Academician Gersh Itskovich Budker (obituary)

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May 1, 1978, marks the sixtieth birthday of the outstanding Soviet physicist, Academician Gersh Itskovich (Andreĭ Mikhaĭlovich) Budker, organizer and director of the Novosibirsk Nuclear Physics Institute and laureate of the Lenin and State prizes.

Andreĭ Mikhaĭlovich was born May 1, 1918, in the village of Murafa of the Shargorodskiĭ District of the Vinnitskaya Province to the family of a rural worker. On finishing the Vinnitskaya Secondary School in 1936 he entered the Physics Department of Moscow University.

The new physics with its remarkable theories captivated Andreĭ Mikhaĭlovich from the very beginning. He accepted it at once without looking back at "common sense" and classical ideas. Later on he always had a negative attitude to attempts to return to the "good old days" of classical physics. Instead, he was able to develop his own imagination to such an extent that the theory of relativity and quantum mechanics, which he understood deeply and in detail, became for him not simply understandable, but natural and evident, became theories with which one could "work." Not without reason, one of the divisions of the specialized course which Andreĭ Mikhaĭlovich taught in recent years at Novosibirsk University was called Relativistic Design.

GERSH ITSKOVICH BUDKER
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Andreĭ Mikhaĭlovich carried out his first scientific work already in his student days under the guidance of I. E. Tamm. It was devoted to the problem of finding the energy-momentum tensor of the electromagnetic field in moving media. Perhaps already in this problem Andreĭ Mikhaĭlovich sensed the great concealed difficulties and together with them the beauty and inexhaustible possibilities of the complicated systems which subsequently he so skillfully investigated and mastered in his work on high-current accelerators and thermonuclear reactors.

Andreĭ Mikhaĭlovich graduated from the University in 1941 and went directly from his last examination into active duty in the army. In an antiaircraft field unit he made his first invention, improving an antiaircraft fire-control system. The commander of the unit named the apparatus created by him AMB.

After the end of the Great Patriotic War Andreĭ Mikhaĭlovich entered the theoretical section of Laboratory No. 2, the celebrated "dvoĭka" (two), headed by I. V. Kurchatov (now the I. V. Kurchatov Institute of Atomic Energy). Still as a very young physicist, he took an active part in the solution of the problems of atomic energy. Under the guidance of I. V. Kurchatov and A. B. Migdal he carried out a series of studies of the theory of a finite uranium-graphite lattice and also on the kinetics and control of nuclear reactors.

In connection with the construction of what was at that time the world's largest proton accelerator at Great Volga (now the town of Dubna) the interests of Andreĭ Mikhaĭlovich switched to the theory of cyclic accelerators. He was the first to turn his attention to resonance processes in accelerators and studied them in detail; he developed a method for calculation of the shimming of a magnetic field and proposed original methods of efficient extraction of a beam from an accelerator. These studies were recognized in 1951 by the State Prize of the USSR. However, Andreĭ Mikhaĭlovich himself already understood clearly that further development of accelerator technology was impossible without taking into account collective processes in the accelerated particle

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beam. With his first pupils, he began the energetic development of the theory of these processes, in essence laying the foundation for a new field of physics—relativistic plasma physics. In particular, he created the theory of the relativistic kinetic equation and found its solution in the so-called antidiffusion approximation (for infrequent collisions).

Andreĭ Mikhaĭlovich never was a "pure" theoretician. In addition to the features of his own character, this was greatly influenced by the school of I. V. Kurchatov. Therefore he immediately attempted to use the remarkable properties of a relativistic plasma for solving urgent problems of accelerator technology. Here—and this already is undoubtedly one of the clearest features of the creative personality of Andreĭ Mikhaĭlovich—he was in no way satisfied by a gradual improvement of existing accelerators, but pertinaciously sought fundamentally new approaches to the solution of this problem. He succeeded in discovering theoretically the astonishingly beautiful configuration of relativistic electrons and ions which he named a stabilized electron beam. After his report of these studies at the Geneva Conference in 1956, the name of A. M. Budker became widely known and his ideas produced great interest among physicists of many countries.

At about the same time Andreĭ Mikhaĭlovich proposed an original approach to the solution of another urgent problem of physics—the problem of controlled thermonuclear fusion. His approach was based on the use of a plasma trap with "magnetic stoppers" and marked the beginning of all so-called "open" thermonuclear systems.

