

TO THE 275th ANNIVERSARY OF THE RUSSIAN ACADEMY OF SCIENCES

PACS numbers: **01.55. + b**, **01.65. + g**

From a physics laboratory to the Division of General Physics and Astronomy

A A Boyarchuk, L V Keldysh

The first scientific physics institution of the Academy of Sciences was the Physics Laboratory of the Imperial Academy of Sciences and Arts in St. Petersburg, which came into being contemporaneously with the Academy itself in 1724.

Late in the XVIIIth century, the physics in Russia had also commenced its advance outside the precincts of the Academy but yet, undoubtedly, under its strong influence. By the end of the XIXth century, research in physics and astronomy was pursued in several universities, primarily in the Moscow and St. Petersburg Universities, in the St. Petersburg Polytechnic Institute, and in the Principal (Pulkovo) Astronomical Observatory established in 1838. Good physics schools of thought evolved in Kazan', Kiev, Tomsk, and Odessa. During the first post-revolutionary years, research activities were confined primarily to Moscow (the University and the Institute of Physics and Biophysics, which was only weakly related to the Academy) and to St. Petersburg (the University, the Polytechnic Institute, and two other big physics institutes — the Physicotechnical and the State Optical Institutes established according to A F Ioffe's and D S Rozhdestvenskiĭ's proposal). These institutes came to be the precursors of present-day physics institutes, which combine theoretical and applied research. The inception of today's system of the institutes of the Division of General Physics and Astronomy of the Russian Academy of Sciences dates back to the 30s. Some had their origin in the already existing scientific institutions. Other institutes and observatories were conceived to meet the country's growing industrial and defense demand.

The Division of Physico-Mathematical Sciences — one of the eight specialized Academy divisions — was formed in 1938. Separated from this Division in 1963 was the Division of General and Applied Physics, which also incorporated several institutes from the Division of Technical Sciences. In 1968, it was transformed into the Division of General Physics and Astronomy bearing this name to the present day. L A Artsimovich was the first Academician-Secretary of the Division from 1963 to 1973. He was succeeded by A M Prokhorov, who retained the position till 1991. L V Keldysh was the Academician-Secretary of the Division in 1991 – 1996, and A A Boyarchuk has been in charge of the Division since 1996.

A A Boyarchuk Division of General Physics
and Astronomy of the Russian Academy of Sciences,
Leninskiĭ prosp. 32a, 117993 Moscow, Russian federation
Tel.: (095) 938 16 95;
Institute of Astronomy, Russian Academy of Sciences,
ul. Pyatnitskaya 48, 109017 Moscow, Russian Federation
Tel.: (095) 951 09 24;
L V Keldysh P N Lebedev Physics Institute, Russian Academy of Sciences,
Leninskiĭ prosp. 53, 117924 Moscow, Russian Federation
Tel.: (095) 135 30 33. Fax: (095) 135 85 55
E-mail: keldysh@gpad.ac.ru

Received 1 June 1999
Uspekhi Fizicheskikh Nauk **169** (12) 1289 – 1298 (1999)
Translated by E N Ragozin; edited by S D Danilov

The Pulkovo Astronomical Observatory, which had long been recognized to be one of world's astronomical centers, and the P N Lebedev Physics Institute (FIAN), established upon division of the Physico-Mathematical Institute, came to be the first scientific institutions of the Division. FIAN moved, together with the Academy, to Moscow and before long became one of the major institutes within the Division. In 1934, P L Kapitsa set up the Institute for Physical Problems, which now bears his name. These two physics institutes delivered every one of the seven Nobel Laureates in Physics in our country. The A F Ioffe Physicotechnical Institute (Fiztekh), which was allotted to the Academy in 1939, played a special part in the formation of contemporary physics in Russia. Fiztekh was the first multiple-discipline physics center in our country wherein a pleiad of brilliant scientists formed to win international recognition. Many of them came to be the founders of institutes and played an outstanding role in the solution of major scientific and technical problems.

The days of World War II were inceptive of the Institute of Theoretical Astronomy (reorganized in 1998) and the Institute of Crystallography, where techniques for growing crystals of practical significance were devised and the problems of crystal symmetry and structure were studied. On May 30, 1945, a decision was made to set up the Crimean Astrophysical Observatory, which soon afterwards became one of the leading centers as regards a wide field of astronomical problems (on the disintegration of the USSR, it passed to Ukraine). That same year saw the inception of the Kazan' Physicotechnical Institute initially established to pursue magnetic resonance research. Its subject field expanded significantly with time to embrace magnetic radiospectroscopy, the physics of the condensed state, and surface studies.

Next followed the age of specialized institutes: in 1953 the Institute of Radio Engineering and Electronics was established — the biggest academic institute in the realm of radiophysics and radio engineering. Its research field covers a wide range of problems: radio-wave propagation and radar, including space radar; microwave engineering and electrodynamics; acousto-, magneto-, semiconductor, and superconductor electronics; the physics and the electronics of solid-state nanostructures; and biomedical electronics.

In the late 50s and in the 60s, small academic towns became one of the progressive forms of setting up academic science. In 1958, the town of Troitsk saw the establishment of the Institute of High-Pressure Physics whose primary goal was to study materials at high pressures and to produce superhard materials, including artificial diamonds. In 1959, the Academy incorporated the Institute of Terrestrial Magnetism, the Ionosphere, and Radio-Wave Propagation (IZMIRAN), which was founded as far back as 1939. Here, the objects of research are solar radiation and cosmic rays (including spacecraft-assisted research), solar-terrestrial relationships, the earth and planetary magnetic fields, the ionosphere, and radio-wave propagation. In 1968, the academic town in Troitsk was supplemented by the Institute of Spectroscopy whose staff pursues research in various branches of atomic, molecular and condensed-state spectroscopy, including laser spectroscopy.

In 1963, the Chernogolovka settlement saw the foundation of the Institute of Solid-State Physics involved in research on the entire complex of current problems of solid-state physics. They range from basic theoretical problems and unique physics experiments to the implementation of specific processes in the Institute's development plant equipped, in particular, with all kinds of metallurgical conversion. At that time, the L D Landau Institute for Theoretical Physics was established, as a constituent part of the Chernogolovka scientific center, on the basis of several theoretical groups previously incorporated in the P L Kapitsa Institute for Physical Problems. It is concerned with virtually all branches of modern theoretical physics, and internationally recognized theorists work at the Institute.

