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THE WAYS OF SCIENCE

-USSR-

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1960 is past, a year that was marked by an abundance of remarkable events in the life of the Soviet Union, a year of enormous production, technological and scientific achievements and victories. Such success is largely due to the contributions made by the Soviet scientists. The scientists' work and achievements are held in high esteem by the Party, the government and comrade N. S. Khruschev. It is a matter of honor for us to further justify such esteem.

The multilateral activities of the scientists of our country are closely associated with the progress of the plan for the building of communism, which confronts the scientists with crucial and ever increasing problems.

The duty of the scientists is to aid in the accelerated development of the national economy on its path to communism, to implement the latest scientific achievements into industrial and agricultural production, and to achieve a maximum utilization of time in the peaceful competition between socialism and capitalism.

In this article I shall attempt to shed some light on these problems as well as on certain directions taken in the development of natural sciences.

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Two dialectically interrelated opposing tendencies are clearly expressed in present day science.

Foremost is the fact that science is becoming constantly more specialized and differentiated. The old scientific disciplines branch out, and as they grow and develop, give rise to new disciplines. They penetrate deeper at the expense of narrowness. The profundity of knowledge possessed by a specialist grows rapidly as he becomes progressively more circumscribed in his knowledge. The scientific tow is combed into fine fibers.

In the second place an opposing process is occuring. The various branches of science come into contact with each other, penetrate into each other and spawn hybrid sciences at such points of contact. This process of development is constantly growing.

During the past century physical chemistry originated from an interrelationship of physics and chemistry. Towards the end of the first quarter of our century chemical physics originated from the interrelationship of chemistry and physics. Biological chemistry was rapidly progressing at the beginning of this century and at the present time biophysics is developing at an equally rapid pace. Geochemistry, which originated on a similar basis at the beginning of the twentieth century, from the interrelationship of geology and chemistry has become a leading discipline in the science of the earth's crust and yielded its own branch -- biogeochemistry. Geophysics is becoming progressively more significant.

Occasionally, fields of science, far removed from each other, such as mathematical logic and philology (with reference to problems of automatic machine translation), gives rise to a new hybrid science, in this case mathematical linguistics. Such a form of hybridization in science produces particularly fertile progeny.

The individual strands of science intertwine into a continous and durable scientific fabric. It is noteworthy that the areas adjacent to the points of juncture between the sciences as well as the hybrid sciences are usually the most rapidly developing and fertile ones. This is not surprising. The methods of research have great and frequently decisive significance for science. When new ideas from adjacent branches of science or from ones that are far removed, penetrate an established, smoothly developing area of science, together with radically new methods of research, the results may be said to resemble the effects of a blood transfusion. It is precisely at the points of juncture and the points of origin of sciences that the perspectives for further scientific development arise. One of the most important tasks in planning scientific development should be to insure the existence of paths for mutual interpenetration of the sciences and the training of personnel specializing for work in scientific fields produced by further hybridization of the sciences, without letting this matter be taken care of by the natural course of events. The creation of a number of new institutes at the Academy of Sciences USSR is specifically directed at resolving this problem.

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Science is man's struggle against the inert forces of nature in order to subordinate them to his will. This broad field of struggle is confronted with a large number of problems of varying significance and nature. They include an unfathomable sea of tactical problems and a certain number of problems of scientific strategy as well as of the direction of strategic movements of this front. No strategy, irregardless of how well chosen, is capable of assuring a victory unless the armament of the army is up to standards. Therefore the scientific equipment of the army of researchers must be constantly perfected. The building of scientific instruments must not be a part of general instrument making but must be an independent, powerful and rapidly progressing branch of our industry.

It is clearly evident that there would be no astronomy without telescopes, no astrophysics without a spectroscope, and without a microscope biology would have remained at an embroyonic stage. At the present time the most promising branches of biology, cytology and virology are inconceivable without an electronic microscope which is constantly being perfected, nor nuclear physics without boilers or the giant atom smashers, chemistry without mass-spectrometers or instruments for measuring electronic and nuclear magnetic resonance, gas chromagraphs and other instruments would be impossible.

A growing number of scientific fields is becoming incapable of further progress without fast electronic computers. Therefore, in order to attain scientific success in general it is quite necessary to develop the science of instrument making, which is constantly looking forward and devising new systems of measuring, as well as that of the corresponding field of design and the relevant branches of industry. This also fully applies to other items of scientific armament, such as reagents, microbe strains, etc.

