Arkadiĭ Benediktovich Migdal (on his seventieth birthday)

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March 11, 1981 was the 70th birthday of Academician Arkadiĭ Benediktovich (Beĭnusovich) Migdal, one of the most prominent Soviet theoretical physicists, the originator of new scientific trends in nuclear physics and the many-body problem, and the founder of a major scientific school.

Migdal's principal area of scientific interest is nuclear physics and many-body systems in general (including the physical vacuum). In these critically important fields of physics, Migdal has posed and solved major pivotal problems of the greatest difficulty ("exercises," as he usually calls them) in which the range of validity of the standard approximate methods of quantum mechanics (notably perturbation theory) is drastically narrowed and new, profoundly nontrivial approaches are necessary. And for more than 40 years now, Migdal has succeeded, with inexhaustible ingenuity and energy, in finding precisely the approaches that are needed. Here, for all of his range and even virtuosity in the art of the qualitative, "fingertip" estimate, he is seldom content with this result alone, and keeps after the quantitative result that will admit of direct comparison with experiment or permit confident prediction of new observable phenomena. In Migdal's works, therefore, we find both the most modern and often highly sophisticated mathematical apparatus and his characteristic mastery at combining the microscopic and phenomenological approaches. It is probably this impressive blending of diverse weapons from the arsenal of modern theoretical physics—which always seem to be fortunately chosen and which are invariably applied with the suborner's skill and balance—that complements the fundamentalism and instructive force of Migdal's works with a certain esthetic charm, so that they emerge as something akin to works of art.

Migdal was born in 1911 at Lida (now in the Belorussian SSR) and spent his early years in Leningrad. Here, in 1928, while working as a school physics-laboratory assistant, he completed (and published, in the journal "Fizika, Khimiya, Matematika, Tekhnika v Trudovoi Shkole") his first scientific paper, which was entitled "On an Error in Application of the Atwood Machine." He then entered the Physics Department of Leningrad State University (LGU) and, from 1931 to 1936, worked as an estimator-engineer at the "Elektropribor" plant, where he also produced several scientific papers.[1)]

Migdal graduated from the LGU in 1936 (his counselor had been M. P. Bronshteĭn) and went on to graduate studies at the Leningrad Physico-Technical Institute (LFTI), where the basic direction of his entire later scientific career was decided.

In his early papers, Migdal discussed the interactions of neutrons with atoms, and specifically the ionization of the atom on collision of a neutron with its nucleus (1939). In solving this problem, Migdal used an original "scrambling" method that was subsequently used widely in solving a variety of problems and won its author a certain amount of recognition. Migdal defended a Candidate's Dissertation on this subject in 1940.

Also in 1940, Migdal moved to Moscow to work on his doctorate in the theoretical section of the Institute of Physical Problems (IFP), which was then headed by L. D. Landau. Here he continued his investigation of processes that accompany nuclear reactions: ionization in β-decay (1941) and in α-decay (1941). Somewhat

1) Migdal himself gave a wry account of one of them in an article in the journal "Kvant" (1975, No. 3).

later, he developed a theory of giant dipole resonance in nuclei (published in 1945) in which he gave a qualitative description of the phenomenon as resulting from displacement of the nuclear protons relative to the neutrons and calculated the position of this resonance. This paper also became a classic and has appeared in many handbooks of nuclear physics. The above studies formed the basis of Migdal's doctorate dissertation, which he defended in 1943.

In 1945, Migdal transferred from the IFP to the Institute of Atomic Energy (IAE), then headed by I. V. Kurchatov, and went to work on the atomic problem. Here he obtained results of fundamental importance. Working from ideas put forth by Landau and himself to the effect that a block of uranium in a moderator may be treated as a source of fast resonant neutrons and a sink for thermal neutrons, Migdal (jointly with A. M. Budker) developed a mathematical-design procedure for a heterogeneous finite reactor. Another very important result obtained by Migdal was the exact solution of the problem of γ-quantum absorption by an unbounded medium with allowance for multiple scattering, a matter of vital importance for calculation of biological reactor shielding.