In 1965, in connection with the national effort to master space, the Institute for Space Research was established as a center for formulating the programs of basic space research. Shortly after that, in 1966, the Special Astrophysical Observatory was set up on the basis of unique ground-based astronomical instruments under construction - a 6-meter optical telescope and a RATAN-600 radiotelescope. At present, the Observatory is in fact the only modern observational site in Russia, its national property, and a center of international cooperation in astronomy.

The Institute of Applied Physics was established on the basis of the eminent Gorkiĭ (presently N. Novgorod) radiophysics school in 1977. It promoted research in the fields of high-power microwave electronics, plasma physics, hydrophysics, acoustics, optics, and laser physics. The Division of Solid-State Physics of the Institute evolved into the Institute for the Physics of Microstructures, which got detached from the parent Institute in 1993 to pursue research on high-temperature superconductivity, solid-state nanostructures, and X-ray optics.

As early as 1983, a complex of laboratories divorced from FIAN to form the Institute of General Physics. Like FIAN, the new institute was a multi-discipline unit: laser physics, fiber optics, plasma physics, acoustics, and hydrophysics.

In Leningrad in 1986, the Institute of Applied Astronomy was set up in the context of the government resolution to bring into existence the 'Kvazar KVO' coordinate-time service adequate for the nation's needs. Other tasks facing the Institute were to determine the parameters of the Earth's rotation and develop very long baseline radio interferometry. In 1990, the Scientific Council on Astronomy, which had been in existence since 1936, was elevated into the Institute of Astronomy, which studies the stellar evolution, the interstellar medium, and planets and pursues space research and observations of man-made cosmic objects.

The following major avenues of research have been formed in the institutes of the Division of General Physics and Astronomy of the Russian Academy of Sciences to date: the physics of the condensed state; optics and laser physics; plasma physics and controlled nuclear fusion; radiophysics, electronics, and acoustics; and astronomy and space research. Over 14 thousand staff members are employed at the 19 institutes of the Division, including over 70 members of the Russian Academy of Sciences, over one thousand Doctors of Sciences, and over six thousand Candidates of Sciences. As of March 1, 1999, the Division of General Physics and Astronomy comprised 48 Full Members and 73 Corresponding Members of the Russian Academy of Sciences.

Physics

The end of the XIXth and the beginning of the XXth century saw the formation of the scientific schools which subsequently came to determine the face of Russian physics and its position of eminence in the history of XXth century science. Their founders were, in the first place, P N Lebedev and slightly later L I Mandel'shtam in Moscow and D S Rozhdestvenskiĭ and A F Ioffe in Petrograd. Furthermore, P. Ehrenfest played a prominent role in the formation of theoretical physics in Russia.

P N Lebedev was more than a masterly experimenter whose works to measure the pressure of light received worldwide acceptance. In essence, he launched the first physics laboratory in Moscow in the present-day sense of the word and the first regular physics seminar. This marked the commencement of the formation of the professional community of physicists. Somewhat later, similar processes occurred in Petrograd, too. Like P N Lebedev, D S Rozhdestvenskiĭ was an optical physicist and with full confidence can be referred to as the founder of the Russian spectroscopic school — at that time the most important line of investigation which advanced following N Bohr's derivation of the quantum atomic model and atomic spectra. D S Rozhdestvenskiĭ also masterminded the development of the optics industry in the Soviet Union.

It therefore comes as no surprise that a considerable fraction of the achievements of Soviet physics, especially so in the first half of the XXth century, were related precisely to optics. Among the prominent ones was the discovery, by G S Landsberg and L I Mandel'shtam, of combination light scattering and its correct interpretation as inelastic scattering with transfer of a part of the luminous energy to the excitation of molecular or crystal lattice vibrations. The subsequent work of G S Landsberg and his collaborators made this effect a powerful analytic tool in research as well as in numerous applications.

P A Cherenkov discovered the radiation accompanying the passage of fast electrons through matter, which had a profound impact on the subsequent advance of physics, especially high-energy physics. I E Tamm and I M Frank interpreted this phenomenon as a kind of light 'shock' wave which appears when a charged particle propagates with a velocity exceeding the speed of light in the given material.

On no account is this discovery to be regarded as an accidental one. P A Cherenkov worked under the supervision of S I Vavilov whose school, like A N Terenin's, was the world's leading school in luminescence research and conducted extensive studies of radiation mechanisms in different materials under various excitation conditions — exposed to light, fast particles, etc. In essence, those were the studies of material structure at atomic-molecular level, the structure of its energy spectrum, the conversion and the mechanisms of transfer of the excitation energy involved in photochemical reactions, etc. The studies also pursued practical goals — the development of luminescent light sources. These studies acquired special significance with the advent of coherent sources of optical radiation — lasers — when the entire body of information gained in this field and the techniques became one of the principal building blocks of quantum electronics.

The concept of an exciton introduced by Ya I Frenkel' has proven to be highly fruitful for crystal optics. An exciton is a collectivized excited state which is not localized at some individual molecule but, being transferred in a resonance manner from a molecule to its neighbor and further, can travel macroscopic distances. Later on, A S Davydov showed theoretically that, when an elementary lattice cell comprises two or several identical molecules, that same mechanism of resonance within-the-cell collectivization is responsible for the characteristic splitting of exciton terms. The experimental investigations undertaken by representatives of the I V Obreimov and A F Prikhot'ko schools confirmed that excitons, including the Davydov splitting, are indeed inherent in the optics of molecular crystals and thus fostered this avenue of investigation throughout the world.

