRINCIPLES AND FORMS

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In the Soviet Union, the tasks of science organisation and management are determined by the general fundamental, long-term goals of society in which full-scale socialism has now been established. Acceleration of scientific and technological progress is one of the main ways of attaining these goals. On that basis, the whole mechanism of science organisation and management is elaborated and developed to ensure planned and balanced development to meet the interests of society as a whole, and the objective laws governing the functioning of science itself. Social property in the means of production makes it possible to optimise the conditions necessary for the efficient development of science.

Just after the victory of the Great October Socialist Revolution, the Communist Party and the Soviet Government laid the foundations of the Soviet state's policy in the sphere of science in the light of the vital need to develop and use it in every possible way in the interests of broad masses of the working people. In his speech at the 3rd All-Russia Congress of Soviets in January 1918, Lenin said: "In the old days, human genius, the brain of man, created only to give some the benefits of technology and culture, and to deprive others of the bare necessities, education and development. From now on all the marvels of science and the gains of culture belong to the nations as a whole, and

never again will man's brain and human genius be used for oppression and exploitation."[1]

The young Soviet state got down to setting up the world's first system of planned and centralised organisation for directing scientific research, including the development of a state network of scientific institutions, their financing according to plan, coordination of their projects, trying in and integration of programmes for the development of science, technology and production, creating the most favourable conditions for scientific work, training the required specialists for the needs of scientific and technological progress, and developing international scientific and technical ties and exchange of scientific information.

Even in 1918, the first year of the Soviet power—a period of economic dislocation and armed intervention by the imperialist states, four times more money was allocated for science than by the tsarist government in 1917. Before the revolution, there were less than 300 scientific institutions (including institutions of higher learning) throughout the whole of Russia, but only from 1918 to 1923 the Soviet power set up 55 new scientific institutes, and within the following 17 years 2,359 scientific institutions were established.

Among those who took an active part in organising science in the young Soviet Republic was a group of outstanding scientists whose creative activity after the Great October Socialist Revolution was given the utmost support by the Communist Party and the Soviet Government. Among them were A.Karpinsky, President of the Academy of Sciences, N.Zhukovsky and S.Chaplygin, who first led the Central Aerohydrodynamics Institute set up in 1918, I.Pavlov, the founder of the Physiological Institute which was opened in 1925; N.Kurnakov, Director of the State Institute of Applied Chemistry set up in 1919; Ya.Samoilov, Director of

the Institute of Fertilisers set up in 1918; K.Timiryazev, V.Vernadsky, V.Komarov, N.Zelinsky, Y.Shokalsky, V.Bogoraz, I.Gubkin, A.Fersman and many others. At the same time, work was started to create the conditions for the massive training of skilled specialists to meet the rapidly growing requirements of socialist construction, including new personnel for science.

Like the whole of the national economy, science developed on the basis of integrated state plans, which many scientists helped to formulate. As early as April 1918, Lenin produced his "Draft Plan of Scientific and Technical Works", formulating the basic tasks and lines of development for science over a period of years ahead.

Let us note that Lenin formulated the principles of long-term and comprehensive planning of accelerated scientific and technological progress for a decade and more. A specimen of such planning was the State Plan for the Electrification of Russia, which was formulated under Lenin's guidance and involved the participation of 200 scientists and engineers, and which mapped out the development of the productive forces through the use of electricity, natural resources, new technology and advanced organisation of production.

In the Soviet period, these specific features of science organisation have been developed in every possible way. In brief, the main features of the present system of science organisation, planning and management are as follows.

The main lines of progress in science and the key tasks of its organisation are determined by the highest organs of the CPSU—its Congresses and its Central Committee. Thus, in March 1976, following extensive discussion across the country, the 25th Congress of the CPSU adopted the "Guidelines for the Development of the National Economy of the USSR for 1976-1980" with a section entitled

"Development of Science". It lays down the main lines for the development of social, natural and technical sciences and indicates the guidelines for improving science organisation. State administration of science development is exercised by the organs of legislative and executive power and by specialised administrative agencies. The highest organ of state power, the USSR Supreme Soviet, considers and approves, through legislative enactments plans for the economic development of the USSR and its state budget, of which the plans for developing and financing science and technology are a part. The two Chambers of the USSR Supreme Soviet have standing commissions for public education, science and culture, which take part in drafting laws and exercising control over the activity of state administrative agencies in the relevant fields.

Overall guidance of scientific and technical activity in the country is exercised by the USSR Council of Ministers, which directs the work of all the ministries and departments in developing science and technology and applying their achievements in the economy. The government approves economic development plans and plans for the financing of research, training of scientific personnel, and use of scientific and technical acievements in the economy, as a component part of the former. In exercising direction of scientific and technical development, the government makes use of a system of special intersectoral administrative agencies, among them the State Committee for Science and Technology, the Committee for Inventions and Discoveries, the State Standards Committee, and the Ministry of Higher and Specialised Secondary Education which directs the training of skilled personnel for various fields of science and for the economy as a whole.

The State Committee for Science and Technology, together with the State Planning Committee, the Academy of Sciences and some other departments, drafts the state plans

for scientific research projects, considers the development of network of scientific institutions, the coordination and financing of research and development, scientific and technical information, and international scientific and technical ties. It has extensive powers in checking up on the activity of scientific institutions, and may issue instructions to ministries to wind up unwarranted duplications or unpromising research and development, or conversely, to start work on new important programmes. The Chairman of the State Committee for Science and Technology is appointed by the USSR Supreme Soviet and is concurrently a Deputy Chairman of the USSR Council of Ministers.

The USSR Academy of Sciences is an important scientific institution, the centre of theoretical research and the coordinator of all scientific work. It has among its members the most outstanding scientists in the country. Administration within the Academy is organised on broad democratic principles. Its highest organ is the General Meeting of full and corresponding members of the Academy, which decides the chief internal organisational problems in the activity of the Academy, discusses the fundamental problems in the development of science, and elects the governing organ of the Academy, the Presidium, the President and the Vice Presidents of the Academy. Let us note that the outstanding scientists, Academicians V.Kirillin and A.Alexandrov, who head the State Committee for Science and Technology and the USSR Academy of Sciences, respectively, are also members of the CPSU Central Committee, the governing Party organ.

USSR ministries and departments pursue a coherent scientific and technical policy in the sectors of the economy of which they are in charge. Sectoral academies have been set up for some fields of science, like the USSR Academy of Medical Sciences, the All-Union Lenin Academy of Agricultural Sciences, and the Academy of Pedagogical Sciences, which are the highest and most authoritative institutions in their fields.

The state organs of the Union Republics have competence in dealing with a broad range of problems in directing scientific and technical development in the institutions and enterprises of which they are in charge. The highest scientific institutions in the Union Republics—academies of sciences—are engaged in work on a broad spectrum of problems in the social, natural and technical sciences, with emphasis on those which are specially important for their particular Republics. Thus, in the Soviet Republics of Central Asia much research is being carried on into irrigation, cotton growing, desert studies, seismology, medicine, veterinary science, heliotechnology and many other problems.

The Soviet Union has made unprecedented advances in every field of social life, including the economy, science and culture. Suffice it to say that while pre-revolutionary Russia accounted for only 4 per cent of the world's industrial output, the USSR now accounts for 20 per cent of the world industrial production, and for an even greater percentage of the world's scientific potential.[2] In 1975, the Soviet scientific potential had the following parameters: it had 1,223,400 scientific workers (including lecturers and researchers at higher schools) or 48 per 10,000 of the population; 4,046,000 persons were engaged in science and scientific services, or nearly 4 per cent of the labour force in the economy; 5,327 scientific institutions; and its appropriations for science came to 17,400 million rubles, or 4.8 per cent of the national income. In addition, millions of inventors and rationalisers were working in various sectors of the economy.

Every year, 30,000-40,000 inventions are registered in the USSR, and nearly 4,000 new models of machines, equipment, apparatuses and instruments are developed, and thousands of sections, shops and production areas are comprehensively mechanised and automated. The efficiency of scientific and technological progress is strikingly expressed

in the fact that at least 75 per cent of the labour-productivity growth comes from rising technical standards in production. In other words, from 1951 to 1975, more than 5 per cent of the 6.7 per cent annual growth of labour productivity stemmed from the growing technical level of production, a most important factor of intensive development. Considering that from 1976 to 1980, 85-90 per cent of the national income growth is to come from rising labour productivity, the contribution to economic growth rate from technical progress will reach 65-67 per cent.

Science organisation and management have been changing with the development of Soviet society, the emergence of new tasks in economic and cultural construction and the progress of science itself. What are the main tendencies in this area today?

