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PACS numbers: **01.52.+r**, **01.65.+g**, **42.62.–b**

DOI: 10.1070/PU2007v050n06ABEH006225

A M Prokhorov: founder of the General Physics Institute

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On 30 July 1982, the Council of Ministers of the USSR issued a decree adopting a proposal by the USSR Academy of Sciences to transform the A Division of the P N Lebedev Physics Institute of the USSR Academy of Sciences to the General Physics Institute of the USSR Academy of Sciences.

The General Physics Institute of the USSR Academy of Sciences (IOFAN) was formally established under a resolution of the Presidium of the Academy of Sciences on 30 September 1982. The General Physics and Astronomy Division of the USSR Academy of Sciences was entrusted with the scientific and scientific-methodical direction of the Institute.

However, resolutions and decrees alone, even those ranking the highest in priority, would not suffice for the genuine creation of an institute. This is merely a necessary condition but far from a sufficient one. There has to be a charismatic leader. Aleksandr Mikhailovich Prokhorov was such a charismatic leader.

He always and everywhere satisfied the requirements of the post he filled, whether it was commanding the reconnaissance platoon of a regiment during the hard times of the Great Patriotic war, heading the Chair of Laser Physics of the Moscow Institute of Physics and Technology (MIPT), being Editor-in-Chief of the Great Soviet Encyclopedia Publ., and Academician-Secretary of the General Physics and Astronomy Division, or being a member of the Presidium of the USSR Academy of Sciences. Nevertheless, the life's cause of the outstanding physicist and science organizer, one of the founders of quantum electronics and laser physics, Nobel Laureate in Physics, Lenin Prize and State Prizes Laureate, and two-time Hero of Socialist Labor Academician A M Prokhorov was the formation of the General Physics Institute, which now bears his name.

Everything in this man was extraordinary. In personal contact with him, one was always amazed by the incredible quickness, perfect clarity, and astonishing exactness of his concrete thinking. His capacity for work, and the breadth, depth, and volume of his erudition compelled admiration.

A M Prokhorov was born into a family of Russian political emigrants in Australia on 11th July 1916. In the early 1920s his family returned from the forced exile to their native land, to Russia. From 1934 to 1939, Aleksandr Mikhailovich Prokhorov was a student in the Physics Department of Leningrad State University; in 1939–1941, a postgraduate of the P N Lebedev Physics Institute (FIAN) of the USSR Academy of Sciences; and in 1941–1944, a participant in the Great Patriotic war, the commander of a regiment reconnaissance platoon. Due to serious injuries, in 1944 he was demobilized. As he later told his close friends, it was his wife Galina Alekseevna who saved his life despite the severe injuries. He owed her his life and his return to scientific activity.

From 1944 to 1946, A M Prokhorov continued his postgraduate studies at FIAN. The central idea which determined the thrust of Prokhorov's scientific life for several decades to come was the idea of monochromatic oscillations in nonlinear systems with a resonance feedback. He passed the milestones which mark the formation of the personality of a scientist, like the work on his Candidate (1939–1941 and 1944–1946) and Doctorate (1946–1951) theses, in the Laboratory of Oscillations at FIAN in the atmosphere of a radiophysical approach and 'oscillatory' mutual aid.

A M Prokhorov (11.07.1916–08.01.2002)

It was precisely this laboratory, which was officially headed by the young Doctor of Physicomathematical Sciences A M Prokhorov in 1954, that gave birth to quantum electronics.

This very laboratory comprised the skeleton of the scientific organism of Division A of the P N Lebedev Physics Institute of the USSR Academy of Sciences.

It was on the basis of this laboratory that Aleksandr Mikhailovich Prokhorov in 1982 established the General Physics Institute of the USSR Academy of Sciences — his main offspring — and became its first Director.