Andreĭ Mikhaĭlovich burned with the desire to embark immediately on the realization of all these ideas. However, the ideas were too complicated, almost fantastic, and he himself was only a theoretician. At this time he took probably the most important step in his life, a very bold and unusual one, not a step, but rather a jump into the unknown—he decided to place himself at the head of a group of enthusiasts, experimenters and engineers, who were prepared to transform his ideas into reality. Andreĭ Mikhaĭlovich did not take this step without internal hesitation and even dread, but nevertheless he made up his mind, made up his mind in the face of insistent advice and exhortations of many close friends. Having no experience in organization of experimental research, but also unfettered by tradition, Andreĭ Mikhaĭlovich advanced his original ideas also in this area: how a creative scientific group should live and develop. Thus was born the Budker school. At first, in 1953, this was a small group of only eight men. However, the results were not long in coming—in the first few years he built an accelerator of the betatron type with a current up to 100 A, which exceeded by two orders of magnitude the currents of the best accelerators of that time. Andreĭ Mikhaĭlovich's small group grew into one of the largest laboratories (The Laboratory of New Acceleration Methods) of the Atomic Energy Institute, and in 1958 it was converted into the independent Nuclear Physics Institute of the young Siberian Division of the Academy of Sciences of the USSR.

Nevertheless, it turned out to be impossible to produce a stabilized beam—the technical difficulties turned out to be insurmountable. This problem still awaits its solution in the future. Andreĭ Mikhaĭlovich understood this, probably, sooner than others did. What should be done? The already rather large group was working intensively with total devotion. Where should this flux of creative energy be directed? He found the solution—colliding beams! The idea of the collision of two accelerated beams already had been mentioned in the literature, and the tremendous advantages in energy of colliding beams in creation of new heavy particles were clear. However, the idea was discussed primarily as a curiosity or an unachievable dream. Actually, the role of the dense target of an ordinary accelerator is played here by the rarified colliding beam, whose density is several orders of magnitude lower than the density of the highest (at that time) vacuum. However, the experience accumulated in Andreĭ Mikhaĭlovich's laboratory—the study of the physics and the creation of a new technology of intense relativistic beams—opened the way towards the solution also of this fantastic problem of obtaining colliding beams of electrons, and later of electrons and positrons. Of course, undertaking such work was a great risk, but a justified risk, without which there are no serious achievements. The decision to construct an installation with colliding beams was not taken immediately. Major support was provided by I. V. Kurchatov, who believed in the bold ideas of Andreĭ Mikhaĭlovich and the creative forces of his group. In this way arose the main direction of the research of the Nuclear Physics Institute and a new direction of experimental elementary-particle physics. Andreĭ Mikhaĭlovich was one of the pioneers of this direction in world physics.

The first installation with colliding electron beams, VÉP-1, was completed only after the move to Novosibirsk. In 1965 it was used to perform the first experiments on verification of quantum electrodynamics down to distances of the order of 10^{-13} cm. Meanwhile Andreĭ Mikhaĭlovich advanced the new, even more captivating idea of constructing an installation with colliding electron-positron beams. The central problem here was the accumulation of a significant positron current (tens of milliamperes), which required "production" of positrons in large numbers. Andreĭ Mikhaĭlovich persistently looked for the solution of this problem, reviewing dozens of different arrangements, inventing, analyzing, improving. It was here that the simple idea was born of the multiple storage of positrons in a magnetic guide field employing radiative damping of beam oscillations as the result of synchrotron radiation. A crucial element of this scheme was high-aperture positron optics, using parabolic lenses of original design and providing effective collection of positrons after a converter. In this way the VÉPP-2 installation was evolved; in 1967 the world's first experiments on colliding electron-positron beams were performed using this apparatus. This direction of work turned out to be very fruitful, and today a significant portion of all fundamental information on elementary particles is obtained in just such experiments. In particular, this method turned out to be extremely efficient for carrying out "clean" experiments and for the study of strong interactions. In 1967 Andreĭ Mikhaĭlovich and his co-workers received the Lenin Prize for this work.

The work on colliding beams was first reported in 1963 at the International Conference on Accelerators at Dubna and aroused great interest. Immediately after the conference the first group of foreign scientists visited the Nuclear Physics Institute. This was the beginning of a close and fruitful collaboration between the Institute and many scientific centers of Europe and America, a collaboration which since that time has continued to grow and deepen and which Andreĭ Mikhaĭlovich always considered to be of great value.

In 1974 experiments were begun using the new installation VÉPP–2M, which in the old energy region (up to 2×700 MeV) possesses a very high "luminosity," and consequently a high frequency of collisions of electrons with positrons. The luminosity of VÉPP–2M (2×10^{30} cm^{-2} sec^{-1}) is up to the present time an order of magnitude greater than the luminosity of all other installations in this energy region. This result was achieved by production of amazingly narrow beams: at the point of collision their height amounted to only 10 microns!