Also dramatic were the discovery and the investigation of excitons in semiconductors made by E F Gross and his disciples B P Zakharchenya, N A Karryev, and A A Kaplyanskiĭ. Unlike molecular crystals, the electrons in semiconductors are delocalized, so that an excited electron can recede from the site it abandoned (the 'hole') to distances many times the interatomic spacing. However, as shown theoretically by G Vanier and N Mott, an electron attracted to a hole by the Coulomb force can be bound to it like an electron in the hydrogen atom. In this case, the Coulomb forces are considerably attenuated by the permittivity of the crystal, so that the effective radius of this mobile 'quasiatom' inside the continuous crystal proves to be many times greater than the dimensions of conventional atoms while the binding energy is, as a rule, found to be lower than the Rydberg by one to three orders of magnitude. It was precisely these hydrogen-like line series that E F Gross and his collaborators discovered, thereby giving birth to an extremely wide field of research not only in conventional semiconductors, but also in the so-called semiconductor nanostructures. Following the parallels between the Vanier–Mott excitons and atoms, S A Moskalenko made his proposal that there exist exciton molecules — biexcitons. This hypothesis was borne out by many subsequent experiments and the existence of biexcitons proved to be no less typical of the nonlinear optics of semiconductors.

The discovery of the Cherenkov effect lent impetus to a search for similar phenomena and other circumstances where fast charged particles emit radiation. In this connection mention should be made of the 'transitional' radiation predicted by V L Ginzburg and I M Frank, which occurs when a fast particle crosses the interface of two media with different refractive indices; of the 'undulator' radiation (V L Ginzburg) occurring when a charge flies past a periodic structure or a force field, which modulates its velocity; and of free-electron masers as a further development of this idea.

E B Aleksandrov's investigation on the interference of atomic states opened up a basically new realm of modern spectroscopy. The point is that the radiating atomic state may be a quantum-mechanical superposition of several stationary atomic states and not just one of them, as was initially assumed by the Bohr theory of atomic spectra. In this case, interference effects appear involving the wave functions of electrons instead of electromagnetic fields, which can radically change the probabilities of different transitions, their time dependences, etc. The possibilities to manipulate atomic states and spectra have become one of the most promising modern fields of atomic physics and optics. Of Russian investigations, noteworthy also is the prediction, confirmed by recent experiments, of the feasibility of attaining along this pathway the amplification of electromagnetic waves without the population inversion required in conventional laser schemes (Ya I Khanin, O A Kocharovskaya). While on the subject of the advance of optics in Russia, one cannot but mention the pioneering works of Yu N Denisyuk who combined D Gabor's holography concept with the idea of color photography. There is no escape from mentioning the wave-front self-inversion in stimulated Mandel'shtam–Brillouin scattering discovered by B Ya Zel'dovich, V I Popovichev, V V Ragul'skiĭ, and F S Faizullov, either. This phenomenon is, to an extent, related to holography and makes it possible to nearly completely compensate for the distortions of the light beam introduced by the inhomogeneities of the medium along its path.

The advent of lasers has come to be the XXth century revolution in optics. However, prior to discussing the vital part played in it by Russian scientists, it is pertinent to enlarge on an equally important field — radiophysics. Its advance in Russia commenced with an outstanding event — the invention of radio by A S Popov. And this was not a solitary breakthrough. Suffice it to recall that in those years P N Lebedev demonstrated a Hertz vibrator of his own (Lebedev's) manufacture which generated the then shortest, millimeter waves. The "N. Novgorod Radiolaboratory" supervised by M A Bonch-Bruevich played a large role in the initial stage of development of radio engineering and radiophysics.

However, the rise of radiophysics as one of the central realms of physics is primarily related to the names of L I Mandel'shtam, N D Papaleksi, and their numerous disciples. For L I Mandel'shtam, radiophysics was just one (though most important at that time) of the areas of manifestation of the physically common class of oscillatory phenomena, including the oscillations propagating through space, i.e. waves. It therefore comes as no surprise that he and his school made equal contributions both to the formation of radiophysics and to the advance of optics. By the beginning of the XXth century, physics had accumulated a wealth of facts concerning oscillations and waves of different types and nature. However, only small-amplitude oscillations described by linear equations were adequately understood. The progress of radio engineering, primarily the problem of signal generation and recording (reception), called for the study of processes whereby the oscillations themselves modify significantly the parameters and the properties of the medium or the device in which they occur. To state it in different terms, brought to the forefront were the problems of the far more diversified and rich field of the nonlinear and parametric processes of oscillation self-action and interaction of different types of oscillations.

It was precisely in this field, which dates back to van der Pol, that the L I Mandel'shtam school achieved the greatest success and gained world-wide recognition. Its achievements in studies of light scattering by different natural medium oscillations (Mandel'shtam – Brillouin scattering, combination scattering, etc.) were by no means fortuitous. Nor were they fortuitous in investigations into the radio-wave generation by converting energy from other types of oscillations. The works of A A Andronov and the Gorkiĭ school established by him played a prominent role in the construction of the general theory of nonlinear oscillations and, in particular, auto-oscillations — the heart of any oscillator operation. Subsequently, the studies of this school of thought extended to nonlinear acoustics, electrodynamics of electron beams and plasma, and ocean dynamics, thus following the general trend of the transformation of the physics of nonlinear oscillations into a part of a still more general field — nonlinear dynamics.

The idea of harnessing the modulation (or the self-modulation) of electron flows for generating and amplifying radio waves found wide use in quite different areas of electronics. The works of the groups, instituted by A V Gaponov-Grekhov and G A Mesyats, in the area of high-current high-power electronics are of world-wide significance and are among the most prominent achievements of Russian radiophysics.

In 1944, E K Zavoĭskiĭ discovered a new phenomenon — electron paramagnetic resonance — the absorption of radio waves with a reversal of the electron spin oriented by an external magnetic field. Quantum-mechanically, this is a transition between the energy levels of the spin magnetic moment residing in a magnetic field, which is quite similar to optical transitions between atomic levels. The effect of electron paramagnetic resonance, one of the most important in the radiospectroscopy of close levels in quantum systems, has, together with the like effect of nuclear magnetic resonance, become the basis for efficient analytic methods in different fields of physics, chemistry, biology, medicine, engineering, etc.