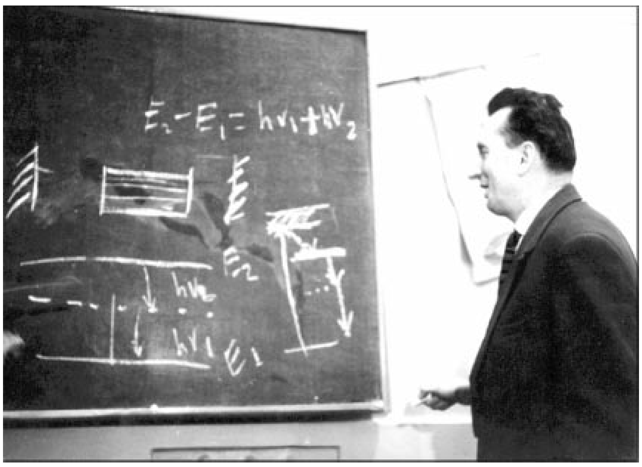
For several years the Laboratory of Oscillations was the only laboratory in the USSR, whose team would actively and purposefully develop quantum electronics. In the West, investigations in the same area were equally vigorously pursued by only one laboratory — the Radiation Laboratory of Columbia University. This research was headed by Charles H Townes.

Quantum electronics was in reality born at the moment an excited quantum system (a beam of appropriately sorted molecules) was placed in a resonator. Molecular monochromatic microwave oscillators (masers) — the first quantum electronic devices — were made in late 1954 – early 1955 in the Radiation Laboratory of Columbia University (J Gordon, H Zeiger, C Townes) in the USA and in the Laboratory of Oscillations of FIAN (N G Basov and A M Prokhorov) in the USSR. The masers operated on a beam of ammonia molecules, the radiation wavelength being equal to 1.25 cm.

In 1959, A M Prokhorov and N G Basov were awarded a Lenin Prize for the development of a new principle of generation and amplification of radio waves.

In 1960, A M Prokhorov was elected a Corresponding Member of the USSR Academy of Sciences.

The 1954 – 1960 time interval is marked by at least two of Prokhorov's considerable scientific achievements. Shortly after the launch of the molecular oscillator with electrostatic sorting of unexcited and excited molecules in a thermally equilibrium beam of ammonia molecules, Basov and Prokhorov came up with a general method for producing nonequilibrium media in quantum electronics. This is the famous three-level technique. All solid-state masers and virtually all high-power lasers operate on the basis of this technique.



A M Prokhorov at a seminar at the Laboratory of Oscillations (1964).

The successes of quantum electronics of the radiofrequency band naturally raised the question as to whether its achievements could be extended to much shorter-wavelength ranges. For radiophysics and the theory of oscillations, the aspiration of increasing the frequency of controllable monochromatic radiation was caused by the logic of the development of these sciences and was quite natural. However, when moving to shorter wavelengths, of basic importance was the problem of resonators, without which there is no way of obtaining monochromatic oscillations. In 1958, Aleksandr Mikhailovich Prokhorov proposed the use of an open resonator for this purpose. In essence, this was an analog of the Fabry – Perot interferometer, well known in optics. A radiophysical, purely 'oscillatory' approach enabled Prokhorov to advance the well-known instrument as a resonator for submillimeter masers and for lasers. Both suggestions — the three-level scheme and the open resonator — came to be the cornerstones of quantum electronics.

Late in October 1964 it was announced that the founders of quantum electronics, Nikolai Gennadievich Basov, Aleksandr Mikhailovich Prokhorov, and Charles Hard Townes, were awarded the Nobel Prize in Physics 1964 for fundamental work in the field of quantum electronics which has led to the construction of oscillators and amplifiers based on the maser – laser principle.

On the first of July 1966, ten days prior to his fiftieth birthday, Aleksandr Mikhailovich Prokhorov was elected Full Member (Academician) of the USSR Academy of Sciences to the General and Applied Physics Division. The academic status had no effect on his attitude to his associates. The democracy, benevolence, and sociability inherent in him would continue to surprise all his acquaintances.

Lasers, laser radiation, the interaction of laser radiation with matter, and their applications in science and technologies constitute the objective basis of Academician A M Prokhorov's world-wide fame. The main point is that lasers, owing to the high oscillation monochromaticity and coherence, have the capacity to ultimately concentrate in space, time, and the spectral interval virtually all radiation energy which attains, as a rule, quite high magnitudes.