In 1951–1953, Migdal and a group of his co-workers were involved in the controlled thermonuclear fusion research that was started at that time at the IAE. Among his papers in this area, note should be taken of a pioneering 1951 study (co-authored with V. M. Galitskiĭ) of the highly important problem of the propagation of cyclotron radiation in a magnetized thermonuclear plasma (published in 1958) and Migdal and S. I. Braginskiĭ's 1953 qualitative theory of the basic physical processes (ionization, skin effect, pileup, "combing off" of gas, etc) that attend the "inertial" pinch effect (published in 1958). During the same period, Migdal collaborated with Galitskiĭ on development of the method of collective variables for description of plasmas (simultaneously with and independently of Bohm and Pines).

During all of these years, Migdal continued active development of fundamentally important quantum-physics problems. His paper on the theory of nuclear reactions with slow-particle production (read at a 1950 seminar and published in 1955) is widely recognized. It was one of the first studies in the theory of strong interactions that was based on use of the analytic properties of the S matrix and on definition of its most important properties. This approach later came to be known as the "polological" or dispersion approach, and the very effect of the "interaction in the final state" (Migdal–Watson effect) is still one of its most brilliant accomplishments.

An original method ("three-dimensional classification") was developed in a 1955 paper that Migdal co-authored with I. I. Gol'dman. In 1954–1955, Migdal derived a quantitative theory of bremsstrahlung and pair production on the passage of a fast particle through matter. Although the qualitative picture of the phenomenon was understood (Landau and Pomeranchuk, 1953), the unusual complexity of the process had made construction of a quantitative theory appear impossible. It was possible to solve this problem by using a new method: the quantum kinetic equation. This method came into extensive use both in Migdal's own work and in the work of others on the multiple-scattering problem.

The next period in Migdal's creative evolution is associated with a modern formulation of the many-body problem based on application of the methods of quantum field theory. Migdal and his closest students were the authors of pioneering work in this area. The 1957 paper on the momentum-distribution jump for an arbitrary Fermi system (the "Migdal jump") and the 1958 effort (with Galitskiĭ) on formulation of a Green's-function method for Fermi systems are classics and are reproduced almost verbatim in references on the many-body problem. The analytic properties of the Green's function, spectral expansion and dispersion relations for the Green's function, an exact energy formula—this list of results of these studies is far from complete. Also widely known in Migdal's 1958 paper in which the problem of the interaction of electrons with phonons in a normal metal was first solved without recourse to perturbation theory.

A natural continuation of these studies was the application of quantum-field-theory methods to atomic nuclei. The first papers in this cycle were "Superfluidity and Moments of Inertia of Nuclei" (1959) and "Single-Particle Excitations and Superfluidity in Fermi Systems with Arbitrary Interaction. Application to the Nucleus" (1961). In the former, Gor'kov's equations from the theory of superconductivity were used to investigate the influence of superfluidity on nuclear moments of inertia, and in the latter a rigorous formulation of the nuclear shell model was given in terms of Green's functions and a diagram technique was developed for finite systems with superfluidity. The next major series of papers (some of them co-authored with students) culminated in preparation of the monographs "The Theory of Finite Fermi Systems and the Properties of Atomic Nuclei" (1965) and "The Quasiparticle Method in the Theory of the Nucleus" (1967). It was necessary to overcome serious difficulties, stemming not only from the spatial inhomogeneity of the system but also from the discreteness of its energy spectrum, in order to apply many-body methods to the finite system. A theory of renormalizations was developed and general relations were established for the local "charges" of the quasiparticles in the nucleus with respect to various external fields—relations that proceed from the laws of conservation and gauge invariance. At the cost of introduction of several universal phenomenological parameters to characterize the quasiparticle interaction near the Fermi surface, the theory made it possible to describe a wide range of nuclear phenomena: the spectra of low-lying states and the probabilities of transitions between them, isotopic and isomeric shifts of atomic and mesoatomic lines, magnetic and quadrupole moments, β-decay and μ-capture probabilities and many others; some of the effects—the isotopic shift, μ-capture, etc.—were analyzed microscopically for the first time. Both of Migdal's monographs have been translated in the United States and have become ready references for theoretical physicists all over the world. During the years since, the theory of finite Fermi systems has withstood testing in numerous experiments, and it now enables us to calculate all low-energy characteristics of nuclei, including nuclear masses and the distributions of neutron and proton densities. It has become a generally recognized trend in the theory of the nucleus and one that is being developed actively both in the USSR and abroad.