Ten years later, a systematic investigation of the potential of radiospectroscopy led N G Basov and A M Prokhorov to the concept of a quantum generator of electromagnetic waves, which combined the methods of classical radio engineering with Einstein's notion of stimulated emission on quantum transitions. This idea was initially realized by them, as well as by Ch. Townes, in the microwave range using a molecular ammonia beam. Next designed were paramagnetic amplifiers on electron-paramagnetic-resonance type transitions. And it took only a few years to overcome purely technological difficulties to realize these ideas and methods in the visible range and devise quantum generators of light — lasers. The investigations into the luminescence mechanisms in different media outlined above became another building block of the emergent quantum electronics.

Therefore, it was as if an integration or, to be more precise, a convergence of optics and radiophysics took place, and an intense exchange of ideas and methods commenced between these realms of physics. Nonlinear optics emerged. The role of greatest prominence in its formation was played by the R V Khokhlov and S A Akhmanov school. As an outgrowth of L I Mandel'shtam's and N D Papaleksi's concepts of parametric generation, they developed a parametric oscillator of light which allowed smooth frequency tuning of the radiation generated. The spectroscopic capabilities of lasers were thereby immeasurably extended, as were the possibilities for selectively exciting one or other of the levels and thus effectively controlling the quantum states and the processes at an atomic or molecular level. S A Akhmanov, V S Letokhov, V P Chebotaev, and their collaborators made a major contribution to the development of novel methods of nonlinear spectroscopy, which are more precise and efficient than the methods of conventional linear spectroscopy.

D N Klyshko predicted the effect of spontaneous parametric scattering, i.e. the decay of a photon in a medium into two lower-energy photons, and later discovered it together with V V Fadeev and O N Chunaev. On the face of it, the effect seemed to be just one of a large number of new nonlinear optical effects. However, before long, the effect was shown to possess amazing metrological potential, making it possible to compare the intensities of different real processes with the intensity of vacuum fluctuations or, more precisely, with the probabilities of spontaneous transitions. The absolute brightness standard, and the absolute (without a reference) calibration of quantum efficiency of different detectors, etc. can thus be realized. In recent years, this effect, which involves nearly simultaneous production of correlated photon pairs, has provided the physical basis for the methods proposed for quantum information processing and transfer (quantum computation, quantum cryptography, etc.)

G A Askar'yan proposed the idea of self-focusing of high-intensity light beams, i.e. the formation of lenses or self-sustaining waveguides by the beams in the medium through which they propagate.

Another branch of radiophysics which made rapid strides in Russia was radio-wave propagation. The mathematical problem is in this case rather complex due to the proximity (on the wavelength scale) of radiation to the interface, and a lot of the credit for its solution must go to V A Fock. E L Feĭnberg, A N Shchukin, V L Ginzburg, and V V Migulin made a contribution of their own to the theory of radio-wave propagation. During World War II and the post-War years, ground-based radar research made great progress (Yu B Kobzarev). At the same time, N D Papaleksi called attention to the interesting possibilities for radar investigation of the Moon and the planets. Extensive investigations in this field were subsequently performed under the supervision of V A Kotel'nikov.

Nonlinear effects too may be of significance in the propagation of radio waves through the ionosphere, because the heating of free electrons by the wave field is the easiest attainable source of nonlinearity. In the USSR, especially in Gorkiĭ, an intensive study was made of the influence of radio waves on the ionosphere, i.e. the feasibility of controlling its properties employing high-power directional radio-wave fluxes. The effect of this kind presumably discovered first — the cross modulation of radio waves propagating through the atmosphere — is legitimately referred to as the Luxembourg — Gorkiĭ effect.

It was the interest in the problem of radio-wave propagation through the ionosphere, as in the problem of gas discharge, which was probably the original cause of the interest of Russian physicists in plasma physics, even though the spark research conducted by D A Rozhanskiĭ early in the XXth century can be regarded as the precursor to these studies. One of the most notable achievements is undoubtedly the A A Vlasov kinetic equation, which makes use of the notion of a self-consistent field induced jointly by external sources and all charged plasma particles. To date this equation is the basis for all theoretical studies of the processes occurring in plasmas.

But plasma physics came to be one of the central realms of contemporary physics only in the second half of the XXth century, following A D Sakharov's and I E Tamm's proposal to implement controlled nuclear fusion in a plasma confined and isolated from the wall by the magnetic field of the inherent current in the plasma. The first systems of this kind were elaborated under the supervision of L A Artsimovich in the USSR and received the name 'tokamaks.' Subsequently, this line of research was pursued under the supervision of B B Kadomtsev and E P Velikhov. Until the present time tokamaks are believed to hold the greatest promise for developing a fusion reactor, and the overwhelming majority of investigations of hot plasmas have been performed precisely on tokamaks. However, these experiments were up against the problem of plasma instability before long. Russian physicists made the main contribution to the theory of instabilities and collective processes in plasmas (V D Shafranov, B B Kadomtsev, R Z Sagdeev, V P Silin, et al.). Several alternate approaches to the plasma confinement problem were proposed, e.g. employing a special configuration of the external magnetic field — the magnetic bottle due to G I Budker. Of the radically different approaches, mention should be made of very fast plasma heating by a focused high-power laser pulse proposed by N G Basov and O N Krokhin. The systems of this kind were first constructed in the USSR. They have already become efficient sources of intense X-ray radiation as have the 'plasma focus' systems, which involve self-constriction of a high-power discharge under the effect of the intrinsic field.

One of the central problems in nuclear fusion is how to accomplish stable plasma heating. Plasma heating by a high-frequency field is believed to hold considerable, if not the greatest, promise today. These fields are most efficiently generated by so-called gyrotrons that were developed and implemented under the supervision of A V Gaponov-Grekhov.

The classical studies of E S Fedorov, who found all of the so-called symmetry groups, were inceptive of Russian crystallography. Its subsequent and modern progress was related primarily with the names of A V Shubnikov — the founder of the Institute of Crystallography, who generalized the Fedorov groups to magnetically ordered crystals; N V Belov who introduced several general approaches to the analysis of the crystal structure of different types of materials and identified hundreds of specific structures, including the basic natural minerals; and B K Vainshtein the originator of the Russian school of structural analysis of biological molecules.