The advent of lasers was prepared by the entire progress of quantum electronics which introduced radiophysical and oscillation theory methods into optics, gave rise to its second birth, imparted dynamism to it, and speeded up its development. Nonlinear optics made its appearance; there emerged coherent optical radiation sources to find wide use in technologies and medicine. Conventional optics started a new life.

The fundamental advances in the area of laser physics led A M Prokhorov and the Designer-in-Chief of the KB-1 Design Office (subsequently the Strela Moscow Design Office, more recently the Almaz Central Design Office), Academician A A Raspletin, to apply to the Central Committee of the Communist Party of the Soviet Union (CPSU) and the USSR Council of Ministers with a proposal to undertake research, with broad cooperation between co-executives, aimed at developing a laser air-defense. This proposal was supported in the Defense Department of the Central Committee of the CPSU and in the Military Industrial Commission (MIC) attached to the USSR Council of Ministers. On February 23, 1967, the Central Committee of the CPSU and the USSR Council of Ministers adopted their resolution, as did the MIC on 26th June of that year. These documents defined the line of work, the list of

1964 Nobel Laureates (left to right): Charles Townes, A M Prokhorov, N G Basov (the Prize in Physics); the English chemist Dorothy Crowfoot Hodgkin (the Prize in Chemistry); the American biochemist Konrad Bloch and the German biochemist Feodor Lynen (the Prize in Physiology or Medicine).

executives, and the terms of laser complex development, which received the code name 'Omega'. In accordance with this Resolution, a laboratory building with an area of 11,000 m^2 was constructed for the P N Lebedev Physics Institute of the USSR Academy of Sciences.

The foundation of the building was laid in 1969; it was completed and introduced into service in 1973. At present it is the main building of the General Physics Institute of the Russian Academy of Sciences (RAS) and its front appropriately bears a memorial plaque with the bas-relief of Aleksandr Mikhailovich Prokhorov — the founder and first Director of the Institute.

Two stainless steel capsules are concealed in the foundation of this building. One of them contains the capital Greek letter Ω. In this way, the IOFAN building retains the memory of the purpose-oriented work to which it owes its existence.

The second capsule contains a handful of 'fianits' — beautiful crystals synthesized on the basis of zirconium and hafnium oxides, which have no natural analogs. Their high hardness, high refractive index, and wide variety of coloring — from colorless to dark-violet — make fianits excellent jewels, which are conquering the world market. More recently, different and much more important applications have been found for them.

These crystals were developed at FIAN, in the Solid-State Physics Laboratory of Division A, which accounts for the presence of the second capsule in the IOFAN building foundation.

The 'Omega' series of applied investigations led to the discovery and comprehensive study of new physical phenomena, new materials, and technologies. This was quite typical for Aleksandr Mikhailovich Prokhorov. The very formulation of the 'Omega' research and the diversity of its findings illustrate his favorite thesis about the interdependence and interpenetration of applied and basic research as the necessary prerequisites for technical progress.

The 1980s was marked by a rapid growth of the Institute and its recognition as the world leader in several avenues of

IOFAN main building.

President of the USSR Academy of Sciences A P Aleksandrov (left) wishes A M Prokhorov happy 60th birthday (1976).

scientific research. Apart from the main building, three more buildings were built on the territory of the Institute owing to Aleksandr Mikhailovich Prokhorov's efforts: for the Research Center for Laser Materials and Technologies, Fiber Optics Research Center, and Natural Science Center of IOFAN. In these parts of the Institute, research on topical problems of science and technology was set up.

Of the investigations performed during the 1980–1990 period, mention should be made of solid-state laser research. Two classes of new active materials were developed. Basic investigations into the transfer, migration, and degradation of impurity-ion electron excitation energy in glasses and crystals led to the development of laser phosphate glasses with a high neodymium concentration and of a new class of crystal materials of the gadolinium–scandium–gallium garnet type. This crystal is remarkable in that it permits an isomorphic introduction into its volume of the donor impurity of chromium ions, along with an active rare-earth impurity ion. Furthermore, these active media possess enhanced resistance to laser and radiation damage. Lasers which utilize these crystals exhibit higher efficiencies and are highly reliable in operation.