In the early 1970's, Migdal embarked on a new course of research–the behavior of Fermi and Bose systems in strong external fields (this coincided in time with his move to the L. D. Landau Institute of Theoretical Physics in 1971). His paper "Vacuum Stability and Limiting Fields" (1971) predicted a fundamentally new phenomenon—the instability of the boson vacuum in a strong external field, with the result that a classical boson field (condensate) appears in the ground state of the system. A quantum-field theory of this phenomenon was derived, and a real physical system in which the effect might occur—the pion field in a nucleonic medium—was indicated. It was shown that a phase transition with formation of a pion condensate should occur in nuclear matter at sufficiently high density. The hypothesis of the possible existence of superdense nuclei in which the energy of compression of the nuclear matter is offset by an energy gain from pion condensation was advanced as an important implication.

These ideas were developed further in later papers. Migdal developed a formalism for quantitative analysis of the pionic degree of freedom in nuclei that constitutes a development of the methods of the theory of finite Fermi systems. Its application made it possible to perform a realistic calculation of the pion polarization operator in nuclear and neutron matter and use it to construct the spectrum of excitations with the quantum numbers of π mesons, and to calculate the critical parameters of pion condensation.

A comparison of theory with experimental data made by Migdal and co-workers led to an interesting hypothesis: real atomic nuclei are close to the critical point of the π-condensate phase transition. Theoretical and experimental studies aimed at confirming this hypothesis are now underway on a broad front. The following candidates are being considered as "precursors" of the pion condensation: enhancement of l-forbidden M1 transitions, the positions of nuclear levels with "pionic" quantum numbers ($0^-, 1^+, 2^-, \ldots$; $T = 1$), and an increase in the inelastic scattering cross sections for protons scattered on nuclei with these levels excited.

The properties of systems in the presence of a developed pion condensate were studied in the papers of another series; among other things, an equation of state was derived for nucleonic matter with consideration of pion condensation. After detailed analysis, Migdal suggested that it might be possible for three qualitatively new types of nuclei to exist: superdense, neutronic and supercharged. The stability regions, expected properties, and methods of detection of these anomalous nuclei were investigated.

A theoretical analysis of pion condensation in neutron stars led to interesting astrophysical implications. It was found that on reaching a critical (for the onset of pion condensation) density, a star can made a transition within $\sim 10^{-3}$ sec to a superdense state, releasing a tremendous amount of energy. Further study of this phenomenon may significantly alter our conception of the mechanisms of supernova flareups.

Migdal's work on the pion condensation has stimulated much interest in theoretical and experimental investigation of extreme states of nuclear matter. Hundreds of papers in which Migdal's conception has been confirmed and expanded upon have been published. The subject has a firm place at the most important international conferences on nuclear physics. Work is being done in the world's leading nuclear-physics centers to find anomalous nuclei in nature, and on collisions of heavy high-energy ions, in which such nuclei might be formed or somehow manifest themselves.

The basic ideas and results of the new direction are reflected in Migdal's monograph "Fermions and Bosons in Strong Fields" (1978) and in numerous articles and reviews.

Over the past decade, in addition to the work on pion condensation, Migdal's creative laboratory has produced more than a few elegant and clever ideas. Thus, he observed a localization property of the Green's function of a charged particle in a strong inhomogeneous field, investigated the phenomenon of electron condensation around a hypothetical supercharged nucleus with $Z \gtrsim (\hbar c/e^2)^{3/2} \approx 1600$ and made several attempts to solve the zero-charge problem in quantum electrodynamics and the problem of nonejection of quarks in quantum chromodynamics. We should note in this context that

FIG. 1. A. B. Migdal on an island in the Sea of Japan, 1964.

not only has Migdal arrived at a theory of elementary particles, but this theory has itself, in a certain sense, come to him, since qualitative approaches of precisely the "Migdalian" type are highly appropriate for it and even necessary at the present stage in its development.

