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ALEKSANDR MIKHAĬLOVICH PROKHOROV

(On his fiftieth birthday)

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JUNE of this year marks the 50th birthday of Aleksandr Mikhaĭlovich Prokhorov, one of the leading Soviet physicists, corresponding member of the USSR Academy of Sciences, and Lenin and Nobel prize laureate. Prokhorov's name is inseparably linked with the creation and establishment of a new branch of physics—quantum radiophysics, and he is presently devoting all his efforts to further development of this field. Prokhorov is a member of the widely known school founded by Academicians L. I. Mandel'shtam and N. D. Papeleksi, and is proficiently continuing the traditions of this school. His work combines very successfully profound pure physical research and the creation of practical operating equipment in which new physical principles and phenomena are employed.

Prokhorov was born on July 11, 1916, in Atherton (Australia), son of a worker-revolutionary who escaped to Australia in 1911 from Siberian exile. The Prokhorov family returned to the homeland in 1923.

In 1939, after being graduated with honors from the physics department of the Leningrad University, Prokhorov enrolled as a graduate student in the Oscillation Laboratory of the Lebedev Physics Institute (FIAN). In 1941 he joined the army; he was released in 1944 after being wounded the second time.

His scientific activity began in 1939 when, under the guidance of M. A. Leontovich and V. V. Migulin, he studied the propagation of radio waves over the earth's surface.

At that time Prokhorov proposed, jointly with Migulin, an original method of probing the ionosphere by a radio-interference method. After returning in 1944 to the FIAN Oscillation Laboratory, Prokhorov rapidly made up for the interruption in his scientific activity and engaged actively in research on frequency stabilization of vacuum-tube oscillators. His first dissertation, under the guidance of S. M. Rytov, was devoted to the theory of nonlinear oscillations. Together with S. M. Rytov and M. E. Zhabotinskiĭ, he received the prize in memory of Academician L. I. Mandel'shtam for developing a frequency-stabilization theory.

After defending the dissertation, he continued to work in radiophysics and in 1948 proceeded to the most vital branch of physics of that time, that of accelerators. He was entrusted with the experimental verification of V. I. Veksler's idea of the possible use of synchrotron-type accelerators to generate centimeter and millimeter waves, in other words, to study coherent radiation in synchrotrons. As is well known, when a relativistic electron moves along a circular orbit (due to the presence of a magnetic field) it emits, besides the fundamental frequency ω, also harmonics $n\omega$. Coherent radiation depends on the electron distribution along the orbit. When this distribution is uniform (betatron), there is no coherent emission. In a synchrotron, where the accelerated electrons occupy only part of the periphery and form bunches of sorts, coherent radiation can be expected.

АЛЕКСАНДР МИХАЙЛОВИЧ
ПРОХОРОВ

As a result of his research, Prokhorov presented a method for determining the dimensions of the electron bunches and showed experimentally that the synchrotron produces coherent radiation at centimeter wavelengths. The results of this work were reported in his doctoral dissertation, which he defended successfully in 1951. The complicated and subtle work on coherent radiation was completed by him in an exceptionally short time. It served as a foundation for many investigations in this field, which are continuing to this very day.

Simultaneously with his research on accelerator physics, Prokhorov began to work, at the suggestion of Academician D. V. Skobel'tsyn, in the field of radio spectroscopy. Heading up a group of young co-workers, Prokhorov was responsible for the rapid progress of this new branch of physics in the USSR. His interest in this field was due greatly to the fact that radio spectroscopy has made use of radar and radio-broadcasting techniques, which were well developed by that time. These methods were applied to a field which was utterly new to radiophysics—the spectroscopy of rotational and vibrational spectra of molecules. Prokhorov's entire subsequent scientific activity has remained characterized by just this feature—rapid, pioneering probing into new fields of physics, using experimental methods and experience accumulated in other branches of physics and engineering.

In radio spectroscopy, Prokhorov tackled the most difficult problem—study of asymmetrical-top molecules. Besides solving purely spectroscopic problems (determination of the structures, dipole moments, and force constants of molecules and of moments of nuclei), his research also followed the line of using microwave absorption spectra to produce frequency and time standards. At first impression this is more an applied problem. But it is Prokhorov's custom to carry out an exhaustive theoretical analysis and gain a deep and thorough understanding of all problems, even those that are seemingly purely technical. It is this very theoretical analysis of means of increasing the stability of molecular frequency and time standards that started the well known cycle of classical researches which he carried out with N. G. Basov and led to the development of molecular generators.*

The operating accuracy of microwave frequency standards is determined by the resolving power of the radio spectroscope, which in turn depends exclusively on the width of the absorption line itself. An effective way of narrowing down the absorption line was to use spectroscopes operating with molecular beam. However, the capabilities of molecular spectroscopes were strongly limited by the low intensity of the observed lines, which in turn was determined by the small population differences of the investigated quantum transition at microwave frequency. The idea that it is possible to increase appreciably the sensitivity of the spectroscope by artificially varying the level populations arose during this stage of the work.