In 1966 Andreĭ Mikhaĭlovich proposed an efficient method for damping noncoherent oscillations in beams of heavy particles, for which there is essentially no radiation damping. The idea of the method is very simple: parallel to the beam of heavy particles a beam of electrons is moving with the same average velocity and a sufficiently low temperature. Then the frequency of binary collisions is greatly increased and the heavy particles are "cooled" and transfer their energy to the electrons. This method has received the name *electron cooling*. The effectiveness of the method was demonstrated in the experimental apparatus NAP by cooling a beam of protons with energy about 100 MeV: in the course of one tenth of a second the protons could be cooled under these conditions to a temperature of 1/20 eV.

Many physicists looked forward eagerly to this result. The method of electron cooling permits compression of a beam of heavy particles in the transverse direction and consequently makes possible multiple storage of such particles in a magnetic guide field, which opens up the possibility of creating installations with colliding proton-antiproton beams. News of the successful realization of electron cooling spread rapidly among physicists of many countries. Several scientific centers, with collaboration of the Nuclear Physics Institute, began to work with this method.

Considering various arrangements for a proton accelerator for future proton-electron and proton-antiproton colliding beams, Andreĭ Mikhaĭlovich proposed a new method of charge-exchange injection. The idea of the method is to inject into the accelerator negative hydrogen ions which then, losing their electrons, are converted to protons and in this way irreversibly captured into the magnetic guide field. Experiments carried out at the Nuclear Physics Institute confirmed the high efficiency of this method. Andreĭ Mikhaĭlovich proposed also to compensate the proton beam circulating in the accelerator by means of electrons, in order to exceed the space-charge limit of the protons. Experiments showed that under certain conditions, in particular with a sufficiently dense plasma inside the beam, the latter will remain stable. By this method a current exceeding by an order of magnitude the space-charge limit of an uncompensated proton beam was stored.

Already in creating the first installations with colliding beams, Andreĭ Mikhaĭlovich proposed using the unique properties of the synchrotron radiation of such beams to carry out a broad class of experiments in the fields of chemistry and biology. At the present time in the Nuclear Physics Institute there is an operating synchrotron-radiation center, in which scientists from many organizations from various cities of the Soviet Union are working. In the VÉPP–2M and VÉPP–3 installations, special channels for synchrotron-radiation have been constructed, equipped with unique detecting apparatus, also built at the Nuclear Physics Institute. A characteristic example of such research are the experiments conducted jointly with the Institute of Biological Physics, USSR Academy of Sciences, on study of the dynamics of structural rearrangements of molecules of living frog muscle in the process of contraction. During the contraction cycle, which lasts about 0.1 sec, it is possible to obtain 60 successive x-ray photographs.

Having advanced the idea of containment of a hot plasma in a trap with magnetic stoppers, Andreĭ Mikhaĭlovich constantly returned to it, considering various aspects of "open" thermonuclear systems. After an initial period of disappointment produced by the abundance of plasma instabilities, Andreĭ Mikhaĭlovich was one of the first to concentrate his efforts in this field on a deeper and more serious study of plasma physics. He proposed, in particular, to investigate the behavior of a thermal plasma which is from the outset in thermodynamic equilibrium, in order to avoid the turbulence characteristic of heating a plasma by high-power electrical discharges.

About ten years went by in which many of the world's laboratories intensively studied plasma physics. Andreĭ Mikhaĭlovich now reached the conclusion that a new phase of solving the thermonuclear problem was beginning. In 1968 at the Third International Conference on Plasma Physics and Controlled Thermonuclear Fusion, which was held at Novosibirsk, he called on physicists to commence directly the development of a thermonuclear reactor. His thought was that plasma physics had already been sufficiently well studied so that it was possible to look for a solution for the first physical thermonuclear reactor. This call had a great influence on the development of thermonuclear research and, in particular, was the start of serious study of the engineering problems of future thermonuclear reactors.

Andreĭ Mikhaĭlovich himself advanced a new approach to solving this problem, the essence of which was to use a magnetic field only to decrease the transverse thermal conductivity of the plasma, while its pressure was contained by ordinary walls. To reduce thermal conduction along the field it was proposed to use an original "multistopper" magnetic field configuration. The idea was that the rate of expansion of a plasma in the longitudinal direction is sharply reduced if the mean free path of the particles becomes of the order of the distance between neighboring stoppers. Experiments carried out at the Nuclear Physics Institute confirm the effectiveness of this method of thermal isolation of the plasma.

On the basis of Andreĭ Mikhaĭlovich's ideas high-power generators of pulsed relativistic beams were built at the Nuclear Physics Institute, the first such beams used for plasma heating. An important role here was played by the use of ultrapure water as a dielectric in the energy-storage capacitors for the generators of such beams. These studies had a substantial influence on the development of the technology of ultrahigh-power energy sources.