On the whole, if one were to classify all theoretical physicists on the basis of their creative mindset and powers with the tags "must do" and "can do" (the result would obviously be a 2×2 matrix), the only way to characterize Migdal would be to say that "he does what must be done, and in the way that it must be done."

Migdal's scientific creativity is inseparable from his role as a teacher. He has instructed dozens of scientists who are now pursuing active careers, among them Academicians, Corresponding Members, and many Doctors and Candidates of Sciences. The brilliant lectures on nuclear theory and approximate methods of quantum mechanics that he has delivered for 35 years at the Moscow Engineering Physics Institute (MIFI) and the specialized theoretical seminars that he directs attract the most capable students to him. His teaching activity did much to inspire his monographs "Approximate Methods of Quantum Mechanics" (written jointly with V. P. Krainov, 1966) and "Qualitative Methods in Quantum Theory" (1975). The unspoken (but unquestionable) reader appraisal of the class, scientific significance, and practical utility of these and other books by Migdal is evident in the simple fact that all copies are snapped up almost instantly.

Migdal is widely known as a brilliant (and at the same time serious and responsible) popularizer of science. He collaborates with the "Znanie" society, where he lectures regularly, e.g. on the psychology of scientific creativity [a subject on which he has written, for example, the attractive brochure "Searches for the Truth" (1978)]. Even Migdal's appearances on television—a rather, shall we say, nontraditional podium for a scientist—are generally recognized as broadly effective and as aiding in the dissemination of scientific ideas.

Migdal's services to Soviet science have been recognized with high honors: he has been awarded the Order of Lenin (1954) and holds two Orders of the Red Banner of Labor (1951)and 1974) and medals; in 1953 he was elected a Corresponding Member, and in 1966 a full member of the USSR Academy of Sciences.

Migdal is, of course, a "born physicist." However, physics is not the extent of his capabilities, interest, and fascinations. He is a talented sculptor and carver of wood and stone. Curiously, he discovered these artistic gifts only 25–30 years ago, i.e., in his full maturity—which speaks for itself regarding his general traits of personality. Migdal's active interest in numerous sports is also widely known. They range through mountain climbing, downhill skiing, and skating to scuba diving.

A special note on the latter is in order. Not many people are aware that Migdal was one of the originators of Soviet underwater sports, the first Chairman of the Presidium of the USSR's Federation of Underwater Sports, which was organized in 1959, and holder of Underwater Sportsman Card No. 1. In the early 1960s, Migdal made three trips to islands in the Sea of Japan and the Pacific Ocean with a group of scuba divers to study all of the capabilities of the aqualung in underwater sports, observation of marine life, and in the economy in general. These expeditions led to the production of three "underwater" documentary films: "The Sea of Japan Above Us," "Moneron Island," and "Among the Islands of the Pacific." Migdal's interest in the development of scuba diving was serious, and not that of an amateur. He foresaw that scuba diving would become a major sport in our country and be used widely in scientific and practical work, and events have borne him out.

His sociability, wit, and irresistable personal charm have won Migdal the friendship and respect of many people in a wide variety of occupations and age groups. He shares generously what Saint-Exupery called "the only realy luxury—the luxury of human communion."

Unfortunately, it is not often that one can state with quiet conviction, without "birthday stretching," that the celebrant has reached 70 in the flower of his creative powers and competence. And while we heartily congratulate Arkadiĭ Benediktovich in the name of all of his many friends, students, and even his readership, wish him "Migdalian" good health and happiness, and look forward as a matter of course to more of his clever new ideas and brilliant scientific results, we are firmly confident that his 45-year career in physics will continue. After all, this is a steady ascent, a path "onward and upward." Like an experienced alpinist, with measured movements, perseverance, and purpose, Migdal raises himself from one peak to the next.

The highest peak has not yet been reached.

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