*The first paper by Prokhorov and Basov on molecular generators was delivered in January 1953.

Research in this direction led Prokhorov and Basov to the construction of the molecular generator. This generator is in fact a beam-type radio spectroscope, supplemented with a device for "sorting" the molecules, which picks out of the beam the molecules at the lower level. This makes possible stimulated emission in the system, at a frequency determined in practice only by the frequency of the given transition.

This signalled the most important period in Prokhorov's life—the period of creation and establishment of quantum electronics, of which he is justifiably regarded as one of the "fathers."

It is no accident that the idea of the molecular generator, and later the laser, was arrived at not by opticists but by radiophysicists. The point is that in the visible region of the spectrum the probability of spontaneous emission at ordinary light fluxes is much higher than the probability of spontaneous emission; it is therefore natural that the optical-spectroscopists did not regard stimulated emission as a phenomenon that can really be observed.

The situation is reversed in the centimeter region of the spectrum. Besides, one must recognize that a molecular generator is a typical self-oscillating system, and its creation calls for operating experience with such systems. Prokhorov possessed extensive experience in this field, since he carried out many fundamental researches on self-oscillating systems at the very start of his scientific activity.

The use of the sorting principle led to the creation of a system with so-called negative temperature, i.e., a system in which the greater fraction of the particles is at the upper energy level. Such a system is capable of amplifying oscillations, and if supplemented with a cavity of sufficiently high Q it can be made into a generator. Quantum electronics was "born" just when the negative temperature system was placed in a cavity.

Soon after the first researches on the molecular generator (in which ammonia was used), Prokhorov (together with Basov) proposed a new original method of obtaining negative-temperature systems, called the "three-level system," which subsequently became the main method for the development of both paramagnetic and optical quantum generators and amplifiers.

During 1955—1960, Prokhorov's attention was centered on the development of microwave quantum paramagnetic amplifiers, which offer many advantages over other types, primarily by virtue of the low intrinsic noise level. He paid particular attention during that period to searches for new crystals for the paramagnetic amplifiers and to investigations of their spectra and relaxation characteristics. Prokhorov and his co-workers studied a large group of crystals that might be effectively used in quantum paramagnetic amplifiers. Mention should be made first of the detailed studies of ruby, whose EPR was investigated in his laboratory for the first time and which was proposed for use in quantum paramagnetic amplifiers. It is widely known that ruby is presently one of the most effective crystals in quantum paramagnetic amplifiers for the microwave band and in lasers. The research on EPR in crystals led to rapid development of a whole family of quantum paramagnetic amplifiers.

Prokhorov's work in quantum radiophysics was highly valued. In 1959 he was awarded (together with N. G. Basov) the Lenin prize for creating and developing a new method of amplifying and generating electromagnetic waves.

Naturally, Prokhorov did not work alone. He has an amazing ability to work with young people, whom he trains from their student days. He knows how to state the problem, to attract interest to it, unsuspectingly render help without exerting pressure, and to offer support in "difficult" times. During the years he has worked at FIAN, he covered the distance from graduate student to director of the Oscillation Laboratory, a post he assumed in 1954. In more than a decade as laboratory director, Prokhorov was able to continue and strengthen the traditions of the school of L. I. Mandel'shtam and N. D. Papaleksi. Under his guidance, the Oscillation Laboratory grew and developed, and its outgrowth were two new FIAN laboratories—the Radioastronomy Laboratory and the Quantum Radiophysics Laboratory.

Prokhorov's and his co-workers' investigations of paramagnetic quantum amplifiers played a major role in the development of quantum electronics in the USSR, which attracted many scientists and radio engineers from widely ranging fields of science and technology. During that time Prokhorov carried out much scientific-organizational work and served as consultant to various scientific institutions in all major and minor, easy and difficult problems of quantum electronics. In particular, he organized the Radio Spectroscopy Laboratory of the Nuclear Physics Research Institute of the Moscow State University, where he had been serving as professor since 1957.

The work on quantum radiophysics soon progressed from the stage of pure scientific research and rapidly found practical applications. Thus, a 21-cm paramagnetic amplifier constructed under his guidance was installed in the parabolic 22-m mirror antenna of the FIAN radioastronomical station in Pushchino (near Serpukhov) for observation of the emission of cosmic hydrogen.

Besides quantum amplifiers, Prokhorov works also in other fields, not connected directly with masers. Thus, very interesting work was done during that time in his laboratory on EPR in free radicals and on dynamic polarization of nuclei.

Prokhorov also paid much attention during that period to searches for new crystals for use in amplifiers and generators at millimeter and submillimeter wavelengths. A study of the properties of many new paramagnetic crystals (including methods of their production) played subsequently a very important role when his interests focused on lasers.