The 25th Congress of the CPSU emphasised that the ultimate task of our social revolution, construction of a communist society, can be fulfilled only through accelerated scientific and technical development. Accordingly, it is now especially important to consolidate the ties between science and life and the practice of communist construction. The introduction of new scientific ideas is now as important as their development. That is why together with the encouragement of the development of fundamental and applied sciences there is the most meaningful and responsible task of integrating science and production, which can be achieved through the joint efforts of scientists and those who work in production.

The following measures may be brought out among those which are now being put through in Soviet science organisation and management.

The importance of formulating and putting through large-scale comprehensive programmes, and the role of goal-oriented programme planning, which helps to make better concentration of the efforts and resources in the crucial

areas, tends sharply to increase. During the drafting of the economic plan for 1976-1980, more than 200 concrete programmes were drawn up for the solution of the key scientific and technical problems. For this purpose a set of projects has been approved, including provision of resources, tying in with plans of capital construction, production and supply In formulating its strategy of scientific exploration, the USSR Academy of Sciences has drawn up a plan for basic research for 1976-1980, providing for implementation and coordination of research for more than 500 major problems, grouped in 84 scientific lines.

Institutes of the USSR Academy of Sciences, together with the ministries and departments, have drafted the Comprehensive Programme of Scientific and Technological Progress and its socio-economic effects for 1976-1990. This programme is an organic component of current and long-term planning and provides the guidelines for successful management of science and the economy. It envisages not only the organisation and staging of research, but also its working up to the point of practical results. The main lines of scientific and technological progress which it lays down will provide the basis for coordinating research and development over a period of years ahead.

The Comprehensive Programme offers various alternatives of possible qualitative changes along the keylines of technical and technological development, models of enterprises and machines of the future, with a socio-economic assessment based on scientifically grounded criteria of quality and efficiency. Among these criteria are savings in manpower resources and improvement of working conditions, enhancement of the creative character and attractiveness of work. Among the criteria for assessing the planned new machinery is the effect it may have on the environment. Protection and improvement of the environment and considerate treatment of the resources used are a key scientific, technical and social problem.

In the process of planning ever more attention is being given to determining the optimal balance between long-term programmes yielding tangible and useful results only in a relatively remote future, and short-term programmes which should rapidly recoup investments and start making a contribution to boosting the national income right away. The right solution of this far from simple problem is important for the balanced development of basic and applied research and development.

Today, better facilities for research in the form of the latest types of automated laboratory equipment, more extensive use of computers for research, experimental and design work provide an important reserve for further raising the productivity and quality of scientific work. Among the characteristic features of modern scientific equipment is not only its high productivity, but also its high cost, something that is exemplified by elementary particles accelerators or space vehicles. This suggests that development of cooperation with other countries in designing and using unique scientific equipment may be promising.

Another substantial problem is rational conjunction of research and teaching at the institutions of higher learning, which have a large body of researchers and teachers in various fields. The USSR now has more than 850 institutions of higher learning, with nearly one-half of the country's doctors and candidates of science. The task is to involve this highly skilled personnel in a more active effort in research, especially basic research. From 1976 to 1980, Soviet higher schools are to graduate 9.6 million specialists with a higher and secondary specialised education, and it is a very important task that they should know how to carry on research and think on creative lines.

A most important task is broader development of diverse and efficient forms of interconnection between research institutions and industrial enterprises. Among the

progressive forms of their integration are production and science-production associations, whose main feature is closer integration of basic research, applied research, experimental engineering and production. There are now over 2,000 production associations which comprise design offices, and now and again also research institutes. From the standpoint of the perspectives of scientific and technological progress the greatest importance attaches to science-production associations, whose main element is research and designing establishments, the results of whose efforts are embodied in batch products. In many science-production associations, research and development outlays come to 25-50 per cent of the value of their product. The figures are roughly the same for the number of personnel employed in science in the total number of industrial and office workers.

The main goal of science-production associations is to develop the latest and highly productive types of hardware, to transfer these in fully finished form to other enterprises or production associations, and to help them to start batch production of these goods. That scientific achievements in the science-production associations are realised with efficiency will be seen very well from the fact that they have helped to reduce by 35-50 per cent the "research-production" period (that is, the time between the start of a project and the manufacture of the product). At the beginning of 1976, production and science-production associations accounted for 24 per cent of the USSR's industrial output, and the figure has been steadily growing.

The development of organisational forms for integrating science and production should increase the share of research and development projects applied in production, which now comes to about 50 per cent. Let us bear in mind that industry has a greater stake in turning out developed products, for the profitability of well-established products is something like 50 per cent higher, as compared

with new products. Improvement of planning and enhancement of the economic substantiation of scientific and technical projects and economic inducement for those who work in science and production in turning out new types of hardware help further to accelerate the rise of the technical level and efficiency of the whole of social production.

NOTES

1 V.I.Lenin, Collected Works, Moscow, Vol.26, pp.481-482.

2 According to the USSR Central Statistical Board, this country has a quarter of the world's scientific workers, the main component of any scientific potential. See USSR in Figures in 1975, Moscow, 1976 (in Russian).

A WORLD OF COGNISED MAGNITUDES

(Concerning the History of Colloid Chemistry)

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In 1914 Wolfgang Ostwald, the German physico-chemist, published a remarkable book, Die Welt der Vernachlässigten Dimensionen, devoted to colloid chemistry, a new science. Completing the book the author wrote: "In accordance with the historical development of natural science we are accustomed to consider the properties of all bodies either from the viewpoint of cognising mass matter or from the point of view of molecular and atomistic theories. Until recently we have been unaware that between matter in mass and matter in molecules there exists a whole world of remarkable phenomena. We have somewhat by-passed this intermediate kingdom. Only now we have come to know that every body acquires special properties and displays peculiar phenomena when its particles are bigger than molecules and yet are so small that they cannot be distinguished under a microscope. Only now we are clear as to the special significance of colloidal dimensions. A world of by-passed magnitudes—that is how we could call this intermediate kingdom of colloids".

These words were written at a time when colloid chemistry was just beginning to claim a right to a notable place among other sciences. The roots of colloid chemistry, however, could already be traced in the works of K.Scheele and

F.Fontana who had discovered gas adsorption with charcoal (1777), T.Lovets who observed the adsorption of substances from solutions (1785), F.Reus who was the first to report the phenomena of electrophoresis and electroosmosis (1808), R.Brown after whom the motion of microparticles in a vessel was named, A.Davydov who proposed the theory of capillary phenomena (1851). This branch of science is based on the ideas and discoveries from various fields of natural science, which were known as early as the 18th and the 19th century and belonged to Lomonosov, Faraday and other scientists. It is believed, however, that the beginning of colloid chemistry was laid in the works of T.Graham who was the first to describe the specifics of colloidal bodies (1861) which he opposed to crystalloids. Already in 1869, however, I.Borshchov gave arguments in favour of the fact that colloids consist of complex crystalline particles.

As ever new data were gradually accumulated the theories of colloidal particle structure and colloidal solution stability were being worked out. The formation of new ideas about the colloidal state of a substance was greatly influenced by D.Mendeleyev who pointed out the universal nature of this state, an idea which in our day is basic and generally recognised. The first three decades of the 20th century were an important stage in the development of colloid chemistry. M.Smoluchowski and A.Einstein worked out the molecular-kinetic theory of Brown's movement and diffusion in colloidal systems. Between 1907 and 1909 T.Svedberg and J.Perrin, while investigating gold sols and a gamboge suspension under an ultramicroscope, i.e., using the methods of colloid chemistry, experimentally corroborated Smoluchowski's and Einstein's quantitative theory which refuted the views of the supporters of Ostwald's energetic school, who was striving to substitute the concept of energy for that of matter.

That period saw the completion of the founding of classical colloid chemistry in its principal directions:

Smoluchowski's molecular-kinetic theory of colloidal system coagulation (1918), Chapman and Stern's electric double layer theory (1910–1924) and Langmuir's theory of molecular adsorption (1917) came into being.

In Russia this stage, especially in the first decade of the 20th century, was very fruitful. The chromatographic adsorption method of analysis proposed by M.Tsvet (1903) received world recognition. The quantitative dependence between the surface tension of solutions and their concentrations, which was found by B.Shishkovsky in 1908, had an important part to play in the further development of the present-day theory of adsorption. The question of the generally possible colloidal state of a substance was finally solved and the idea of the division of substances into colloids and crystalloids rejected (P.Veimarn, 1905–1910). In 1903 A.Dumansky began systematic research in the field of colloidal solutions with a view to determining the dimensions of colloidal particles, the properties of sols, their viscosity, electric conductivity, stabilisation and optical properties.