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What are the tasks of the Soviet scientists? Which scientific directions, areas and problems should be considered strategic? It is today possible to examine only a few examples within the framework of a newspaper article. These happen to be the directions in which the Academy of Science USSR is endeavoring to direct the major portion of its efforts.

The extent of man's mastery over nature, the extent of his freedom from hard and fatiguing physical work and the productivity of human labor depend on the amount of energy at his command. If the amount of energy which is available to man were much greater than that yielded by countries producing the most energy, such dreams of fiction stories as the diversion of great rivers into deserts, the melting of polar ice, the leveling of mountains, penetration into the depth of the earth's crust and the mining of useful minerals there, would become reality. Other problems, such as interplanetary flight, for example, require a high concentration of energy in order to be successfully resolved. Hence the field of energy research occupies an important place in science.

For the next several decades carbonic fuels such as oil, gas and coal will still be the principal sources of energy. Therefore the most important group of tactical scientific problems is the development of scientific basis for increasing efficiency in the use of carbonic fuels. Increasing the effectiveness of the existing sources of energy - turbines, motors, the discovery and perfection of new principles in the transformation of heat energy into electrical energy by means of simpler and at the same time more effective devices (plasmoid thermoelectric cells, semi-conductor thermoelectric cells and their different combinations, magnetic-hydro-dynamic method and the generation of electrical energy by means of the direct utilization of chemical energy of fuel in the so called fuel element). Further combinations in the use of fuel for the production of energy and for chemical purposes is necessary as well as the use of hydro-energy sources, the establishment of a single energy distribution network in the USSR and long distance transmission of high voltage electrical energy. These are important tactical problems of science and technology.

Work in exploiting additional sources of energy such as those of the sun, wind, tides and thermal waters deserves close attention. The strategic problem in this field should be the utilization of the potential energy of nuclear transmutations. This problem is half resolved.

The atomic ice breaker "Lenin" and the atomic power stations use the energy released through nuclear fission of uranium which is an element possessing the heaviest atom (among the elements found in nature), and consequently the heaviest nucleus. That collosal potential energy of the uranium nucleus, which, when released instantaneously on orders of the Truman administration in the form of atomic bombs over Hiroshima and Nagasaki and which destroyed these two cities and maimed hundreds of thousands of people, is harnessed at the atomic power stations and is being used for the building of communism.

The energy contained in a single kilogram of uranium is equivalent to the energy produced by the combustion of 2,0:0 tons of good quality coal. According to an estimate taken from American sources, world reserves of the two heavy elements — uranium and thorium, in forms suitable for utilization at the present time, amount to approximately 26,000,000 tons, representing a reserve of energy equivalent to the combustion of tens of trillions of tons of coal. Therefore atomic fuel is an excellent "supplement" to our basic present day sources of energy -- carbonic fuels. The utilization of atomic energy, however, along with its extensive advantages, such as its compactness and great mobility, contains certain drawbacks -- the necessity of procuring these rare elements and the presence of disagreable by-products.

All this compels the scientists to concentrate their attention on the solution of a new energy problem -- problem number one is the development of controlled thermonuclear fusion i.e. reactions of the atomic nucleus of the helium element from the nuclei of light elements. Such fusion is accompanied by a collosal release of energy. One kilogram of "heavy hydrogen" of deuterium in converting to helium releases an amount of energy equivalent to that yielded by the combustion of 40,000 tons of coal. The enrgy released by an explosion of the hydrogen bomb is the energy of thermonuclear fusion released instantenously. The energy of the sun and stars is also the energy of thermonuclear fusion of helium from ordinary hydrogen.

To achieve (controlled) thermonuclear fusion a rarified plasma (i.e. a gas consisting of electrons and bare atomic nuclei) obtained from appropriate light weight elements has to be further heated to a temperature exceeding a hundred million degrees "only". It is hard to comprehend the difficulty of such a problem. Before experiments in thermonuclear fusion the highest temperature achieved by man was measured in thousands of degrees. Material that could withstand not just hundreds of millions of degrees but even tens of thousands of degrees does not exist and is inconceivable. A great achievment of the physicists was the invention and construction of a magnetic entrainment separator, where the reactor vessel surrounding and containing the super heated plasma column is a magnetic field.

It is impossible to forecast the time when the physisists will be able to create controlled thermonuclear reactions. Its accomplishment will be a strategic success. Man's concern over the availability of energy will be eliminated forever. Heavy water (deuterium) will serve as immensely concentrated source of fuel. One liter of water contains an amount of heavy hydrogen the energy of which is equivalent to 400 kilograms of oil. It is evident that the earth's resources of energy would be inexhaustable.

