Nikolaĭ Nikolaevich Bogolyubov (on his seventieth birthday)

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Academician Nikolaĭ Nikolaevich Bogolyubov, a major contemporary scientist, was born on August 21, 1909 in Nizhniĭ Novgorod (now Gor'kiĭ). N.N. Bogolyubov began his scientific work in Kiev, where, from the age of thirteen, he began to work in the Seminar of Academician N.M. Krylov and, as early as 1924, wrote his first scientific paper.

The initial period of N.N. Bogolyubov's scientific creativity was concerned with mathematical problems such as direct methods in variational calculus, the theory of almost-periodic functions, methods for the approximate solution of differential equations, and dynamic systems.

Even this very early work of the then young scientist on the development of direct methods for the solution of extremal problems made him widely known. One of the papers in this series was awarded the Prize of the Bologna Academy of Sciences.

During this period, N.N. Bogolyubov produced a new development of the theory of homogeneous almost-periodic functions, having exhibited the close connection between this theory and the general theorem on the behavior of linear combinations of values of an arbitrary bounded function.

From 1932 onward, N.N. Bogolyubov collaborated with his teacher, N.M. Krylov, in the development of a completely new branch of mathematical physics, namely, the theory of nonlinear oscillations, which they referred to as nonlinear mechanics. They directed their research toward the development of new methods for the asymptotic integration of the nonlinear equations describing oscillatory processes. N.N. Bogolyubov developed a new mathematical formalism for the investigation of general nonconservative systems with a small parameter. In papers devoted to this problem he investigated the nature of the exact stationary solution near an approximate solution for a sufficiently small value of the parameter, and established a number of theorems on the existence and stability of quasiperiodic solutions.

NIKOLAĬ NIKOLAEVICH BOGOLYUBOV

Among methods formulated and developed by N.N. Bogolyubov in nonlinear mechanics, the method of averaging and the method of integral manifolds are particularly important and are now regarded as classic.

The fundamental ideas and results of N.N. Bogolyubov in nonlinear mechanics are the basis for many modern studies in general mechanics, the mechanics of continuous media, celestial mechanics, the mechanics of solids, the mechanics of gyroscopic systems, the theory of stability of motion, the theory of control, regulation, and stabilization, the mechanics of space flight, mathematical ecology, and other branches of natural philosophy and technology.

N.N. Bogolyubov's qualitative studies of the equations of nonlinear mechanics, which have essentially led to a new development of the theory of invariant measure, have been of major importance for the subsequent development not only of nonlinear mechanics but also of the general theory of dynamic systems. This theory was founded on the concept of the ergodic set and on a series of penetrating theorems on the possibility of decomposition of the invariant measure into irreducible invariant measures localized in ergodic sets. All these concepts have long been regarded as classic modern theory of random processes.

The mathematical methods developed by N.N. Bogolyubov for the investigation of dynamic systems have enabled him to adopt a fundamentally new approach to the mechanics of systems consisting of a large number of particles. In the early papers belonging to this series (the first was published in 1939), he considered the appearance of stochastic regularities traditionally described by the Fokker-Planck equation for dynamic systems exposed to the random effect of a thermostat. He first used the example of a rigorously solvable model to

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exhibit the general features of the evolution of a statistical system and the establishment of its state of equilibrium. It turned out that the random process describing the behavior of the system could be looked upon as a dynamic Markov process, depending on the choice of time scale, whereas, in the general case, it was a non-Markov process. The concept of time hierarchy was thus first introduced into nonequilibrium statistical physics and was eventually found to be the key concept in all subsequent developments in the statistical theory of irreversible processes.

The major contribution made by N.N. Bogolyubov to the statistical mechanics of nonideal classical systems took the form of a series of papers eventually incorporated in his widely known monograph "Problems of Dynamic Theory in Statistical Physics" (1946) in which he developed the method of chains of equations for equilibrium and nonequilibrium many-particle distribution functions.

The concepts introduced in these papers were new to physics and formed a new stage in the development of statistical mechanics following the era of Gibbs and Boltzmann. At present, no serious investigation in the theory of nonideal systems, both classical and quantum, can be carried out without using some modification of the formalism of correlation functions developed by Bogolyubov and the Bogolyubov hierarchy of equations for them.