Colloid chemistry had become an independent science with its own objects and methods of research: appropriate monographs and textbooks were published, periodicals began to appear, a special course in this discipline was introduced in some universities. The outstanding scientists T.Svedberg, J.Perrin, R.Zsigmondy (1925–1926) and I.Langmuir (1932) became Nobel laureates for works on colloid chemistry and surface phenomena.

After the October Revolution scientific centres were set up in the USSR to study sol stability (N.Peskov) and the mechanism of coagulation processes (A.Rabinovich); there came into being the physico-chemistry of surface layers as a branch of colloid chemistry (A.Frumkin) and also independent trends dealing with lyophilic colloidal systems (S.Lipatov), the physico-chemistry of polymer systems (V.Kargin) and aerosols (I.Petryakov-Sokolov, N.Fuks). The elaboration

of adsorption theory (N.Shilov, M.Dubinin) exerted a marked influence on the development of colloid chemistry.

The 1930s-1960s were notable for the comprehensive study of the molecular mechanism of interfacial phenomena and processes in heterogeneous systems and for the elaboration of scientific principles of their control for practical purposes. There came the period of modern colloid chemistry which has finally become the physico-chemistry of disperse systems and surface phenomena. The term "colloid chemistry" continues in use only by tradition.

The main content of this discipline is linked with the study of such questions as the conditions of formation and the properties of disperse systems' particles stabilising interfacial layers and films, the physico-chemistry of contact interactions, aggregation and coagulation, and also a wide spectrum of problems relating to the formation of the structure and properties of disperse systems.

Modern colloid chemistry owes its origin to the highly fruitful effect of molecular physics, chemical kinetics, mechanics, the chemistry of inorganic substances and high-molecular compounds, crystallochemistry and other sciences. It also owes its appearance to the continuous differentiation of natural science, which is a steady tendency in the development of science.

In view of the fact that any organic and inorganic substance and biocolloids of animate nature can be in a disperse state, it is possible to say that colloid chemistry is the common physico-chemical basis of many individual sciences, including those studying living organisms, soils disperse minerals and rock, various other materials and the technologies of obtaining industrial suspensions, emulsions, surface-active substances, ceramics, metalloceramics, lubricants, composite materials and so on.

Consequently, the process of differentiation of this science due to an abundance of its objects of study—disperse

systems—and a variety of their properties which find extremely wide application in technology, nature and everyday life inevitably leads to the revelation of behaviour patterns common to disperse bodies and the elaboration of theories of their state and the scientific principles of control of their properties. This was the reason for the overall integration of colloid chemistry.

Both processes—the differentiation and integration of colloid chemistry—form a dialectical unity, for here one observes the interpenentration of various sciences whose theories and methods serve to disclose the physico-chemical nature of the molecular forces of surface disperse particles with a view to cognising the mechanism of their interaction with the dispersion medium and in the system as whole.

Owing to its universal character colloid chemistry greatly influences technological progress. This science takes an active part in transforming the productive forces, while the achievements in the theory of the physics and chemistry of colloids expand and deepen the knowledge of the laws underlying many natural phenomena.

The high theoretical and experimental level of this science made it possible to solve important problems, in particular, the problem of colloidal system stability,which is connected with the understanding of the attractive and repulsive forces acting between particles. Late in the 1930s B.Deryagin and L.Landau (USSR) and later Fervey and Overbek (Holland) developed the physical theory of colloidal system stability (now referred to as DLFO theory) which explained dispersion coagulation with electrolytes by taking account of long-range forces of a universal physical nature. The further experimental verification and more precise definition of DLFO theory had resulted in the generalisation of the theory of colloidal particle electric double layer (Martynov, Overbek, Frens and others), which takes account of the chemical specificity of ions that affects dispersion coagulation and colloidal system stability.

The development of the theory of electrosurface phenomena in our day has helped to work out the theoretical principles of many technological processes: formation of electrophoretic coatings, electric filtering of liquids from disperse impurities, improvement of the quality of fibre dyeing, intensification of the secondary methods of extracting oil by displacing it with water, thereby opening the way to a new electrotechnology.

Over the last thirty years an intense study has been made of the lyophilic nature of substances, which makes it possible to specify the existing ideas about the forms of bound water, to determine the thickness of hydrate layers, to show the role of the hydrogen link in the process of wetting, sorption, to establish the dependence between the lyophilic nature and dialectical properties of many disperse systems, closely to approach the quantitative assessment of the lyophilic property of substances and to create a harmonious theory describing the properties of bound water (A.Dumansky, P.Rebinder).

Along with this, in the field of the lyophilic nature of substances one observes a new trend related to the profound changes in the molecular nature of the surface of solid phases by way of adsorption or chemical "engrafting" of organic substances sharply differing in polarity. The discovery of the irreversible adsorption of polymermacromolecules on the surface of metal sols has resulted in the creation of new metallopolymer materials possessing valuable technical properties. The conversion of hydrophilic mineral systems and metal oxides into organophilic ones has provided ample opportunities for obtaining adsorbents, catalysts, structure-forming substances for glues, lubricants, lacquers, rubber fillers, stable drilling solutions, defectoscopic developers for surface control of mashines.

The emergence in the 1950s of physico-chemical mechanics, a new boundary field of science, is a striking example of

the dialectical unity of the two opposite processes: the differentiation and integration of sciences. This field has united the knowledge and methods of molecular physics, mechanics and colloid chemistry.

P.Rebinder (USSR), the founder of physico-chemical mechanics, saw the basic objective of this science in establishing regularities in obtaining various solid bodies with preset mechanical properties.

The theory dealing with the formation of the structure of such bodies is based on peculiar, clearly non-classical physico-chemical factors.

The elimination of structure defects with the subsequent strengthening of highly disperse but already defect-free particles by glueing, pressing, soldering and welding has proved to be a radical way of increasing the strength of materials. The way to strength lies through destruction. This way, however, is not the only one; it is supplemented with another one consisting in material strength control by changing the degree of supercooling in the process of crystallisation and by forming minute crystals of a definite size through the regulation of their intergrowth conditions (works of the Rebinder school).

Recent years have seen growing progress in the investigation of the forces of contact interactions between solid particles in a liquid medium. These problems are closely connected, on the one hand, with DLFO theory analysing the forces of interaction between particles and, on the other, with physico-chemical mechanics studying the rheological properties of disperse structures, their formation and destruction. Substantial successes have already been achieved in elaborating methods for assessing coagulation link energy and calculating the strength of disperse structures.

Physico-chemical mechanics is the bridge connecting various, previously isolated, fields of technology, namely, the field of classical colloid-disperse, so-called coagula-

tion, structures and the synthesis of non-classical crystal structures like metalloceramics, Pyroceram and so on.

As a result of its rapid development, physico-chemical mechanics has acquired great economic significance. Physico-chemical mechanics and colloid science provide the basis for a new scientific discipline, colloid-chemical materiology, which has as its task the development of the scientific principles of the process of obtaining and using new disperse materials possessing properties meeting the requirements of modern technology.

In the 1950s great progress was made in the colloid chemistry of polymers with well-developed supermolecular structures possessing the properties of a microheterogeneous two-phase system. Latexes for synthetic polymers, above all rubbers, may serve as an example of such systems. The basic principles and patterns have been developed for polymerisation in emulsions with the obtaining of latexes, as well as the scientific principles of latex technologies for processing polymers into articles. Many processes for obtaining polymers and articles based on them (reinforced plastics, filled polymers, coatings, glues and so on) are determined by the interfacial surface phenomena in the polymers.

Colloid chemistry is not only a system of knowledge. Being a universal and multi-subject science with an abundance of objects of study, it is constantly delving into the most complex phenomena and processes encountered in nature and in living matter, using its wide contacts with biochemistry, biophysics, molecular biology, electrophysiology and other biological sciences. We are on the threshold of founding biological colloid chemistry. Like chemistry as a whole it is rising to the level of the 4th conceptual system--evolutionary chemistry.[1]

The development of this branch of science will be connected with the studies of fundamental scientific problems, such as the study of biological membranes <u>in vivo</u> by

the colloid-chemical methods in cell suspensions, tissues and viruses, and of the biochemical activity of adsorbed microorganisms and enzymes; the cognition of the mechanism of biologically important processes in ionised biopolymers; the study of the structure of water in biological objects and of its role in metabolic processes and in the growth and aging of cells and viruses; the creation of the theory of biological structure self-assembly as a process controlled by surface forces; the study of contacts between cells and their mobility, and so on.

Already now there is need for a whole complex of investigations to be carried out in connection with the problem of the origin of life according to Oparin's theory and Bernal's hypothesis.