A rich variety of polymorphic transformations from one crystal structure to another are observed at high pressures. These transformations are not infrequently attended by a radical change of physical properties. The dielectric-metal transition is an example. Several transitions of this sort were investigated in the Institute of High-Pressure Physics established by L F Vereshchagin. The graphite-diamond transformation is among the most significant, as is the transition of quartz — one of the most abundant crustal minerals — to the dense phase — stishovite, which was discovered by S M Stishov. Similar research though at higher dynamic pressures in high-power shock waves was pursued by L V Al'tshuler and S B Kormer and their collaborators.

The progress of research in the extremely wide field of the physics of condensed state, including the physics of solids, liquids, quantum liquids, etc., is largely related to the name of A F Ioffe, his school, and the Physicotechnical Institute he established. The compromise between thorough physical investigations and material technology studies and the search for possible practical applications of new scientific accomplishments were always inherent in this school. In this connection mention can be made of A F Ioffe's investigation into the electric strength of dielectrics and of V A Fock's theory of thermal breakdown devised in the context of this investigation. In succeeding years the problem of electric breakdown was taken up by many groups of Russian physicists. In the process, however, the problem would alter to become a problem of tunnel effects and avalanche multiplication of free electrons and holes in semiconductors and semiconductor devices and a problem on the breakdown by intense laser pulses. One recent prominent achievement in studies of the interaction of crystals with intense laser pulses was the discovery of so-called laser-induced annealing by E I Shtyrkov and I B Khaibullin. This effect of practical significance involves instantaneous melting of the near-surface crystal layer by a high-power pulse with subsequent rapid recrystallization.

S N Zhurkov with collaborators and several other teams made a notable advance in the understanding of the nature of the strength of real materials and its association with the fluctuation nucleation and the development of different defects, their accumulation in time, etc. Another considerable step forward was the elucidation, due to G V Kurdyumov, of the nature and the mechanism of martensitic transformations in alloys — the heart of the hardening process and the basis for obtaining the hardest alloys. Yu A Osip'yan and collaborators discovered the effect of photoplasticity, i.e. the light-induced variation of mechanical crystal properties.

The discovery of barium titanate by B M Vul is recognized as a prominent event in the physics of ferroelectrics. Before long, barium titanate became a model material in studies of displacement type ferroelectric transitions (unlike the ordering-type transitions). V L Ginzburg constructed a phenomenological theory of ferroelectrics, which first pointed up the softening, as the transition point is approached, of one of the vibrational crystal modes as the driving force for the transition. This theory was conceived in the spirit of the general L D Landau approach to phase transitions of the second kind, which associated them with the origination of some kind of ordering and spontaneous violation of one or other type of symmetry.

In the course of time, however, the most important place in the activity of the Physicotechnical Institute and A F Ioffe himself was occupied by semiconductor physics, with its potential applications in the system of data transfer and processing and also in energy converters from one form to another — photoelectric, thermoelectric, etc. Mention should be made of the following remarkable achievements along this line. N A Goryunova and collaborators introduced a new notable class of diamond-like semiconductors to the physics and technology — compounds of the elements of the IIIrd and Vth groups of the periodic system of elements. Zh I Alferov and collaborators made semiconductor heterojunctions and lasers on the basis of these compounds. In essence, the latter came to be the decisive step on the road to designing, on the atomic level, of submicron- and nanometer-scale structures (as well as of their electronic spectra) through the so-called dimensional quantization of energy levels in spatially bound 'quantum wells.' The specified systems with fully controllable properties now are the central objects of semiconductor physics and a number of other domains of solid-state physics.

Also noteworthy is the systematic study of liquid semiconductors pioneered by A F Ioffe, A R Regel', and their collaborators. They formulated the criterion for minimum free carrier mobility — the precursor of subsequent extensive investigations on the electron localization problem and the metal-dielectric transformations in disordered (noncrystalline) systems.

I E Tamm was the first to show that the interfaces between two crystals and the neighborhood of a crystal surface can give rise to specific near-surface electron states and the corresponding energy levels. They have a pronounced effect on the electron work function, the passage of current through the interface, absorption of atoms at the surface, heterogeneous catalysis, etc. In connection with the passage to micro- and nanostructures, the role of various surface states becomes increasingly significant in practical applications.

The topical problem of solid-state physics of the last decade was the study of so-called mesoscopic systems of linear size (usually submicron) retentive of even the phase coherence of electron wave functions. One of the most spectacular manifestations of this coherence demonstrated by Yu V Sharvin is the oscillatory dependence of resistance on the magnetic flux. This effect is akin to the quantization of the magnetic flux in superconductors and is closely related to persistent currents in mesoscopic circuits in a magnetic field.

The work of L D Landau on the quantization of motion of a charged particle in a magnetic field and the ensuing diamagnetism of electrons in metals — an insoluble enigma for classical physics — remains classical for the physics of magnetic phenomena. The term 'Landau level' is still one of the most frequently encountered in solid-state physics. The general classification of all magnetically ordered structures is made in terms of space magnetic groups introduced by A V Shubnikov and studied comprehensively by his collaborators.

Ya I Frenkel', Ya G Dorfman, and W Heisenberg were the first to point to the exchange interaction as a basis for magnetic ordering. S V Vonsovskiĭ and S G Shubin proposed the so-called $s-d$ model. Together with its numerous modifications, it has served as the basis for microscopic consideration of the nature of real magnetic structures of transition metals. The theory of L D Landau and E M Lifshits provided a possibility to fully describe the structure of domains and the dividing domain walls in ferromagnets. Of fundamental significance for the present-day understanding of the nature of magnetic ordering, including the antiferromagnetic and weakly ferromagnetic states, were the studies of A S Borovik-Romanov and his collaborators, among them their investigation into the nuclear magnetism of the superfluid phase of helium-3. I Ya Dzyaloshinskiĭ interpreted the effect of weak ferromagnetism as a state originating when the antiferromagnetic ordering is weakly violated by relativistic effects.