It is natural that all processes, occuring in nature and releasing large amounts of energy deserve the closest attention, even though they may not appear to have a practical application at the present time. One of these are cosmic rays with their truly cosmic levels of particle energy measured at $10^{10} - 10^{18}$ electron-volts. These are phenomena engendering sub-atomic particles in high energy fields close to atomic nuclei, in particular the origination of anti-particles, similar to the anti-proton and the anti-neutron, out of which it will someday be possible to create "anti-atomic elements" -- "anti-atomic periodic system". This is a so-called dematerialization of particles and anti-particles with a release of their mass in the form of an electro-magnetic field -- a process that yield a maximum amount of energy, three powers greater than that given by thermonuclear fusion. All of these problems have an exceptional significance in comprehending the structure of matter as well.

The solution of this principal problem would aid in the solution of a number of other problems, such as those enumerated above and relating to the transformation of geography and climates as well as in the solution of the next strategic problem -- that of providing man with a greater expanse of mineral resources. Inexhaustable amounts of energy would permit man to utilize much poorer and more scattered mineral sources -- and there is a much greater number of them than of the concentrated and rich sources; to reach for them into greater depths of the earth's crust and into ocean depths, which cover two thirds of the earth's surface.

Then carbonic minerals such as gas, coal and peat would be used to a much greater extent for chemical synthesis, a process which at the present time utilizes only a few percent of the oil output, but will sharply increase from decade to decade.

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Chemical synthesis in the broadest terms is another strategic direction.

Man has for a long time been utilizing matter and materials found in nature in a finished or semi-finished form, for the satisfaction of various needs such as food, clothing, implements for work and self-defense, building materials, fuel, drugs, paints and other items. At the present time all materials, except food, are produced artificially as well; they are often almost identical to the natural product, but frequently differ somewhat, however they are satisfactory for the performance of the same or similar tasks. Theoretically it is possible to produce artificially any substance found in nature as well as an unlimited number of additional substances. The latter include a number of dyes, drugs, explosives and so forth.

In order to synthesize a natural substance it is necessary to know its structure -- the atomic and molecular order and the molecular arrangement. At the present time this problem is solved with reasonable ease and the center of attention is shifted to the process of synthesis -- the creation of the necessary atomic combination in the molecule and of the molecules among themselves.

The way of life and the technology of present day society have immesurably increased the demand for a varied number of materials. Technology requires materials able to withstand high temperatures and having a high energy content, possessing a number of specific electrical, magnetic and optical properties, substances of exceptional hardness or those possessing other properties. Public health demands a wide assortment of drugs having a physiological effect on the organism. Daily life requires various materials for various purposes, of varying durability and beauty. Here are a great number of problems of synthesis integrated into a broad general field. In certain cases the problem consists of obtaining a small amount of much needed substances (such as drugs for a specific purpose), in other cases it is a matter of mass production synthesis consisting of millions of tons of such items as fertilizers, plastics and rubber.

The synthesizing of superhard substances, harder than carborundum and the widely used carbides, such as tungsten carbide etc., contains the possibility of greatly accelerating the processing of metals and drilling and boring. These possibilities are presented by the synthetic diamond and by an equally hard material, borazon, which is not found in nature. The order of the day for chemical crystallographers contains plans for synthesizing such natural and widely used industrial minerals a mica, rock crystal, asbestos and purely artificial fibrous mineral materials.

Many varieties of crystals (and textures) serve as semi-conductors with their present day important applications. They are used for a number of other electrical and radiotechnical purposes -- such as insulators, piezo-electric material, polaroids for various segments of the spectrum and light filters. All these are obtained artificially through synthesis.

In many cases most important is the construction of a solid body out of crystals and not the construction of a molecule out of atoms. This applies to metals and alloys. This already common metallurgical process should be widely developed also in the field of organic synthetics of high molecular weight (polymers). It will then be possible to expect a sudden improvement in these new materials that are gaining in popularity, similar to that made in the strength of present day varieties of steel as compared with unprocessed metals.

All types of carbonic materials of high molecular weight have now come to be widely used in industry. Synthetic rubber, or, to use a better term, various synthetic rubbers have already become quite commonplace, they are on every automobile wheel. Synthetic resins are extensively used by the electrical and cable industries, in lacquers and various other articles. Synthetic fibers and fur surpass their natural counterparts. Synthetic substitutes for leather are beginning to compete with this natural ancient material and will, of course, soon replace it. Synthetic nylon materials are better than ivory. Fluoride plastics possess considerably better chemical stability than even platinum. Reenforced plastic is stronger than many varieties of metal.