In 1951 John Bernal suggested that monomers had polymerised into polynucleotides not in a free state but being adsorbed on clays suspended in the water of costal zones and sand-banks. The task of the whole of natural science is to disclose the mechanism of all the three stages of chemical evolution: 1) the emergence of biomonomers from primordial gases; 2) the emergence of biopolymers from monomers and 3) the formation of supermolecular systems from polymers. The aim of colloid chemistry is direct experimental verification of this idea, especially the study of the second stage of chemical evolution, for micellas and solid surfaces play the role of activators in the formation of biopolymers. That is why the formation of polynucleotides from mononucleotides adsorbed on natural clayish minerals, their multiplication (replication) and further condensation may become the main line of research on the problem of the origin of life.

In our day the problem of environmental protection has assumed a global character. What worries the world is the ecological crisis caused by the violation of the interaction between man and nature. In the USSR real measures are being

taken to protect the environment, in view of which scientific principles are being worked out for the rational utilisation and protection of soils, mineral wealth, the vegetable and animal kingdoms, the air and waters; complex investigations of the ocean are being conducted on an ever wider scale. Colloid-chemical science is being used for the solution of such problems as the removal of mineral salts from industrial discharges, the purification of pit waters by means of electrodialysis, reverse osmosis, continuous ion exchange, dust combating in pits and industrial centres, adsorption purification of natural and industrial gases, electrofiltering of liquids, regeneration of waste oils, cleaning of the sea surface from oil films and so on. One fully agrees with Overbek, a major theoretician in the field of colloid chemistry, that one has to open one's eyes and turn one's attention to the ample possibilities colloid science has for environmental protection and pollution control.

Possessing a reliable arsenal of cognitive means, colloid chemistry today is making ever deeper thrusts into the essence of surface phenomena, expanding the study of disperse systems in nature and in technology, enriching natural science with new discoveries and helping to turn science into a direct productive force.

In the period of classical colloid chemistry researchers filled the gaps in the cognition of the properties of colloidal particles as a world of by-passed magnitudes, whereas in the period of modern colloid chemistry scientists are viewing a world of cognised magnitudes, while this science itself, being in a state of continuous development, is making ever new successes in disclosing the picture of the colloidal state of substances.

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[1] See V.Kuznetsov's article in this issue.

GROWTH OF KNOWLEDGE ABOUT THE EARTH'S HYDROSPHERE

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The problem of studying and rationally utilising water resources is acquiring increasing importance. The long study of natural waters by many branches of science has given rise to definite ideas about the quantity and state of the water in diverse reservoirs, of their circulation, their origin and balance in individual territories and bodies of water, and in the world as a whole, of the structure and physico-chemical properties of water. However considerable the results that have been achieved, many questions linked with the problem of water require deeper study.

Lately, among the publications devoted to this problem works are appearing on the history of the development of the ideas about the hydrosphere. Such works are still few in number and they are usually short and schematic or deal only with individual questions of the development of knowledge. It may be said that since the publication of Academician V.Vernadsky's fundamental work A History of Natural Waters (1933-1936), which showed, albeit in concise form, the development of views on many problems of the hydrosphere, no similar work has appeared in the USSR or any other country. The writing of a complete history of the development of ideas about the problem of water on our planet is a task that awaits its fulfilment. This article generalises the development of ideas on the basic problems of the hydro-

sphere, namely the history of questions such as the study of the Earth's hydrography and the determination of the quantity of water in different reservoirs; the elucidation of the origin of water, the formation of the hydrosphere and changes in the water mass in the course of geological time; the study of the water cycle on the Earth.

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The scientific and practical importance of profound knowledge of the hydrosphere, i.e., of the sphere of water on the Earth, is as obvious as the truth that there is no life without water and that the biosphere consists mainly of water.

The concept "hydrosphere" was introduced into literature in 1875 by E.Suess, who developed the fact of the existence of a single aquatic envelope, established in the course of round-the-world voyages, to the level of a scientific generalisation. In a broader sense the concept "hydrosphere" was used in 1910 by the English oceanographer John Murray, who in his work The Oceans distinguished the following "concentric spheres", which he called geospheres: the atmosphere, the hydrosphere, the biosphere, the lithosphere, the tectosphere and the centrosphere. According to Murray, the hydrosphere consists mostly of the waters of the ocean, and it includes also lakes and rivers. Part of this water may be in a solid or gaseous state, in the shape of ice, snow, hail and vapour. Water also penetrates deep into the stony crust of the Earth, where it hydrates minerals, and also comprises a considerable part of the biosphere.

Much attention was given to the question of the Earth's spheres by V.Vernadsky. He called the World Ocean the hydrosphere. However, he repeatedly stressed that the hydrosphere was inseparable from other spheres and, proceeding from the unity of all of the planet's waters, developed, in addition to the concept of the hydrosphere in the sense of the World

Ocean, also the theory that the planet has a single aquatic envelope consisting of five separate water jackets: liquid, gaseous, solid, capillary and ionic. He held that the lower boundary of the liquid aquatic envelope lay at a depth of 10 kilometres in the ocean and 6-8 kilometres (possibly 13.5 kilometres) on land, while the upper boundary ran at an altitude of 15, at the most 20, kilometres. He wrote that water vapours were the only form of water characteristic for the entire Earth's crust.[1] He considered that the lower limit of water vapours was the boundary of the Earth's crust, 60 kilometres, where water, as other substances, is in a state that does not fit into the concepts of liquid, solid and gaseous bodies. Without touching upon the question of the phase states of water at great depths and its links with minerals, we shall only note that today many researchers are inclined to agree that the liquid state of water is predominant throughout the entire thickness of the Earth's crust.

Vernadsky was less emphatic about the upper boundary of water vapours. While allowing for the possibility of its penetrating into the rarefied atmosphere, and from there into outer space (as from it into the atmosphere), he wrote that it is almost unquestionable that there is water beyond the troposphere—in the stratosphere—and, very possibly even farther, in the ionosphere. The so-called silvery clouds, at a height of over 80 kilometres, are possibly accumulations of water, perhaps of liquid water.

The question of whether water vapours penetrate far into the stratosphere is debatable. Many researchers consider that at a height of over 15 kilometres the stratosphere is dry. However, the rocket experiments conducted during the past few years in the stratosphere have brought to light complexes of $(H_2O)_n$ and $(H_2O)H^+$ (the latter have also been discovered in the mezosphere). G.Martynkevich (1969) writes that a comparison of the results of rocket probes with the data of soundings and of aircraft and aero-

static measurements of humidity permits bringing serious arguments against the theory that the upper stratosphere is dry.

Although the question of the height reached by water vapours requires further study, it is nonetheless evident that the upper boundary of the hydrosphere may be determined at approximately the height of the tropopause (8-17 kilometres), having in mind that, as G.Yuri (1959) maintains, at present the water below the tropopause does not disintegrate photochemically.

In writing of the Earth's aquatic envelope, Vernadsky noted that whatever its state—liquid, solid (and filmy) or gaseous, all of the planet's water, including the entire World Ocean, is an integral continuous whole, filled with gas and, as a sponge, embracing the entire land area, the hydrosphere and the troposphere, forming a single aquatic envelope of the planet.[2]

Let us refer to some other definitions of the hydrosphere. In the first edition of the Great Soviet Encyclopedia the hydrosphere is defined as an "aquatic envelope of the Earth" (Vol.16) without specification. According to the second edition, the hydrosphere is a "broken aquatic envelope of the Earth situated between the atmosphere and the Earth's solid crust and representing the totality of oceans, seas and continental water basins" (Vol.11). Further, in the hydrosphere are included continental icefields, rivers, swamps, and lakes, but subterranean waters and the water vapours of the atmosphere are left outside it. In the Soviet Encyclopedia's third edition A.Sokolov defines the hydrosphere more narrowly, excluding not only subterranean waters and water vapours but also glaciers (Vol.6). According to the Encyclopaedia Britannica (Vol.11, 1965, p.975) the hydrosphere is "the whole mass of oceanic waters filling the major depressions in the Earth's crust, and covering about 72 per cent of its surface".

The noted hydrogeologist F.Savarensky (1935) suggested dividing the hydrosphere into a surface and an underground hydrosphere, i.e., alongside surface waters he included subterranean waters. The definition given by A.Ovchinnikov (1970) agrees with this understanding of the hydrosphere. According to him, the hydrosphere embraces oceans, seas, lakes, swamps, rivers, streams, subterranean and subsoil waters, and also the water in minerals and rocks. According to this definition, glaciers and atmospheric moisture, the most mobile and active part of the water element, are for some reason not included in the composition of the hydrosphere. Further, it must be noted that although the definition covers the water in minerals and rocks, it has in mind only liquid water that is not part of the molecules of solid substances.