Decisive in many respects was the contribution of Russian scientists to low-temperature physics and especially the physics of quantum liquids and crystals. The discovery, by P L Kapitsa, of the superfluidity of liquid helium proved to be a notable step on this road. Like superconductivity which had been discovered by H Kamerlingh Onnes earlier, this phenomenon should have initially seemed improbable. The phenomenological theory, due to L D Landau, explained this phenomenon by postulating a certain spectrum of elementary excitations — the lowest quantum excited states of a macroscopic system of Bose particles — and thereby introduced the very notion of a quantum liquid. This theory was at once the triumph of the conception of elementary excitations as a peculiar kind of almost noninteracting quasiparticles, which may have nothing in common with real particles that strongly interact with each other and form a crystal or a liquid. This conception was first introduced by I E Tamm for phonons — the vibrational quanta of crystal lattices — and later by Ya I Frenkel' for excitons. However, this conception yielded so dramatically nontrivial a result when applied to precisely the Bose liquid. Subsequently, N N Bogolyubov proposed, in the context of a simplified model of a weakly nonideal Bose gas with a repulsive interaction, a microscopic substantiation of the acoustic spectrum of elementary excitations — the key element of the spectrum postulated by L D Landau.

É L Andronikashvili, V P Peshkov, A I Shal'nikov, et al. performed notable experimental investigations of the unique properties of superfluid helium in the Institute for Physical Problems established by P L Kapitsa. Subsequently, L D Landau also formulated the theory of a Fermi liquid. The theory, which was later borne out by liquid helium-3 research, showed how dramatically these two liquids — helium-3 and helium-4 — differ due to the difference in statistics despite a practically equal interaction of their atoms. L P Pitaevskiĭ pointed to the probable existence, later confirmed experimentally, of the superfluid phase also in helium-3 owing to an effect akin to the Cooper phenomenon in superconductors — the formation of a condensate of atom pairs.

A I Shal'nikov and his disciples pioneered experimental studies of no less unique an object than a quantum crystal of helium-4, which exists only under pressure, moderate as it is. A F Andreev predicted a diversity of quite unusual phenomena concerning the motion of defects (quantum diffusion) in such a crystal, coherent 'waves of crystallization' at its boundary with a liquid phase, etc. The waves of crystallization, in particular, were studied by A Ya Parshin and K O Keshishev in the Institute for Physical Problems. The quantum kinetic theory of the phase transitions of the first kind was constructed by I M Lifshits and Yu M Kagan.

It is pertinent to note that the Russian low-temperature physics owes much of its success to the highly productive techniques and equipment for liquefying gases, including the so-called turbine expansion engines, which imparted great economic significance to this branch of science.

The microscopic nature of superconductivity, discovered as early as 1911, remained a mystery for nearly half a century. But several years prior to its solution, V L Ginzburg and L D Landau constructed a phenomenological theory in the spirit of the above-mentioned general Landau theory for phase transitions of the second kind. However, a distinguishing feature of this theory was the quantum nature of the order parameter introduced into the theory — a macroscopic wave function obeying the nonlinear Schrödinger wave equation. This theory made it possible to quantitatively describe most superconductivity-related effects and to predict several new ones. It proved to be so advantageous that the majority of practical calculations of specific effects are performed in the framework of the Ginzburg – Landau theory (which has been rigorously substantiated by L P Gor'kov from a microscopic theory) even after the construction of a consistent microscopic theory by J Bardeen, L Cooper, and J R Schrieffer.

Moreover, the approach proposed went far beyond the scope of superconductor physics. It has been generalized by V L Ginzburg and L P Pitaevskiĭ to superfluid Bose liquids while the so-called Ginzburg – Landau functional has been extended to a great diversity of branches of theoretical physics, including quantum field theory and quantum cosmology.

As applied to superconductors, one of the most significant results of the theory was the picture, elucidated by A A Abrikosov, of how the magnetic field penetrates so-called superconductors of the second kind — in the form of thin vortical filaments with the superconducting state destroyed at the center. That is why the sample as a whole remains superconducting up to values of magnetic field (or current) far exceeding those which mark the onset of magnetic field penetration, which is of significance in developing superconducting magnets, passing high currents, etc. Commonly referred to superconductors of the second kind are 'dirty' superconductors, i.e. those which possess a relatively short electron free path. It is supposedly this behavior of superconducting alloys in the magnetic field that was observed by L V Shubnikov long before an understanding of this picture began to emerge. In high-temperature superconductors exposed to strong magnetic fields or subjected to high currents, there occurs a complex pattern of interaction of vortices, of their spatial ordering and motion to ensure small dissipation. This was considered by A I Larkin and collaborators. Subsequent to devising the microscopic theory, many effects of prime significance were calculated by L D Landau's collaborators — A A Abrikosov, L P Gor'kov, I M Khalatnikov, et al. One of the most elegant effects is the electron reflection from a normal metal — superconductor interface in the form of a 'hole,' predicted by A F Andreev. The effect arises from the necessity, for the electron penetrating into the superconductor, to entrain one more electron from the normal metal in order to form a new Cooper pair in the superconductor. Mention should be made of the paraconduction effect predicted by A I Larkin and L G Aslamazov, i.e. the fluctuation occurrence of the domains of the superconducting phase in a normal metal at above-critical temperatures.

The electron properties of metals are determined by the structure of their energy spectrum in the vicinity of the Fermi energy or, to state it in different terms, by the geometry of the Fermi surface, which is very complicated even for most simple metals. I M Lifshits formulated the general program for experimental determination of the Fermi surface of real metals. With this object in view, he and a group of his disciples (M Ya Azbel', M I Kaganov, É A Kaner, A M Kosevich, V G Peschanskiĭ, et al.) pursued systematic theoretical studies of many thermodynamic properties (primarily the oscillation ones in quantizing magnetic fields) and kinetic characteristics (including galvanomagnetic and resonance ones for an electronic spectrum of arbitrary form), and showed what kind of information on the structure of the Fermi surface can be inferred from one or other experiment. Cyclotron resonance under the conditions of the anomalous skin effect predicted by M Ya Azbel' and É A Kaner stands among the first on the list. (In this case, the electron free path is much greater than the radius of the Larmor electron orbit in the magnetic field, which in turn is many times the skin depth.) Also standing among the first on the list is the resonance on the so-called 'jumping trajectories' kept close against the sample surface by the magnetic field, which was discovered experimentally by M S Khaikin. Ample experimental evidence of this kind is due to N E Alekseevskiĭ, Yu P Gaidukov, V F Gantmakher, M S Khaikin, V S Édel'man, et al.