A big leap ahead has recently been made in synthesizing valuable and durable plastics. The principle has been found for obtaining "sterospecific polymers" which are far more durable than the polymers of a similar composition and molecular structure, but with an irregular space structure. Specifially, polymer plastics of the polypropilen variety will be produced by us in quantities of hundred thousand tons.

Chemists and physisists working out the principal problems in this field will have to make additional progress by mastering the pre-molecular structure, which will lead to still greater durability.

What, then, is the fate of natural materials with the constr progress of scientific and industrial chemistry? As better and cheaper synthetic materials are produced and the corresponding industries develop, the natural materials will be replaced by artificially produced materials. The possibilities of artificial synthesis are far greater than any process taking place in nature. Industrial chemical production is exceptionally compact, demands a minimum of labor, and is quite well suited for automation. It is known that in its earliest stages of development the chemical industry gave to the world such methods of producing drugs that by the end of the last century they replaced many of the drugs formerly obtained from plants. Crops of indigo plants and alizarin bearing plants, which our forefathers used as a dye for fabrics, have vanished from the face of the earth. Furthermore, it seems to me, that a possible next phase in the development of the synthesis process, after the development of the high molecular weight polymer industry, will be the synthesizing of food, which will be of considerable aid to the country's agriculture.

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There is another very important problem in synthetics at the point of contact between chemistry, physics, biochemistry, biology and, probably, cybernetics, which should really be considered as a strategic problem of the science of to-day. Animal and plant cells and even single micro-organic cells perform amazingly complex and purposeful synthesis process and accomplish this at room temperatures and under normal pressure at an amazingly fast rate. One of the peculiarities of such organic synthesis is that it is an enzyme, or catalytic, synthesis. Enzymes are catalysis, that act to accelera chemical reactions and are produced by the organisms themselves.

The chemical industry is expanding its use of catalysis, in the majority of cases, however, incomparably simpler and coarser types of catalysis than enzymes are used. Enzymes are used in industry but to an insufficient degree. Live cells include compound, very complex, well coordinated enzyme systems, which function in a specific sequence, in such a manner that each chemical stage has its corresponding key -- its specific enzyme. Thus, simultaneous synthesis of albumin, carbohydrates, fats and other lipoids, nucleic acids, hormones and of the enzymes themselves and other matter is performed within the cell.

Science of the postwar period revealed that cells in the synthesis process, at least in the basic class of high molecular weight compounds in live organisms, of albumin, utilize dies. The dies are molecules of nucleic acids -- which are also high molecular weight compounds with incorrectly repeated architectural design of the nucleus. These dies reproduce themselves as the cells divide, and each new cell of an organism is provided with an identical assortment of these dies, which is the reason why they synthesize albumin of a similar structure. With the birth of a cell in a new organism through the merging of the paternal and maternal cells, a new assortment of dies from both varieties of cells are created on similar basis which is why synthesis occurs with the use of both paternal and maternal dies. Hence the phenomena of heredity.

The most significant portion of virus particles which represent the most primitive forms of life, are also nucleic acids. Virus, in infecting the cells of the victim's organism, transmits to them only its die -- nucleic acids, which, after invading foreign cells and using their enzyme systems, construct albumins there, on the order of those which enter into the structure of the virus particles, and create them out of the resources of the victim organism. The improper cell behaviour in an organism afflicted with malignant growths is also associated with the chemistry of nucleic acids -- with a disturbance of the proper die process.

The revelation of this most extensive picture and mastering of methods for intervention into the process of the chemical origin of the cell is a basic problem in the knowledge of natural science at the point of contact between chemistry, physics and biology, which will lead to an innumerable number of practical consequences. This work has been started and is developing successfully. By means of a chemical influence on cells, which interferes with their normal division, so called polyploid forms with differing hereditary characteristics are obtained. Irradiation with x-rays and gamma rays breaks or reforms the nucleic acid strains and brings forth new properties that are capable of being transmitted through heredity. The latter is a method used in obtaining the most productive forms for the manufacture of antibiotics, which are micro-organisms.

The discovery of these fine mechanisms and control over them will probably be wrought with consequences for chemistry and the chemical industry as well as for biology.

Is it not enticing to have factories where the synthesis of matter of any complexity is accomplished beginning with the loading of raw material (such as food), at room temperature and not under pressure, first, deterioration and then the synthesis? Man, as usual will go farther than nature along this path, and will construct such enzyme and molecular die groups that will serve as a source of raw material, and will differ in nature and in the way of production from the factory cell that served as the sample.