According to S.Kalesnik (1970), the hydrosphere covers all chemically unbound waters on the Earth's surface in a liquid or a solid aggregate state. This definition does not include subterranean waters.

A.Chebotarev (1964) calls the hydrosphere the broken water envelope of the globe situated on the surface and in the thick of the Earth's crust and representing the totality of oceans, seas and water bodies on land (rivers, lakes, subterranean waters), including the accumulations of water in a solid phase (snow, glaciers). Like A.Ovchinnikov and S.Kalesnik, he does not mention the moisture of the atmosphere, but includes glaciers and subterranean waters in the hydrosphere.

G.Kalinin (1968) and M.Lvovich (1970) consider that the hydrosphere consists of the following parts: the World Ocean, subterranean waters, glaciers, lakes, subsoil waters, channel waters and the moisture of the atmosphere. In assessing the volume of subterranean waters they limit them to free gravitational waters which are not bound chemically or physically with minerals (to a depth of 5 kilometres),

in other words, subterranean waters are accepted as they are understood by F.Savarensky.

E.Gavrilenko and V.Derpgoltz, authors of The Earth's Depth Hydrosphere (1971) consider that the question of the boundary of the Earth's hydrosphere must be replied in the negative because it is not possible to establish distinctly either the upper or the lower boundary. In an earlier work (1963) V.Derpgoltz defined the hydrosphere as a solid belt encircling our planet, the lower boudary of which is close to the zone of the Mohorovičič layer, while the upper boundary gradually disappears in the upper atmosphere. A.Alpatyev (1969) notes that to this definition of the hydrosphere it would be hard to add anything less debatable. We likewise feel that this definition of the boundaries of the hydrosphere, evidently coinciding with the boundaries of the water envelope, the concept of which had been developed by V.Vernadsky, is the only scientifically correct one.

As Vernadsky pointed out, in the deep parts of the Earth's crust, namely in the region of the lower boundary of the broadly interpreted hydrosphere, there must be a process of the synthesis and destruction of the molecules of water. As regards the upper boundary of the hydrosphere, it evidently lies, as we have noted, at the height of the tropopause.

In the light of the foregoing, the hydrosphere in the broad sense of the word must be taken to mean the entire envelope of the Earth extending down to the upper mantle, where under conditions of high temperatures and pressures, the disintegration of the molecules of water is accompanied by their continuous synthesis, and up approximately to the height of the tropopause, above which the molecules of water are subjected to photodissociation.

But we consider that it is also correct and expedient to use the term "hydrosphere" in a narrower sense, namely, in the sense it is used by the above-mentioned hydrologists

G.Kalinin, M.Lvovich and A.Chebotarev, who include in the hydrosphere only the subterranean waters of the upper tier of the Earth's crust, i.e., liquid-drop water that can move in rock and flows out and is extracted from them. It would evidently be wrong to confine the hydrosphere to the World Ocean.

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As for the quantity of water in various parts of the hydrosphere and its total in the world, we shall limit ourselves to the briefest data from the history of these computations.

Although the round-the-world voyages of the 16th century left no doubt that the predominant view, shared also by Christopher Columbus, that there was more land than sea was wrong, up to the very end of the 18th century it was believed that the ratio between land and sea was 1:1 (the actual ratio being 1:2.43).

On this basis and accepting arbitrary magnitudes of the average depth of the ocean, the first computations of the quantity of ocean water in the world were made in the mid-17th century. Figures for the quantity of water in the ocean close to the actual magnitude could appear only after the voyage of the Challenger in 1872-1876, which brought a mass of data on ocean depth.

According to a computation made by the Department of Cartography of Leningrad University, it is estimated that the volume of water in the World Ocean is equal to 1,338 million cubic kilometres.

Bernhard Varen was interested in the question of the total quantity of subterranean waters, writing of this in his Geographia Generalis (1650); two hundred years later Georges Buffon asserted that the quantity of subterranean waters was very small. The first ever known attempt to es-

timate the volume of subterranean waters was evidently made by the French hydrogeologist Achille Delesse, who in 1861 computed that there was 1,175,085,000 cubic kilometres of water in the Earth's crust down to a depth of 18.5 kilometres. He acted on the view, still held to this day, that although at the depth the temperature of water is 50 per cent above critical, the super-critical pressure does not allow the water to turn into the vapour phase. Computations by other scientists were made later.

The quantity of subterranean waters estimated by various researchers, whether in the Earth's crust as a whole or in its definite layers, differ considerably. The volume given by Vernadsky ($1,400 \times 10^{15} m^3$) is much larger than the estimates of other scientists, with the exception of the obviously indefinite assessment made of the mass of subterranean waters by A.Poldervaart—$(400-1,300) \times 10^{15} m^3$. But Vernadsky had in mind not pure water but a solution containing more than 40 per cent saline residue at great depths.

The question of the quantity of fresh water is important. Poldervaart regards as fresh all liquid waters in the sedimentary layer of land, where, according to his estimates, they total 22×10^6 cubic kilometres. In the journal Courier UNESCO, July-August 1964, devoted to the problem of water and human life, the French scientist M.Battisse offered the opinion that there is much more fresh water under ground than on the surface. In the same issue, L.Leopold, a leading American expert on subterranean waters, referred to data by R.Nace on the quantity of water in an 800-metre layer of the Earth's crust and noted that compared with this the reserves of water that could be accumulated with the aid of river dams are insignificantly small. In the journal it was pointed out that the volume of liquid fresh water on the Earth amounts to nearly one-third of the total, while more than two-thirds of it is in the form of ice. In short, in the opinion of some researchers the quantity of subterranean fresh waters amounts to several (up to ten) million cubic

kilometres. However, in view of the absence of convincing proof, there are more modest estimates of the reserves of subterranean fresh waters. For instance, the French scientists R.Furon (1966) believes that the figure 500,000 cubic kilometres, given for the volume of fresh water in rivers, lakes and water-bearing strata is much too optimistic.

The highly differing estimates of the volume of subterranean waters evidence that the amount of reliable data that could permit drawing these estimates closer together is still inadequate. The computation of the actual reserves of subterranean waters, particularly fresh water, remains a task that can only be accomplished by planned collective effort.

Space does not permit giving here even the main data on the history of calculating the volume of water in rivers, lakes, swamps, the soil, living organisms, glaciers and the atmosphere. But if the quantitative data on various kinds of natural water that may be considered as the most substantiated are to be given in a table, the latter will be as follows.

Parts of the hydrosphere	Volume, '000 km^3	Intensity of circulation, years
World Ocean	1,338,000	3,000
Subterranean waters of the entire lithosphere	800,000	-
of which, free gravitational waters up to a depth of 5 kilometres	60,000	5,000
Cryosphere	25,000	9,600
Lakes	500	20
Rivers	2	0.055
Soil	80	1
Atmosphere	14	0.027

At present only the data on the volume of water in the World Ocean and the atmosphere may be regarded as trustworthy.

Lastly, we shall note the attempts to determine the quantity of water in the planet as a whole, and particularly in its mantle. Bearing in mind the decrease of the content of water with depth, P.Chirvinsky (1922) and V.Zalomon (1924) estimated that in the former its weight is 3×10^{-4} per cent and in the latter—2×10^{-2} per cent.

The water in the hydrosphere, like the substance of the lithosphere itself, came from the mantle. If it is considered that the mantle, which is 2,900 kilometres thick and 900,000 million cubic kilometres in volume, has a water content of up to 0.5 per cent, as in stone meteorites, then it contains at least 13,000-15,000 million cubic kilometres of water, i.e., ten times its volume in the World Ocean. But there are still higher estimates of the quantity of water in the mantle. According to J.Kulp (1951), for instance, the mantle contained 2.5×10^{25} g of water, of which 14 per cent went into the Earth's crust, on the Earth's surface and into outer space. A.Vinogradov (1959) estimates the quantity of water in the mantle at 2×10^{25} g (including 7.5 per cent discharged water).

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The question of the origin and sources of water on the Earth is touched upon in every cosmogonic legend and hypothesis, but its solution on a scientific basis has only become possible in the 20th century. At the very beginning of our century doubt was cast on the theory that most of the water of oceans formed simultaneously as a result of the condensation of water vapours of the primary dense atmosphere and the precipitation of water on the cooled surface of the Earth.

Increasing recognition was won by the view that the bulk of the water in the ocean came from water vapours rising from the depths of the Earth over a long geological time. This view received strong backing, especially when the theory of the Earth's formation from substances that were in a molten state from the very beginning or were gradually heated to a liquid state was superseded by the theory of the Earth's formation from cold solid material that had never been greatly heated in the upper layer of the Earth or melted only locally, in deep hearths, mainly as a result of the action of radiogenic heat.