Under no circumstances is the foregoing list of avenues and accomplishments of Soviet (Russian) physics to be regarded as complete. More likely it is merely some illustration of the more general picture presented in the anniversary issues of the journal *Uspekhi Fizicheskikh Nauk* [Soviet Physics – USPEKHI] from 1947 to 1987. There remain many achievements as good as those mentioned above. A good case in point is the so-called Hartree–Fock method, one of the principal ways of making approximate calculations of quantum systems comprising more than one particle. It serves as the initial approximation to the majority of multiparticle problems. As other examples we refer to the methods of obtaining strong (up to 300 kGs) magnetic fields devised by P L Kapitsa and the method of obtaining superstrong (up to 20 MGs) fields by explosive compression of the magnetic flux proposed by A D Sakharov and A I Pavlovskiĭ. Undeniably worthy of mention is the unique phenomenon of the omniscient course of theoretical physics by L D Landau and E M Lifshits (now continued by L P Pitaevskiĭ), which has been translated into many languages.

Astronomy

As the most ancient of exact sciences, astronomy has developed in the Russian Academy of Sciences throughout its history. The Academy founder, Peter the First, would personally make purchases of astronomical instruments in European countries. The first astronomical observatory resided in the tower part of the Cabinet-of-Curiosities building in St. Petersburg. M V Lomonosov gave considerable attention to astronomical observations; widely known is his discovery of the atmosphere around Venus during its passage across the Solar disk in 1762. From the national tasks of mapping the territory of the country, sustaining a precision time service, and ensuring sea navigation, a demand arose for instituting the Principal Astronomical Observatory, which was established on Pulkovo Hill near St. Petersburg in 1838. Through the effort of its founder and first director V Ya Struve who performed long-standing high-precision observations of the positions and the passage times of the stars, excellent star catalogs were made to legitimately bring the fame of 'world's astronomical capital' to the Pulkovo Observatory in the second half of the XIXth century. Moreover, his labors brought into being a scientific school of thought, which initially gained recognition due to its astrometric and subsequently astrophysical investigations.

Since the beginning of the XXth century, especially after the Revolution, the Academy placed emphasis on the development of the observational basis of astronomy. In the late 20s, a telescope with a primary mirror of 1 m in diameter was purchased in England for the Simeiz Division of the Pulkovo Observatory; the telescope was destroyed during the fascist occupation of the Crimea. After the War the Crimean Astrophysical Observatory of the USSR Academy of Sciences was established (it has passed to Ukraine now). In 1961, the Academician G A Shain telescope with primary mirror 2.6 m in diameter, in size ranking first in the USSR and third in the world, was mounted in the Observatory. 1964 saw the establishment of the Special Astrophysical Observatory equipped with world's biggest 6-m optical telescope and the

RATAN-600 radiotelescope. Also noteworthy was the deployment of two 22-m radiotelescopes in Pushchino and Simeiz, along with construction of the 'Kvazar' complex comprising three 32-m radiotelescopes. Observations have already commenced on one of them. Several telescopes were constructed for solar observations, including the solar tower telescope with a mirror 90 cm in diameter, one of world's biggest, in the Crimean Astrophysical Observatory. A complex of radiotelescopes for solar observations was built in Irkutsk.

The account of the accomplishments of domestic astronomy commences with solar system research. A major contribution to the solution of the problem of its origin was made by O Yu Shmidt and his disciples, who substantiated the hypothesis that the planets had formed from a gaseous dust cloud. The mechanism of planet formation put forward by V S Safronov has now gained world-wide acceptance. A M Fridman's and N N Gar'kavyiĭ's study predicted the positions of Uranus's satellites, later confirmed by cosmic observations. On the basis of radio observations of the Moon, V S Troitskiĭ found that its surface layer is hard and not dust-like, as had been conjectured earlier. This conclusion was amply borne out when our natural satellite was visited by space vehicles and astronauts. A M Fridman and collaborators showed that the Moon could not have formed due to the detachment a fraction of Earth in collision with some space object, because this collision would have resulted in a significant change of the terrestrial orbit. Of special note is the pioneering radar research of Venus performed under the supervision of V A Kotel'nikov, which made it possible to determine the planets' orbits more precisely.

As we turn to stellar research, the papers by G A Shain and O Struve on the pioneering determination of the rotation of stars are to be mentioned first. G A Shain also discovered a great excess of the ^{13}C carbon isotope in the atmospheres of carbon stars in comparison with the Sun. É R Mustel' and M E Boyarchuk were the first to show that the shells of nova stars have an excess of CNO elements, which is extremely valuable for the understanding of the nature of their flares. A M Cherepashchuk found that the Wolf–Rayet stars — the result of evolution of massive stars — are helium stars. A V Tutukov with collaborators showed that late in the evolution of close binary stars their components can merge into one star owing to the emission of gravitational waves.

Russian astronomers achieved much progress in studies of nonstable stars. In the 40s, V V Sobolev constructed a theory of moving stellar shells which provided the basis for the analysis of stellar spectra. Moreover, this theory was a help in deducing that symbiotic stars, whose spectra comprise quite contradictory features of hot and cold plasmas, are binary systems. N I Shakura and R A Syunyaev considered the disk accretion in binary systems. D V Bisikalo et al. constructed a three-dimensional model of exchange in binary systems. P P Parenago and B V Kukarkin pioneered the compilation and continual update of the 'General Catalog of Variable Stars.'

In 1938, L D Landau proposed the first physical model of a neutron star. The existence of neutron stars was subsequently borne out. Pulsars — rapidly rotating neutron stars — were discovered. Ya B Zel'dovich and his disciples I D Novikov, R A Syunyaev, et al. showed that the accretion of substance to a neutron star or a black hole should be attended by intense emission of X-ray radiation. This was recorded in the course of extra-atmospheric observations. Nowadays it has been found that most known X-ray objects are binary stars. V S Imshennik and D K Nadezhin developed a model of supernova explosions with the inclusion of transient shell radiation. I M Gordon, V L Ginzburg, and I S Shklovskiĭ pointed to the significance of synchrotron radiation to account for the radiation emission by cosmic objects over a broad wavelength range. I S Shklovskiĭ put forward a model of one of the most intriguing objects — the Crab Nebula — and a method of determining the distance to planetary nebulae.