Construction of lasers with semiconductor laser pumping should also be placed among the works in this area. Requirements imposed on the active media of such lasers were formulated, and materials meeting these requirements were made, around which solid-state lasers with unique properties were developed. Today, solid-state lasers with semiconductor laser pumping have triumphantly come to the forefront in quantum electronics. In this case, A M Prokhorov's foresight again proved to be correct.

In the area of new laser creation, indubitably of interest is the development of color center lasers utilizing alkali-halide crystals at room temperature, as well as lasers utilizing stimulated Raman scattering.

In the field of laser applications, special mention should be made of Prokhorov's works pertaining to medicine. Among them are the world's first laser ophthalmologic facilities, new surgery in gynecology and urology, and the development of photodynamic therapy — a radically new medical technique in oncology. Interesting results have been obtained with the use of excimer lasers for the treatment of destructive forms of tuberculosis, as well as laser urological complexes, including a laser lithotriptor (a medical device for eliminating calculi in the human body). This last device utilizes a new effect discovered at the Institute, which consists in the disruption of dielectrics under two-frequency irradiation.

Aleksandr Mikhailovich Prokhorov pioneered investigations in several areas of nanophysics and nanotechnology at the Natural Science Center, which are being successfully pursued at the present time.

The 1980s–1990s saw fiber optics triumphantly become a part of everyday life. Investigations in this field were also pioneered by A M Prokhorov already in the early 1970s. Optical communication and the Internet have become necessary attributes of the modern person. The Fiber Optics Research Center attached to IOFAN has made a substantial contribution to the solution of several problems encountered on the way to these truly revolutionary transformations.

Such was the case until the onset of the 1990s, when the Institute, like all Soviet science and all our country, experienced the results of the disintegration of the Great Power. Nevertheless, the potential laid by A M Prokhorov afforded not only safety for the Institute as such, but also the retention of its position in world science.

What is the A M Prokhorov General Physics Institute of the RAS today?

The institute has a staff of 1028, of which 508 are research workers, 122 Doctors of Sciences, 281 Candidates of Sciences, and 48 postgraduates.

In the Institute there are three doctoral dissertation councils with specializations in radiophysics, acoustics, laser physics, condensed-state physics, theoretical physics, plasma physics, optics, and technology and equipment for the fabrication of semiconductors, materials, and devices of electronic engineering. Beginning in 2000, 56 candidate's and 38 doctoral theses have been defended at the Institute.

Six chairs of leading Russian universities are affiliated with the Institute: four chairs of the Moscow Institute of Physics and Technology, a chair of the Moscow State Institute of Radioengineering, Electronics, and Automation, and a chair of the D I Mendeleev Moscow Academy of Chemical Technology.

Since 2000, staff members of the Institute have published 24 monographs. In 2005 alone they published 951 papers, 311 of which in foreign publications.

According to the editors of the *Kvantovaya Elektronika* (*Quantum Electronics*) journal, the Institute is the main contributor of articles: in 2004 and 2005, staff members of

A M Prokhorov (right), after reporting to the Presidium of the RAS, and Yu S Osipov, President of the Russian Academy of Sciences (1996).

the Institute published in this journal 50 and 35 papers, respectively.

Total financing rose from 111 million rubles in 2000 to 368 million rubles in 2005. In 2005, the budgetary financing was 91.2 million rubles and the out-of-budget one was 276.8 million. In 2005, the out-of-budget financing comprised 120 projects supported by the Russian Foundation for Basic Research, 19 projects of the Russian Federation Ministry of Education and Science, and 130 different contracts. Work on 14 grants from the International Science and Technology Center (ISTC) and 3 grants from the American Civil Research and Development Foundation (CRDF) is presently underway at IOFAN.

Cooperation with research organizations from 15 countries is underway in the framework of bilateral and academic agreements. Joint laboratories have been set up with scientific institutions from Canada, Italy, and France. Up to 300 foreign scientists and specialists visit the Institute annually.