However, even with the acceptance of the hypothesis of the Earth's initial total melting it was found that only a small portion of the water of the hydrosphere could have been formed through the condensation of atmospheric vapours, and that most of it had accumulated as a result of its emergence to the surface from the magma. The degasation of water from the depths of the Earth's crust and mantle has been convincingly demonstrated by the method of geochemical balances and confirmed by experiments with zonal melting.

The question of the law underlying the formation of the hydrosphere in time—whether it proceeded evenly and continues to this day or whether it ended in remote times—remains debatable. But Vernadsky's theory of the hydrosphere's ancient origin, a theory accepted by almost all scientists, must evidently be recognised as having been unshaken.

Most researchers agree that the income and expenditure of water in the biosphere, insignificant as they are, are now balanced and that consequently, the total quantity of water on the Earth has remained relatively unchanged, possibly since archaean times. The criticism levelled by some researchers at Vernadsky's proposition that the mass of the water is a characteristic constant of our planet as being at variance with the general theory of development in nature

cannot be regarded as justified. And here is why. Recognition of the relative constancy of the planet's water mass does not conflict with the dialectical principle of development in the same way as that principle is not violated by the recognition of the existence of many other constants of the Earth's nature.

The hydrosphere, which we have considered in a stationary state, is actually an extremely dynamic system with innumerable water cycles, physical conversions and chemical reactions. This results in the unity of the Earth's waters, which was always emphasised by Vernadsky and other scientists and was clearly shown in the 1920s by V.Glushkov's detailed diagram of the water cycle.

Due to its various cycles, water—that simple substance which has many extraordinary properties—plays such a great role in natural processes that Vernadsky could say: "The picture of visible nature is determined by water."

NOTES

[1] V.Vernadsky, Selected Works, Vol.IV, Book 2, Moscow, 1960, p. 38 (in Russian).

[2] V.Vernadsky, Chemical Structure of the Earth's Biosphere and Its Environment, Moscow, 1965, p. 223 (in Russian).

RESEARCH INTO THE HISTORY OF BIOLOGY

Vadim NAZAROV, Cand.Sc.(Biol.)

The history of biology in the USSR, as a special field of research, has gone a long way, from the early descriptive publications to the fundamental generalising works. As the range of historico-biological studies grew, their character and content underwent a change: in producing a chronicle of science, the Soviet historians of biology gradually overcame the "description by personalities" approach, going on to an analysis of the development of scientific problems, ideas and methods of research. Relying on the Marxist conception, they have shown that the progress of biological knowledge, like that in every other sphere of scientific endeavour, is ultimately determined by the requirements of socio-production practice, by the whole aggregation of society's material and spiritual conditions.

The Institute of the History of Natural Science of the USSR Academy of Sciences, set up in 1945 (since 1953 it has been known as the Institute of the History of Natural Science and Technology), has become a leading centre of research into the history of biology coordinating all the effort in this field on the scale of the whole country. In the early postwar years, the primary task was to study the past of biology in this country and to bring out the role of Russian and Soviet scientists in its development and their contribution to world science. The advance of knowledge of animate nature in Russia up to 1917 was reflected in

many monographs published by the scientists of the Institute and was generalised in a four-volume collective work entitled A History of Natural Science in Russia published between 1957-1962.

To mark the 50th anniversary of the Great October Socialist Revolution, a large number of monographs, collections and articles was prepared and published to sum up the results of the half-century of development of the different biological sciences, branches and trends. In 1967, a fundamental work, entitled Development of Biology in the USSR, was published in the anniversary series "Soviet Science and Technology over the 50 Years". It was prepared by a large group of leading Soviet specialists in and historians of biology. The most important advances in biology in this country during that period were reflected in a book by A.Belozersky and S.Mikulinsky entitled Successes of Soviet Biology (1967). The development of biological research in the institutions of the Academy of Sciences over the pre-revolutionary period of its existence was described in the two-volume History of the USSR Academy of Sciences (1958-1964).

The publication of a two-volume collective work, A History of Biology, was an important event in the historiography of biology. Volume I, covering the development of biology from ancient times to the early 20th century, was edited by S.Mikulinsky and appeared in 1972. One of its chief merits is that it shows the development of biology in close connection with the development of society and the history of the world outlook.

Volume II (the beginning of the 20th century to our day) was edited by L.Blyakher and appeared in 1975. It reflects the progressive differentiation and integration of the system of biological sciences, which, on the one hand, have led to the fragmentation of once integrated sciences, into relatively independent disciplines and trends, and on the other, to the emergence of complex branches of bio-

logy which have taken shape on the basis of a synthesis of once disparate sciences. Much attention is given in the volume to the formation of the molecular branches of biology and their role in transforming the whole complex of the biological sciences.

In the past few years, many other important works on the history of biology have appeared in the Soviet Union. Among the works on the evolutionary theory, which continues to be the theoretical basis of the whole of biology, there is, above all, the book by K.Zavadsky[1], who analysed the formation and development of the main lines in evolutionary theory in the post-Darwinian period down to the early 1920s. He has considered with equal thoroughness the main stages in the history of the study of species and species formation since ancient times in a book entitled Species and Species Formation (1968).

B.Raikov's posthumous book, German Evolutionary Biologists Before Darwin: Lorentz Oken, Karl Friedrich Burdach, Martin Heinrich Rathke (1969), presents some interesting facts from the prehistory of the evolutionary theory. L.Blyakher's monograph, The Problem of Inheritance of Acquired Traits (1971), considers the history of a priori and empirical attempts to solve the problem, and argues that these cannot be inherited. E.Mirzoyan's Development of the Doctrine of Recapitulation (1974) presents the history of the doctrine of the organism as a whole in individual and historical development. That same year, V.Nazarov produced his monograph entitled Evolutionary Theory in France after Darwin. The history of the struggle for the materialist theory of evolution is presented in popular form in two books: B.Medinikov's Darwinism in the 20th Century (1975) and S.Reznik's The Revealed Mystery of Life (1976).

From 1974 to 1976, a number of monographs appeared on the history of individual problems in the evolutionary theory, among them: A.Georgiyevsky's Problem of Pre-adaptation (A Historico-critical Study); T.Averyanova's Population

Studies in Applied Botany; Z.Rubtsova's Development of Evolutionary Cytogenetics of Plants in the USSR; and Y.Gall's Struggle for Existence as a Factor of Evolution (A Historico-critical Analysis of Botanical Studies in the USSR). Since 1973, the Institute has issued annual collections entitled History and Theory of the Evolutionary Doctrine, edited by K.Zavadsky, presenting problem articles, surveys and reviews of new books. One of the issues (1974) was devoted entirely to an analysis of I.Schmalhausen's evolutionary views and their importance for modern biology.

In the past 10-15 years, genetics, molecular biology and the complex of ecological disciplines have come to the fore both in importance and volume of research within the system of biological sciences. This has been reflected in the works on the history of these branches of biology. Thus, in 1967, A.Gaisinovish published his Origins of Genetics to show the development of the conceptions of the laws underlying heredity and mutability from the 18th century to the early stages of the young science following the rediscovery of Mendel's laws. A large number of articles deal with the history of genetics in the USSR. A new edition in 1968 of the works by the leading Soviet scientists in a collection entitled The Classics of Soviet Genetics was of much importance for an understanding of the achievements of Soviet genetics in the prewar period, and for an objective evaluation of its contribution to world science. It included works on general genetics by N.Vavilov, N.Koltsov, G.Nadson, and G.Filippov, S.Chetverikov, G.Levitsky, A.Serebrovsky, N.Dubinin and G.Karpechenko.

V.Soifer's Essays on the History of Molecular Genetics (1970), A.Belozersky's Molecular Biology—A New Stage in the Cognition of Nature (1970); the history section) and the relevant chapters from the book, Development of Biology in the USSR (1967) deal with the history of molecular genetics and molecular biology as a whole.

The collection Essays on the History of Ecology (1970, edited by G.Novikov et al.) is a major work on the history of ecology.

A considerable number of monographs have been issued on other branches of biology, including the historical essays: R.Petrov's Immunology from Pasteur to Our Day (1968); S.Krivobokova's Biological Oxidation (1971); V.Gutina's Biochemistry of Anaerobic Decay of Hydrocarbons (1974); A.Shamin's Biocatalysis and Biocatalysts (1971); L.Chesnova's Problems of General Entomology. Development of Transmission Theory (1974), A Short History of Botany by N.Bazilevskaya, N.Belokon and A.Shcherbakova (1968); Kh.Trass's Geobotany. History and Present Trends (1976); N.Bogoyavlensky's Russian Anatomy and Physiology in the Distant Past (up to the Second Third of the 18th Century) (1970); E.Vermel's A History of the Cell Theory (1970) and others. New regional historico-biological works have also appeared, such as R.Rakhimbekov's From the History of the Study of Nature in Central Asia (1970), A.Tashliev's Zoological Science in Turkmenistan (1971), B.Mazurmovich's Development of Zoology in the Ukraine (1972).