All of this multifaceted activity, it would appear, must have completely absorbed Andreĭ Mikhaĭlovich. To him, this was a small matter—and this is also undoubtedly one of the most pronounced features of his character; he persistently looked for immediate applications and utilization of everything that his Institute knew and could do, to the current vital problems of the national economy, and he came up with—industrial accelerators! These modest devices are not striking in their size or in the energy of their particles. However, they are very necessary to industry, and Andreĭ Mikhaĭlovich gave up a significant fraction of his time, energy, and inventiveness to the development of this activity at the Institute. Beginning in 1963, under his direct guidance an entire series of special electron accelerators was developed, accelerators with an average power from a few kilowatts to a megawatt and an electron energy from several hundred kilovolts to 2 MeV for radiation processing of materials. This permits going over to a fundamentally new production technology in widely different fields of the national economy. Here are several characteristic examples: a considerable increase in the thermal stability of polyethylene insulation; preparation of special thermosetting flexible tubes of polymer materials which "remember" their initial dimensions; disinfestation of grain; decontamination of sewage; cutting and welding of metals; and much more.

In this way the unique scientific program and organizational structure of the Institute arose. It must be emphasized that the success and achievements of the Institute, which are widely known both in our country and far beyond its borders, have been the result not only of the basic ideas of Andreĭ Mikhaĭlovich, but also of his untiring daily work, his indefatigable search for original solutions of a multiplicity of particular problems, at first glance small ones, but which no major enterprise can avoid.

Andreĭ Mikhaĭlovich considered that the best method of solving a complicated problem, be it in physics, technology, or organization, is a collective search by means of constant comprehensive discussions of all possibilities even the most fantastic ones. Such collective creativity must, of course, be supplemented by intensive individual work of each of the participants. Andreĭ Mikhaĭlovich himself worked with exceptional intensity, always and everywhere, knowing no rest, even in the last years of his life when he was already seriously ill. As a rule, he found the necessary solution.

Andreĭ Mikhaĭlovich was not only an outstanding physicist, but also a remarkable teacher. The urge to teach others his favorite science, to discover not only physical laws but also human talent, and to train future investigators, was an integral feature of his multifaceted personality. Andreĭ Mikhaĭlovich began teaching while still a very young physicist, at the just organized Physico-Technical Faculty of Moscow University. It was here that he selected his first pupils. On moving to Novosibirsk, Andreĭ Mikhaĭlovich took an active part in organization of Novosibirsk University. He developed an original course of general physics, organized and headed the chair of general physics, and then the chair of nuclear physics. At his initiative there was created at the Novosibirsk Electrotechnical Institute a special Physico-Technical Faculty which produced not a few talented engineering physicists. Andreĭ Mikhaĭlovich and his pupils actively participated in organizing and conducting the All-Siberian Physico-Mathematical School Olympiads and taught at the Physics-Mathematics School for young prospective scientists at Novosibirsk University. But, of course, the main school of future researchers and engineers was and is the Nuclear Physics Institute, and full participation of students in scientific work, seminars, discussions, and debates. And those who were fortunate to work directly with Andreĭ Mikhaĭlovich were particularly lucky. He recognized in science neither organizational charts nor ranks, and demanded only one thing—not to "rend the air" but to invest thought in each word, not remaining the prisoner of formal syllogisms. In reward for this he generously disclosed his innermost thoughts, the result of many nights of intense meditation, original concepts, unexpected parallels and analogies, the wise advice of a man who had lived a long and complex life. Particularly interesting were the sessions of the Scientific Council of the Institute, which met each Wednesday at noon at the Round Table, which symbolized the inadmissibility of administrative decisions in science. Endeavoring to bring into the discussion and solution of the most important scientific and organizational problems of the work of the Institute as many as possible of his colleagues, including the very youngest ones, Andreĭ Mikhaĭlovich created in recent years three more subject-oriented scientific councils, which also meet weekly.

The Institute was the favorite child of Andreĭ Mikhaĭlovich. He never was simply the director. The Institute is the realization of his creative conceptions in physics, technology, and the organization of science. The Institute is also a new scientific school in high-energy physics, accelerator technology, and plasma physics, a school with its own traditions, principles, and ideals. However, the Institute is, moreover, a huge group of scientists and engineers, workers and employees, a group with its own complex life, which Andreĭ Mikhaĭlovich understood so well and directed so skilfully. In him was combined the scientist, the inventor, and the organizer. In this productive fusion lie the foundations of the Institute and the guarantee of its success, past and future.

Translated by Clark S. Robinson