The Institute organizes the annual international conferences on Advanced Laser Technologies, the International Laser Physics Workshop, and the Zvenigorod Conference on Plasma Physics and Controlled Thermonuclear Fusion. The Institute is one of the organizers of the International Quantum Electronics Conference/Lasers, Applications, and Technologies (IQEC/LAT).

The main lines of basic research conducted at the Institute are defined by the Regulation of the Presidium of the RAS: condensed-matter physics, optics and laser physics, radiophysics and electronics, acoustics, and plasma physics. A more detailed description of these areas consists of 27 appellations which embrace virtually all modern areas of the above lines of research.

To exemplify the most important scientific results, mention should be made of the following.

The effect of selective adsorption of a spin modification of water molecules was discovered. For the first time in world practice, it was possible to separate water into spin-modified fractions — ortho and para water.

By the example of chromium-doped germanium cuprate, a new magnetooptic effect was discovered: violation of spin precession in a doped quantum chain.

Phase conjugation in acoustics was theoretically substantiated and experimentally realized in magnetoelastic media.

Methods were developed for the synthesis and processing of carbon nanotubes, around which new unique photonics elements were produced.

A new type of magnetic resonance due to orbital ordering was discovered.

The characteristic features of electrodynamics were revealed for composite media possessing a negative effective refractive index.

The existence of new quasiparticles was theoretically predicted and experimentally borne out: these quasiparticles — waveguide-plasmon polaritons — are formed in photonic-crystal layers with metallic nanostructures.

A radically new method was elaborated for the detection and determination of extremely low concentrations of organic compounds, which relies on the laser desorption of ions from the nanostructurally irregular surface of silicon.

Several new laser materials were proposed, around which new types of solid-state lasers with unique parameters were constructed.

Work is in progress on the hot plasma confinement in the toroidal magnetic field of the L-2M stellarator.

Work is underway to investigate the formation dynamics of the pico- and femtosecond laser microplasma of multiply ionized gases and solids.

Image-converter tubes, streak cameras, and diffractometers are being investigated and elaborated. A temporal resolution of 160 fs has been attained.

An ultrahigh-vacuum (10^{-10} Torr) scanning tunnel microscope GPI-300 was developed.

Infrared imagers were developed on the basis of 2D platinum-silicide infrared radiation detector arrays. These imagers are applied in medicine and for thermal audits to monitor electrical and heat power engineering units. In the Central Hospital of the RAS, a room equipped with a medical infrared imager has been set up for thermographic examinations.

Equipment was made for photodynamic therapy, including the autofluorescent diagnostics of early forms of cancer.

Fundamental research in the field of diode laser spectroscopy led to the development of a technique for detecting *Helicobacter pylori* bacteria by way of spectral analysis of the air exhaled by a patient.

The Physics Instrumentation Center, which was organized by A M Prokhorov and which now is a branch of the IOFAN, is operating successfully. The center sets itself the task of bringing the Institute's developments to small-batch output. In particular, the center produces the ophthalmologic excimer laser facility Mikroskan TsFP for refraction surgery. The facility enables correcting hypermetropia, myopia, and astigmatism by means of a laser flying spot.

The laser facility Mariya for the therapy of destructive forms of tuberculosis was awarded a Gold Medal at the 51st Brussels-Eureka Salon.

Crystals made on the basis of partially stabilized zirconium dioxide, which were developed by Institute staff members back in the 1970s, have been modified to find use in the development of unique medical instruments, multipurpose biological prosthetic appliances, and biologically inert implants with a high fatigue strength for dental and orthopedic surgery.

The word 'innovation' is highly popular nowadays. We are not sure whether Aleksandr Mikhailovich Prokhorov used this word, but he fostered innovations throughout all his life.

The above, by no means complete, list of basic and applied scientific results is, in our opinion, a prominent example of the realization of Aleksandr Mikhailovich Prokhorov's idea that there is no way of dividing investigations into basic and applied. Only their indissoluble bonds and interpenetration ensure the progress of modern science and the prosperity of society as a whole.

The authors are grateful to T B Volyak and S V Garnov for their substantial assistance in the preparation of this material.