In 1970, the Institute resumed publication of its periodical collection From the History of Biology. Alongside articles on the major problems and methods in biology and the conditions and factors promoting its progress, it contains material on the scientific activities of Soviet and foreign biologists, reviews of new books and bibliographical surveys.

Publication of the works of the world's outstanding biologists is being continued in the Soviet Union. Selected works by N.Vavilov, E.Geoffroy Saint-Hilaire, I.Pavlov, and D.Pryanishnikov have been issued in the "Classics of Science" series. To mark the centenary of K.Baer's birth, two collections of his articles have been published in Estonia under the title Folia Baeriana (1975, 1976), on various aspects of his scientific biography and activities (in Es-

tonian, Russian, German and Latin). The Philosophy of Botany by C.Linné has been prepared for publication by I.Amlinsky and is now at the printers'. This is to be the first Soviet publication of this highly important work by the great Swedish botanist. In 1971, Meditsina Publishers in Moscow issued the well-known tractate by Cl.Galen On the Uses of the Parts of the Body of Man, and three years earlier it also published the selected works by G.Mendel, Ch.Nandin and A.Sageret, which were prepared for the press by A.Gaisinovich.

There have also been publications of the selected works of outstanding Russian and Soviet biologists of the 20th century, among them: A.Belozersky (1976), A.Borisyak (1973), N.Vavilov (1967-1970), G.Morozov (1970-1971), G.Nadson (1967), A.Palladin (1975), V.Parin (1974), L.Ramensky (1971), V.Sukhachev (1972-1975), and M.Kholodny (1970). There has been a third edition of A.Severtsov's Main Lines of the Evolutionary Process. The Morphological Theory of Evolution (1967), a second edition of I.Schmalhausen's Factors of Evolution. Theory of Stabilising Selection (1968) and Problems of Darwinism (1969). A third edition of Y.Filipchenko's The Evolutionary Idea in Biology is to appear shortly.

The letters of the great biologists of the past have always been an important source for the study of their scientific legacy. In the recent period, there have been publications of the letters of I.Mechnikov and K.Baer. The Institute is preparing for the press a three-volume edition of the letters of Charles Darwin, which is to be the world's most complete publication, including those published recently and not included in the well-known five-volume edition compiled by F.Darwin. The letters of N.Vavilov are also being prepared for publication.

In the past decade publication has been continued of books on the life, scientific activities and various aspects

of creative effort by the leading biologists. Most of these are not confined to a description of the events in the scientific biography of these men or an analysis of their contribution to science, but present a broad picture of the overall development of biological problems and natural science as a whole in connection with the socio-economic, historical and cultural conditions of the corresponding epochs. The books reflect the various aspects of the individual psychological features of scientific work, the shaping of national schools and so on.

Publication of the academic "Scientific Biography" series, founded in 1959 on the initiative of the Institute, has a leading part to play in this type of literature. From 1967 to 1976, monographs in this series were devoted to A.de Bary, M.Bogdanov, A.Bogomolets, M.Voronin, V.Vrassky, F.Galton, A.Gurvich, A.de Candolle, L.Dollo, P.Zhivago, A.Zavarzin, K.F.Kielmeyer, N.Koltsov, A.Krasnov, G.Cuvier, C.Linné, K.Ludwig, G.Morozov, A.Nordman, L.Orbelli, I.Pavlov, B.Raikov, I.Sechenov, N.Steno, A.Trembley, N.Kholodny and M.Tsvet. A bibliographic index of the publication of the series[2] over its 15 years came out in 1975, and this in itself shows the work that has been done in this field.

Among the other publications let us note these monographs: B.Volodin's Mendel (Vita Aeterna) (1968), Y.Milenushkin's, N.F.Gamaleya (1967), V.Korsunskaya's, Charles Darwin (1969), G.Gurev's Charles Darwin and Atheism. An Essay on the Great Naturalist's World Outlook (1975), V.Korsunskaya and N.Verzilin's V.I.Vernadsky (1975), the collection Konstantin Ivanovich Skriabin. Life and Activities (1976), N.Zalkind's The Moscow School of Anthropologists in the Development of the Science of Man in Russia (1974), M.Yanovsky's Mysteries, Conjectures, Insights (1975), and others.

Methodological questions in the development of biology are prominent in these and various other works, and their

importance tends to grow nowadays in view of the overall trend towards the integration of biological knowledge, the systems coverage of the phenomena being studied, and the elaboration of the foundation of theoretical biology. With the rapid progress of research at the lower (subcellular and molecular) and higher (population-species and bio-geocentric) levels of organisations, the heuristic function of the methodological principles in the concrete areas of biology have been clearly brought out. It is quite natural, therefore, that the methodological problems of genetics should be dealt with in the largest number of works, among them Academician N.Dubinin's monograph, Some Methodological Problems in Genetics (1968), Corresponding Member of the USSR Academy of Sciences I.Frolov's Genetics and Dialectics (1968), and Mendelism and the Philosophical Problems of Contemporary Genetics, written by I.Frolov and S.Pastushny (1976).

Consequently, in the Soviet period, a circumstantial study has been made of the development of Soviet and Russian biology and of the most important advances in world biology. Continuing the fine traditions of Russian science, Soviet scientists have made a contribution to the treasure-house of biological knowledge. The production in the USSR of a fundamental work on the development of biology was a great achievement. Other valuable works on the history of the most important branches and problems of biology have also been published.

At present, Soviet historians of biology have concentrated on a profound study of the history of the new disciplines in this field of knowledge which have emerged only in this century, to produce a systematic analysis of the attempts to structure general biological conceptions falling within the sphere of theoretical biology, to elaborate a structural-systems approach and methods of analysis and so on. The elaboration of the history of these important and promising lines of development in modern biology will un-

doubtedly promote its frontal advance in the cognition of the substance of life.

Studies and publications in the USSR on the history of the other sciences have acquired equal scope.

NOTES

[1] K.Zavadsky, The Development of Evolutionary Theory after Darwin. 1859–1920s, Leningrad, Nauka Publishers, 1973, 424 pp. (in Russian).

[2] Z.Sokolovskaya, '200 Scientific Biographies', Moscow, 1975, 192 pp.

DEVELOPMENT OF CHEMISTRY IN SOVIET TURKMENISTAN

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On its vast territory, Soviet Turkmenistan has a great diversity of climates, natural-scenery, geological, and geophysical, soil and geographical conditions. It is a rich storehouse of oil, natural gas, sulphur, potassium salts and other minerals. Up until 1917, none of this wealth was of any use to man: there was virtually no industry in Turkmenistan, and the people lived in economic privation and ignorance. There was not a single institute, or even specialised secondary school.

The situation underwent a fundamental change in the Soviet period. Turkmenistan now has six institutions of higher learning and dozens of specialised secondary schools training specialists in 150 fields. The State University at Ashkhabad now has a body of over 11,000 students. Turkmenistan has its own network of research institutions and a national Academy of Sciences, which in 1976 marked its 25th anniversary. Its institutes are engaged in basic research on a modern level in fields of science like physics (radiophysics, semiconductors, the ionosphere, ultrasound); chemistry (organic catalysis, reaction kinetics, oil chemistry and petrochemical synthesis); biology and other sciences.

What are the objective socio-economic and subjective factors which have made it possible for science in Soviet Turkmenistan to rise to such a level?

Among these factors are, above all: a) involvement of the whole Central Asian region in the USSR's overall effort to build a socialist society; b) steady implementation of the policy of the Communist Party and the Soviet Government to wipe out illiteracy, and set up a network of schools and scientific institutions; c) utmost assistance to the Republic from Russian scientists; and d) implementation of plans for electrifying and industrialising the country, and studying and developing its natural resources.

Through Lenin's nationalities policy, the entire Soviet economic and intellectual potential has been actively used to raise the once backward areas to the level of the highly developed central areas. A characteristic example in this context was the establishment of a university in Tashkent in 1920 as a centre for training scientists and teachers for all the Central Asian Republics. Many of the research chemists now working successfully in Turkmenistan were trained at the University's chemical department. In 1922, a Turkmen Scientific Commission was set up in the Tashkent University. It was, in effect, the first cell in the organisation of national scientific institutions in Turkmenistan. At about that time, analytical-chemistry subdivisions were set up at experimental stations and industrial enterprises in the Republic.