N.N. Bogolyubov investigated the chain of equations for the distribution functions in the case of statistical equilibrium and put forward regular methods for the most important physical cases, i.e., those of short-range (low-density gas) and long-range (system with Coulomb forces) interactions in the form of an expansion in terms of a small parameter or the reciprocal powers of the specific volume referred to the cube of the interaction range, or the powers of the specific volume referred to the cube of the Debye length.

In nonequilibrium systems, these expansions of the distribution functions are suitable only for very short intervals of time because of the appearance of secular terms. The resolution of this difficulty and the associated development of regular perturbation theory methods in nonequilibrium statistical mechanics was achieved through the application of a particular version of previously developed methods in nonlinear mechanics and the introduction by Bogolyubov of a major physical concept, namely, the existence of different scales of time.

The physically reasonable concept of the single-particle distribution function appears only in a certain approximation when one considers time scales that are large in comparison with the time necessary to weaken correlations. For this type of distribution function, it is possible to obtain a closed transport equation, for example, a Boltzmann-type equation.

To derive the transport equation itself, Bogolyubov replaced the Boltzmann hypothesis of molecular chaos, associated with neglecting correlations between the dynamic states of colliding particles with a new physical approach in which the conditions necessary to weaken correlations are used as the boundary conditions imposed on any initial condition that is consistent with the particular special case under consideration, so that the explicit structure of the collision integral appears at the dynamic level. This method can be used not only to obtain the main Boltzmann term but also to investigate higher-order approximations.

Further studies of the evolution of the system performed by Bogolyubov show that the next stage is already hydrodynamic and is connected with a transition to a still coarser time scale substantially exceeding the time of traversal of one mean free path (i.e., the time of formation of local thermodynamic characteristics). At this stage of evolution, the single-particle distribution function is itself dependent on the hydrodynamic parameters of the system (local velocity, density, and specific internal energy). N.N. Bogolyubov then constructed a closed set of hydrodynamic equations for the latter quantities by starting directly with the Liouville equation and without introducing the transport equation (1948). This idea was the logical completion of the description of the evolution of many-particle systems and has had considerable influence of the subsequent development of the theory of nonequilibrium processes.

Equally fundamental results were obtained by Bogolyubov in quantum statistics. By generalizing the method of classical correlation functions to the case of quantum statistical systems, he developed chains of equations for the equilibrium and nonequilibrium statistical operators, and put forward a method for constructing the transport equations in the quantum case (1947). The idea of different scales for microscopic processes in statistical systems was subsequently used by N.N. Bogolyubov to derive the equations of the hydrodynamics of superfluid liquids (1963).

N.N. Bogolyubov has recently returned to general problems in the evolution of statistical systems. In his 1975–1978 papers, he considerably extended the idea of transient processes in nonequilibrium systems and extended the microscopic structure of the Boltzmann approximation in kinetics. By applying his previously developed description of the evolution of stochastic processes in the case of a small system (consisting, possibly, of even one particle), weakly interacting with a large system, in conjunction with a new effective and, as always, powerful Bogolyubov-type technique, he was able to unify the approach to the description of all the stages of the evolution process, including both the kinetic stage, with all the higher-order correlations between the particles, and the hydrodynamic stage.

N.N. Bogolyubov's name is firmly linked with the creation of the modern theory of nonideal quantum macrosystems.

In his paper read in 1946 to a meeting of the Division of Physicomathematical Sciences of the Academy of Sciences of the USSR, N.N. Bogolyubov gave a brilliantly simple and physically penetrating explanation of superfluidity. He showed that the phenomenon of superfluidity in a Bose system with weak interaction is due to the appearance of a condensate in the system. If the condensate is thermodynamically stable, the interaction not only does not destroy this state but, on the contrary, stabilizes it. N.N. Bogolyubov constructed the most effective mathematical formalism for the phenomenon and described the formation of the condensate by segregating the classical component from the operator wave function. He then used a canonical transformation, now widely known as the Bogolyubov transformation, to diagonalize the quantum part of the Hamiltonian. This transformation determined the quasiparticles that did not interact in the first approximation, and enabled him to establish that correlations between pairs of particles with opposite momenta played the main role in the stabilization of the condensate. These investigations led to the development of the microscopic theory of superfluidity and thence to a rigorous description of the energy spectrum of superfluid systems and to an explanation of the relationship between superfluid and normal states. Modern research into the properties of nonideal Bose gases begins with the Bogolyubov spectrum and the Bogolyubov structure of the ground state as the starting point.