The die is nucleic acid and contains a code for the albumin structure, which is synthesized by means of this code. We can only suspect the principles involved in the activities of this code. In any case, it is this code that is responsible for allowing the synthesis of a specific albumin out of the twenty different amino acids found in cell sap. At the same time even if the size of the albumin molecule is limited to the size of one thousand amino acid residues, using twenty varieties of these residues, it is possible to construct approximately 10^{1300} (a number expressed by the figure one with thirteen hundred zeros) different albumin specimens. Here this problem encounters the perplexities of the theory of information.

The structure of the given type of nucleic acid transmits to the cell the material data on the type of albumin molecules that are to be synthesized in the cell. This touches on cybernetics -- science of control systems, in this case controlling the synthesis of a certain definite variety of structure. Organic automation is amazing! It can undoubtedly teach us many things about industrial automation.

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The last strategic problem of science and technology, which I will be able to touch upon here, but one that is probably the most important of all is associated by all facets with the building of communism -- it is the problem of automation in all of its varieties. Step by step mechanization relieves man from hard and fatiguing forms of physical labor. The automation of industrial processes progresses even further and leaves man with supervisory and guiding factors only. Here is a vast field of research work, as rational automation usually requires an adjustment to its requirements and even a reorganization of the technology of production itself. The so-called cybernetic or directing machines relieve man who is already not a laborer but a master or engineer, of the function of guiding the process as well.

One of the outstanding inventions of the twentieth century, that was so abundant in this respect, was the invention of the rapidly functioning electronic computers. Controlling machines are a part of that. They receive data from the transmitting element of the instrument regarding the numerical values representing links of the production process (parameters), and by comparing such data with a previously introduced program, are able to compute the optimum course for the process at hand and transmit orders directly to the various automatic production links regarding the necessary changes in the parameters. The application of electronic computers in science and technology is expanding. The launching of satellites into predetermined orbits, flights of interplanetary space ships, calculations for atomic reactors and many other operations were impossible without such computers.

At the present time intensive work is being conducted in various countries on the perfection, miniturization and on increasing the speed of such computers. Increasing the speed (ten fold) of these computers broadens the horizons of their application. Problems formerly insolvable due to the overwhelming bulk of the necessary computations are now solved. A researcher in the structure of matter using x-rays or electronography, who spent days on an experiment and many months for the computations is now free from such burdensome work, and the structural methods will undergo extensive development. There are many such examples. It is therefore appropriate to expect a widescale penetration of science and then of technology and every-day life by mathematical methodologies.

Ever increasing areas of science will become exact and quantitative. The generation now entering school will live and create in a world with a much greater awareness of mathematics; this must be taken into consideration by the national organs of education. The fact that computations will be made by machines instead of by man will improve and accelerate the various processes only with the presence of a comprehensive knowledge of mathematics by wide circles of workers, who are delegated with the responsibility of utilizing the new opportunities provided by science.

It is particularly important to attain a stage, within the immediate future, where all of our accounting and planning organs, from the lowest to the highest ones, would become equipped with such perfected techniques. Machines are capable of computing hundreds of possible alternatives in accordance with a previously introduced program and to choose the best one. I believe that the savings resulting from this measure alone would justify all of the generous investments made in science.

Electronic machines are capable of, and indeed do, fulfill certain logical functions in addition to the arithmetical computations. This permitted, for example, their utilization in translation from one language into another.

Machines do (and must) serve in the field of information. As a new year's dream, but a dream which is already gaining a scientific foundation, it is possible to imagine universal information machines, the durable memory of which will contain a recording of entire libraries, which will be constantly brought up to date automatically by means of communication channels. Such a machine must, on demand of its subscribers, possibly other machines, furnish information on any combination of inquiries in the form of photostats of the original or of the printed copy transmitted to any point along the communication channels.

The problem of scientific information requires deep thought. The amount of data published in scientific literature is growing at a colossal pace. At the present time the number of scientific periodicals throughout the world (not counting books) has grown to several tens of thousands. Information on chemical subjects alone, appears in eight thousand magazines. Approximately two new magazines begin publication daily. How to find the necessary data among this Himalaya of scientific literature (I am using S. I. Vavilov's expression?)

How can one visualize the literature and the scientific information of the future? The future way of information is by machine. It is necessary to rapidly comprehend this and to boldly bring it to reality.

The power of science is immeasurable, and man's mastery over nature is already great. The solution of strategic problems in science will aid in the establishment of a material and technical basis for communism, it will arm the man of communism with complete mastery over nature, nature of the earth and planets, and will open still broader vistas for joyful creative work.

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