In the 1920s and 1930s, the Party and Soviet organs in the Republic concentrated on setting up general-education schools all over the country, training teachers and wiping out illiteracy among the population. In less than 20 years, literacy increased 9-fold, and by 1939 had reached 80 per cent. By the early 1930s, the objective conditions had matured for the development of higher education in Turkmenistan. This called for the training of local inhabitants as

specialists with a higher education primarily in such mass specialties as teachers, doctors and agronomists. That is why teacher-training, medical, and agricultural institutes were the first institutions of higher learning to be set up in Soviet Turkmenistan.

The chemical personnel at these institutes also helped chemical science in the Republic to make its first strides. Indeed, the late 1920s and early 1930s may be regarded as the period in which chemical science originated in Turkmenistan.

When the first five-year economic development plans were drawn up in the early 1930s, outstanding scientists, among them E.Fersman, N.Gubkin and D.Shcherbakov, came to the Republic to provide scientific and technical consultations. N.Kurnakov was also a permanent consultant in the development of the Republic's salt resources. At the request of the Turkmen Government, the USSR Academy of Sciences called a scientific conference in Leningrad in December 1933 on the development of Turkmenistan's productive forces. It was attended, on the one hand, by members of the Academy of Sciences led by its President A.Karpinsky, and on the other, by Turkmen leaders, headed by Chairman of the Turkmen Government K.Atabayev.

The conference laid down the guidelines for developing Turkmenistan's productive forces through the extraction and processing of mineral resources like natural salts, natural sulphur and oil. In this way, the chemical industry became the basis for the Republic's economic development. The conference also considered a complex of socio-cultural problems, notably the development of higher education and science in the Republic. It decided to make use, from 1934 on, of USSR Academy of Sciences institutes to train scientific national personnel by assigning them to academic scientific institutions for long terms. This has been one of the main ways of training highly skilled research personnel (doctors and can-

didates of sciences) for Turkmenistan over a period of more than 40 years. It is still being widely used. In the past few years, assistance to Turkmenistan in training scientific personnel for developing new fields of natural science has also come from the Academies of Sciences of several Union Republics (among them Uzbekistan, the Ukraine and Azerbaijan) and a number of leading universities in the country (among them Moscow, Leningrad and Gorky).

In 1941, a few months before the outbreak of the Great Patriotic War, a Turkmen branch of the USSR Academy of Sciences was established in Ashkhabad for planned natural-science research in various fields, including chemistry. Scientists from Moscow, Leningrad and other cities of the USSR provided the guidance for the research carried on at the branch. The war-time economy called for the main emphasis on the maximum and most efficient use of mineral and raw material resources available in the Republic for the needs of the front and the requirements of the Republic. During the war, a number of departments from Moscow and Odessa universities were evacuated to Ashkhabad, so that prominent scientists, among them A.Frost, A.Bergman and I.Gerasimov, were immediately involved in the work of the Turkmen branch.

Chemical laboratories were set up within the institutions of the Academy's branch to carry on important research into the adsorption and catalytic properties of natural alumosilicates, the composition and physico-chemical properties of artificial and natural saline systems. In the 1940s, extensive work was carried out to establish the vitamin content of wild herbs in Turkmenistan and methods worked out for the extraction of vitamin C from vegetable products. The results of these studies were used for the production of vitaminised extracts for the needs of military hospitals. The works of two Moscow scientific schools, headed by N.Kurnakov and N.Zelinsky, had an influence on the development of chemical research in Turkmenistan. These schools took an active part in studying natural resources—

salt and oil—and helped to train national scientific personnel, to determine the lines of research and took part in setting up scientific institutions in Turkmenistan.

Thanks to the assistance coming from the more developed Soviet Republics in training scientific personnel and shaping the network of scientific institutions, by the early 1950s the Republic had all the conditions for establishing a single scientific centre. The national Academy of Sciences was set up in Turkmenistan in 1951. By then, the student body at the institutions of higher learning had grown considerably, a Polytechnical Institute was opened in Ashkhabad, and this helped rapidly to increase the number of specialists graduated in every field of economics, culture, public health and education in Turkmenistan.

In the 20 years from 1953 to 1973, the total number of specialists with a higher and secondary specialised education in Turkmenistan went up from 20,000 to 127,400. Of especial importance was the fact that 44.5 per cent of them were women.

In the 1950s, there was a very rapid development of science, and the growth in the numbers of scientists and engineers and of their professional standards in Turkmenistan, with most headway being made in research in the field of chemistry. In 1957, the Institute of Chemistry was set up under the Turkmenistan Academy of Sciences. From the outset, it set itself the basic tasks of studying the Republic's oil and salt resources, determining the prospects for the development of chemico-technological and chemical mining branches of industry, and research into the unique natural compounds of vegetable origin rich in alkaloids, essential oils and other substances with physiologically active properties that are of practical interest for the pharmaceutical industry.

In the past few years, Turkmenistan has become one of the chief scientific centres developing research into

the chemistry of oil. With the use of modern physical and chemical methods, detailed and systematic studies have been made of the composition, properties and chemical structure of hydrocarbons and other components of oil from the oil fields along the Eastern coast of the Caspian Sea, and also of the ozocerites of the Cheleken Peninsula. Turkmenistan's subsoil is rich with natural-gas deposits mainly of the gas condensate type. In view of the rapid commercial working of a number of large gas fields, studies were made of the properties and hydrocarbon content of these condensates, and schemes worked out for their chemical processing. Extensive experimental work has been carried out in the chemistry of oil and the chemical processing of oil and gas, and these have been generalised in a number of dissertations and monographs.

Turkmenistan's subsoil and surface waters are exceptionally rich in mineral salts. Take the unique Kara-Bogaz-Gol, a gulf on the Caspian Sea, which is justly known as the "golden bed" because of its deposits of a tremendous range of natural salts running to billions of tons. It is natural, therefore, that physico-chemical research into saline systems, ranging from the simplest artificial (two-, three- and four-element) systems to the complex natural system like that at Kara-Bogaz-Gol has been the main line of research and will remain such for a long time to come. Elaboration of the fundamental technology of the recovery, separation and complex chemical use of the salt resources of Kara-Bogaz-Gol is the major scientific and technical problem on which work is being carried on not only at the Institute of Chemistry of the Turkmen Academy of Sciences but also at a number of major research institutions of All-Union importance. Much has already been done not only to evaluate the potentialities of Kara-Bogaz-Gol in terms of the sodium sulphate, magnesium and other salts whose extraction has gone on for a long time, but also the concentrations of bromine and certain other dispersed and rare elem-

ents. A study has been made of the uniformities underlying the changing composition of saline systems depending on the temperature and other external factors determining the succession of precipitation in the form of various mineral components of brines. The conditions for the practical technological implementation of the extremely important reaction for converting potash chloride into potassium sulphate are being studied.

A study of salt equilibria and the kinetics of reactions and processes of separation in complex saline systems prepared the scientific basis for elaborating a rational industrial technology for the integral extraction and use of the salt resources of Kara-Bogaz-Gol. The study of the kinetics and modelling of the process and apparatus is the basis for the elaboration of scientific principles for improving and modernising the extraction of iodine and bromine from oil-drilling waters. Cooperation between research chemists and workers at chemical and petrochemical enterprises and R & D establishments has been having a favourable effect on the practical use of scientific results.

Turkmenistan's chemical science has tremendous potentialities for the economic development of the vast areas of the Kara Kum deserts. Already now chemicals and residual oil products are being used in solving important economic problems like the fixing of quicksands in order to provide protection for natural oasis lands, industrial installations, populated localities, railways and highways. There is much promise in the use of low-cost, light and anticorrosion polymer materials for the manufacture of tubes to transport fresh water to outlying experimental desert pasturelands and to irrigate cotton fields and other farm crops on cultivated oasis lands. The extensive use of everyday chemistry items and products helps to create various conveniences for the life and work of those who live in the arid zone.

In less than a half-century, the beginnings of the oil,

gas, chemical and oil-refining industries have been set up and developed in the Republic. Turkmenistan accounts for a sizable share of the Soviet Union's output of chemicals like sodium sulphate, sulphur, iodine, bromine, detergents and high-quality motor oil, bitumen and coke.

The rapid development of science in general and of chemistry in particular in Soviet Turkmenistan shows the boundless potentialities which the socialist system opens up for realising the people's endowments. The formation and rapid development of science in the Republic and the training of highly skilled national scientific personnel have resulted from Lenin's nationalities policy, and this has helped, in a very short historical period, to bring about the radical transformation of the Turkmen people's life as a whole, and to raise their standards of education, science and culture to those of the most advanced nations of the world.

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