The generality of the new concepts introduced in the above paper, including, in particular, the connection between the stability of the classical state and the positive-definite quantum part of the Hamiltonian was much greater by far than was necessary for this particular problem, and it is now clear that it is among the classic concepts of statistical physics and quantum-field theory.

In September 1957, N.N. Bogolyubov applied his canonical transformation, generalized to fermion operators, to the rigorous development of the theory of superconductivity based on the Fröhlich model, which takes into account electron-phonon coupling in metals. The vacuum of quasiparticles determined by this transformation is a state with an undetermined number of particles—a peculiar condensate—whose formation is governed largely by correlation between particles with opposite momenta and spins. The stability of this condensate, in fact, determines the particular properties of the superconducting state. The method of canonical transformation is the most effective in taking into account the existence of Cooper pairs near the Fermi surface and has thus turned out to be the most powerful means of investigating energy spectra of superconductors. It has been used to establish that, in addition to fermion-type excitations, connected with the breaking of correlated pairs and characterized by a definite value of the energy gap, the system also contains collective Bose gapless excitations that are of fundamental importance (1958).

Thus, N.N. Bogolyubov's 1957 papers provided the microscopic theory of superconductivity, which was developed by him independently of and almost simultaneously with the work of Bardeen, Cooper, and Schrieffer.

The idea of superconductivity as the superfluidity of Fermi systems led Bogolyubov to the discovery of a new fundamental effect in the superfludiity of nuclear matter (1958). This concept is now the basis of modern theory of the nucleus.

In subsequent studies, N.N. Bogolyubov showed that the stabilization of the condensate in nonideal systems was a consequence of degeneracy in the number of particles, a feature characteristic of systems with an infinite number of degrees of freedom. His studies of systems with degeneracy led Bogolyubov to the formation of the now widely known method of quasiaverages (1961). When used in conjunction with his method of two-time temperature Green functions (1959) and the technique of spectral expansions, this method is essentially a universal means of investigating systems whose ground state is unstable against small perturbations (relative to the source of pairs in the case of superconductors and the introduction of a weak magnetic field in the case of a ferromagnet).

An important achievement of the method of quasiaverages is Bogolyubov's fundamental theorem (1961) showing that spontaneous violation of symmetry is always accompanied by long-range interactions in the system. This theorem has been used to solve the fundamental question of the structure of the energy spectrum of low-lying elementary excitations in nonideal Bose and Fermi systems by relating this problem to the requirement of gauge invariance.

The ideas and methods developed by Bogolyubov for the study of nonideal quantum systems have not only had an enormous influence on the development of modern statistical physics, but have also turned out to be exceedingly fruitful in relation to other important problems in quantum field theory connected with the problem of degeneracy and stability of vacuum. The very idea of a possible instability of vacuum in quantum field theory arose as a result of his studies.

Quantum field theory has attracted Bogolyubov's attention since the early 1950's. The most important feature of his work in this area was the introduction of new concepts. Quantum field theory had only one effective formalism at that time, namely, perturbation theory, and the main defect of this formalism, i.e., the ultraviolet divergence, could be eliminated only as a result of the somewhat suspect renormalization of mass and charge. Bogolyubov's papers emphasized that the interpretation of the divergence as a *defect* of the theory was essentially connected with the direct transplantation of conventional macrophysical concepts onto quantum field theory. The nature of these divergences is rooted in the representation of microphysics in which an elementary particle is looked upon as a quantum of the local wave field. It follows that an acceptable mathematical formalism must organically incorporate generalized functions.

In his researches into quantum field theory, Bogolyubov abandoned the usual Hamiltonian formalism and based his theory on the S matrix introduced by Heisenberg. In his papers published in the early 1950's, he showed that the S matrix could be deduced from the interaction Lagrangian in all orders of perturbation theory by demanding only the validity of the basic physical principles of the theory of relativistic invariance, spectral decomposition, unitarity, and causality. The development of a new causality principle, now well known as the Bogolyubov microcausality condition, has played an important role in these and subsequent investigations.

Bogolyubov's theorem that the scattering matrix is determined in all orders of perturbation theory to within quasilocal operators, with the reason for nonsinglevaluedness residing in the singular nature of the coefficient functions of the S matrix, has exposed the origin of the ultraviolet divergences and has pointed to a reasonable way for their removal, namely, the Bogolyubov operation (1955). The perturbation theory developed in this way is essentially purely axiomatic. As a matter of fact, it is the first rigorous axiomatic scheme in quantum field theory.