The design of molecular generators for shorter wavelengths, especially optical ones, encountered serious difficulties connected with the choice of resonators (without which quantum generators cannot operate). In 1958 Prokhorov proposed to use for submillimeter waves a new type of resonator (the so-called open resonator) in the form of two parallel mirror surfaces. It is important that the dimensions of the open resonator were much larger than the wavelength. Investigations of resonators of this type, carried out by Prokhorov's co-workers, have shown that such a resonator has a very high Q. At present all lasers employ just these open resonators or their modifications.

In 1960 Prokhorov was elected a corresponding member of the USSR Academy of Sciences, in the Division of General and Applied Physics. Since that time has devoted more and more of his efforts to the study of processes occurring in crystal-equipped lasers. The experience acquired by him earlier in investigations of crystals by the EPR method turned to be most useful here. Great attention is being paid by him also to work on improving such crystal properties as high optical homogeneity, high mechanical properties, and microstructure. We note that such problems were not dealt with in crystal physics before.

We must particularly emphasize Prokhorov's efforts towards producing and investigating fluorite crystals alloyed with dysprosium and other additives. Lasers operating with such a crystal have high efficiency and operate in the cw mode with high output power. Laser action with sunlight as the pump was achieved with a fluorite crystal.

Prokhorov's research on crystals were aimed at attaining high pulsed power, cw generation, increase in generator efficiency, etc.

New developments of powerful lasers have enabled Prokhorov to observe the breakdown produced in air by the electric field of a light wave in the focus of a laser beam and to carry out interesting research on the high-temperature plasma obtained thereby. This investigation served as the starting point for a large cycle of research in this direction.

In 1963, a new operating quantum-generator principle was developed under Prokhorov's guidance, using two-quantum transitions. The idea of such a generator is that if population inversion is established for two levels with energy difference $h\nu$, generation at two frequencies whose sum is equal to ν is possible. If the field intensity is appreciable, then the two-quantum transition probability becomes sufficiently large. A generator operating on this principle can operate at any frequency for which the foregoing condition is satisfied. The future of quantum electronics lies in the creation of quantum generators using multi-photon (and particularly two-photon) transitions.

A notable year in Prokhorov's life was 1964 when he, N. G. Basov, and C. H. Townes were awarded the Nobel prize in physics for pioneering work in quantum electronics.

In the subsequent years Prokhorov succeeded in making notable progress in the creation of cw lasers, which can be used for radio communication and technological operations.

It must be specially emphasized that great attention to practical applications of various researches has always been characteristic of Prokhorov's various activities. Indeed, the work on stabilizing the frequency of vacuum tube generators, on which he worked during the early years, was at that time an urgent problem; the investigation of the coherent emission from a synchrotron was directly aimed at obtaining radiation of millimeter wavelength; the research on paramagnetic resonance led to the development of a number of low-noise amplifiers, which were subsequently incorporated in many operating installations. A similar situation obtains today.

The work which is presently guided and directly supervised by Prokhorov is far from limited to research on lasers. A major place in his present-day research is occupied by mastery of the far infrared. At present this band is a blank spot in the elctromagnetic spectrum. There are no suitable radiation sources or receivers, and the transparency of materials for this section of the spectrum has not been well studied. Consequently great interest attaches at present to work on quasioptical methods in the submillimeter band, which is intensely pursued in Prokhorov's laboratory. The use of grating elements in the quasioptics of the millimeter and submillimeter bands has led to the development of new procedures for operating with these waves. Prokhorov and his co-workers produced a number of cw quantum generators for the micron band.

Recently Prokhorov has been guiding research on a different track—solid-state physics, particularly the microwave properties of solid-state plasma. This will uncover possibilities of producing new physical instruments and in addition will be useful for the creation of a new type of solid-state amplifier.

At the same time, a special system for the production of continuous superstrong magnetic fields of intensity of hundreds of kOe is being carried out under his scientific guidance. This will be the first installation of this type in the country.

Prokhorov is a scientist with a wide range of interests and engages in research in a variety of branches of physics. The results of his investigations were published in more than 160 scientific papers.

Prokhorov's contributions to the organization of scientific research and to the coordination of work done by various institutions on quantum electronics has been widely recognized. He is a member of the Division of General and Applied Physics, vice president of URSI, and chairman of its Soviet committee.

Prokhorov is a member of the Communist party of the Soviet Union. All his scientific-organizational and pedagogical activities have shown a high degree of party loyalty, manifest in fulfillment of his duties as a scientist in conjunction with his duties as a communist. This is seen, as already emphasized, in Prokhorov's tendency to develop those scientific trends which, besides being of great general scientific significance, are capable of making a maximum contribution to the building of communism. He imbues his co-workers, whose deep respect and love he has won, with the same spirit.

Prokhorov's work as a scientist and communist has left an important mark on the development of modern physics. His work on quantum electronics is a major contribution to the world's science. His scientific-organizational work has a strong influence on the entire aggregate of work on quantum radiophysics carried out in the USSR.

In celebrating Prokhorov's fiftieth birthday, the Soviet scientific community wishes him health and further creative success in his scientific activity.

Translated by J. G. Adashko