Bogolyubov's paper, read to the Seattle Conference in 1956, signalled a new stage in the development of both the axiomatic approach and the physics of strong interactions generally. In this paper (with its characteristic Hilbert-type "we should know, and therefore, we will know"), N.N. Bogolyubov used his microcausality principle to establish the causal structure of the amplitude for pion-nucleon scattering, and directly proved the possibility of analytic continuation of the amplitude to complex energies. The proof was connected with the discovery of a new principle of analytic continuation of generalized functions of many variables and the associated "edge of the wedge" theorem which has become the foundation of a new branch of mathematics.

N.N. Bogolyubov's work on dispersion relations resulted in a new development in the theory of strong interactions. The point is that he not only constructed a consistent formalism independent of the assumption of weak interaction between elementary particles, but also introduced a whole series of ideas in the course of the derivation. Dispersion relations are now the basis of a new language in the theory of strong interactions. Physicists were given the new concept of the scattering amplitude as the only analytic function of scattering variables, and it is precisely this concept that has played a decisive role in subsequent developments of the theory. At first sight, this purely mathematical concept was a reflection of deep physical connections between apparently different processes. It became clear that even if the scattering amplitude could not be found for a given process, it was possible to find its connection with the amplitudes for other processes. The idea of coupling between different reaction channels was the starting point for many heuristic derivations of the scattering amplitude.

The work of Bogolyubov and his pupils is the foundation for very different and broad applications of the axiomatic method such as asymptotic estimates at high energies, the description of low-energy regions using the unitarity condition, and so on.

Many ideas and researches in other branches of relativistic particle dynamics are also due to Bogolyubov.

His papers on the theory of elementary particle symmetry appeared in 1965–1966. These researches led, in particular, to the introduction of a new quantum number which is now referred to as the "color" and plays a fundamental role in modern versions of the theory of weak and strong interactions.

The foregoing account is far from exhausting the entire range of Bogolyubov's scientific activity. He has also been responsible for many fundamental researches in the theory of plasma and transport equations that are of great applied importance.

Bogolyubov's papers have dealt with many branches of mathematics, mechanics, and physics. He has been responsible for many fundamental scientific researches in each of these areas. He has published more than 200 papers and monographs.

The main feature of Bogolyubov's scientific style is his ability to isolate key aspects of a problem, to identify its basic solubility, then, unimpeded by difficulties, to develop a suitable formalism for the solution of the problem through an organic combination of mathematics and physics. Anyone studying Bogolyubov's work will be reminded of the period when those engaged in the study of exact sciences were referred to simply as natural philosophers. This characteristic has enabled Bogolyubov to make a decisive contribution to the development of theoretical physics in the course of the last four decades and, in effect, to develop a new modern mathematical physics. All this has long since ensured N.N. Bogolyubov's place among the leading world scientists who have made their own individual imprint on theoretical physics in the second half of this century.

Bogolyubov has devoted much attention to the education of the new generation. He has been responsible for the development of a number of scientific schools, such as the School of Mathematical Physics and Nonlinear Mechanics in Kiev and the School of Theoretical and Mathematical Physics in Moscow and Dubna. Many famous scientists are proud to refer to N.N. Bogolyubov as their teacher.

Bogolyubov is also concerned with organizational problems in science. He is at present a Member of the Presidium of the Academy of Sciences of the USSR, Director of the Joint Institute of Nuclear Research, and Editor-in-Chief of the journal Teoreticheskaya i Matematicheskaya Fizika, which he created.

N.N. Bogolyubov has devoted much time and attention to public work in his role as Delegate to the USSR Supreme Soviet.

The country greatly values his scientific and public activities.

Bogolyubov has been awarded the Lenin Prize, the USSR State Prize (twice), the Lomonosov Prize of the USSR Academy of Sciences, the Order of Lenin (five times), and many other orders and medals. In 1969, Bogolyubov's outstanding work was marked by the award of the Gold Star of a Hero of Socialist Labor.

N.N. Bogolyubov's outstanding contribution to science, and his great scientific and public authority, have been acknowledged by his election as foreign member to many academies abroad. He has been awarded honorary doctorates by leading universities around the world, and many international prizes and medals.

In his seventieth year, N.N. Bogolyubov is at the height of his creative powers. We wish him many long and happy years of creative inspiration and new discoveries in science.

Translated by S. Chomet