During the post-War years, G A Shain discovered a wealth of diffuse nebulae, and I S Shklovskiĭ showed that the forbidden hydrogen lines with a wavelength of 21 cm should be observable in nebulae of this type, which was confirmed by observations. N S Kardashev calculated that the observation of radio lines arising from transitions between extremely high atomic levels is possible, and these lines were recorded. S B Pikel'ner was the first to show that the filamentous structure of supernova remnants is due to the radiation of shock waves.

The structure of the Galaxy has been much investigated. V A Ambartsumyan discovered clusters of nova stars — stellar associations thereby marking the beginning of a new line of investigation of star formation. He also pointed to the significance of galactic nuclei for the understanding of their evolution. In 1937, V A Ambartsumyan determined that the age of our Galaxy is only 10^{10} yr rather than 10^{13} yr, which is in complete agreement with present-day estimates. A M Fridman with collaborators showed that in galaxies there exist cyclonic whirls along with well-known spiral structures.

During the 60s – 70s, B E Markaryan discovered a family of galaxies with an excess of radiation in the blue spectral region wherein transient phenomena occur. In 1965, N S Kardashev, L I Matvienko, and G S Sholomitskiĭ proposed a way of realizing very long baseline radio interferometry allowing observations of radio sources with record resolution.

Considerable attention has been given to cosmology. In the 20s, A A Fridman solved the Einstein equations and showed that the Universe should be expanding, which was amply borne out by E Hubble's observations. Worthy of mention is a series of papers by Ya B Zel'dovich and his disciples, the model of cellular Universe structure in particular, and also the papers by A D Linde et al. on the inflationary Universe. Ya B Zel'dovich and R A Syunyaev studied the scattering of relict radiation by hot electrons of galactic clusters. In 1972, Yu N Pariĭskiĭ reported the first observation of this effect. D A Varshalovich and collaborators studied intergalactic clouds by investigating absorption lines in the spectra of distant galaxies.

A substantial body of literature is devoted to solar physics. I S Shklovskiĭ devised a hot corona model in which ionization is due to electron collisions. A B Severnyĭ, É R Mustel', and S I Syrovatskiĭ studied solar flares and arrived at the conclusion that a rearrangement of local magnetic fields occurs during the flares. S B Pikel'ner determined the nature of the chromospheric network and the supergranulation. V L Ginzburg showed that the solar radio emission in the meter wave band originates in the corona. This was amply borne out by observations of the solar eclipse in Brazil. V L Ginzburg and V V Zheleznyakov performed a series of theoretical studies of the radio emission of the quiet and active Sun; the significance of synchrotron radiation was pointed out. V V Zheleznyakov made advances in the development of the theory of cyclotron radiation in dwarfs and, together with A A Litvinchuk, inquired into the role of induced processes in the formation of annihilation lines in the spectra of cosmic sources.

The advent of man-made space vehicles opened up new possibilities for the study of cosmic objects, primarily the Moon, the planets, and circumterrestrial space. Many priority results were obtained in our country: photographs were first made of the lunar far side, panoramas of the lunar and venusian surfaces were obtained, and samples of lunar soil were delivered to the Earth. Relying on the analysis of the samples, the Moon age was evaluated at 4.5 billion years. Several series of the vehicles sent to Venus made it possible to map its surface and study the composition and the dynamics of its atmosphere in detail; balloons were launched into an atmosphere of other planet for the first time. In the 70–80s, spacecraft pursued research on Mars and its satellite Phobos. Their surfaces were mapped and the martian atmosphere was studied. A wealth of spacecraft explored circumterrestrial space and the effect of solar activity on the Earth's magnetosphere; in this connection it is pertinent to note the discovery of the Earth's radiation belts. Solar research was pursued on several missions, the 'Koronas-I' mission being the most significant.

In 1986, a fascinating space experiment was conducted: two Soviet 'Vega' spacecraft, together with spacecraft of other countries, flew past Halley's comet in its immediate vicinity. This made it possible to investigate in detail the structure and composition of the cometary nucleus and the dust and gas constituents of the coma. Its gas constituents were also studied with the aid of the 'Astron' astrophysical station.

In the 80s, two astrophysical stations, 'Astron' and 'Granat,' were sent into orbit to stay in operation for over eight years. The former allowed absolute measurements in the UV range to be carried out for a great number of stars while the latter was used to study the X-ray radiation of many transient objects. In particular, the GRS 1915 + 105 source was discovered wherein, according to more recent radio observations, the apparent velocities of the motion of plasma clouds are supraluminal. A large variety of instruments were used to record gamma bursts, i.e. transient releases of huge amounts of energy in the high-energy range. The 'Konus' instrumentation intended to record gamma bursts was used aboard many Soviet spacecraft as well as aboard the American 'Wind' satellite. The 'Relikt' satellite was used to carry out panoramic observations of the brightness of the relict radiation.

Space experiments have always been accomplished on the basis of broad domestic and international cooperation. Along with domestic industrial plants, the institutes of the Division of General Physics and Astronomy took an active part in their implementation: the Institute for Space Research; the P N Lebedev Physics Institute; the Institute of Terrestrial Magnetism, the Ionosphere, and the Radio-Wave Propagation; the A F Ioffe Physicotechnical Institute; etc.

* * *

This brief and inevitably incomplete essay on the achievements of national physics and astronomy is an attempt to show the significance of the contribution made by the scientists of our country to the progress of these realms of science. It may be said without exaggeration that the century gone by has been the age of physics and astronomy. The contribution of physicists to the formation of the image of contemporary civilization at the turn of the new millennium can hardly be overestimated. Astronomy has been able to provide answers to numerous questions of the origin, the structure, and the evolution of the Universe — questions that have always been and continue to be stirring to the human mind. The achievements of Russian physicists and astronomers have gained world-wide recognition, and have been awarded Nobel prizes and numerous prizes and medals of foreign academies, international scientific organizations, and societies.

Commemorating the 275th anniversary of the Academy of Sciences, we would like to believe that there comes an increasingly deep realization that the renowned traditions of Russian science should be retained and its accomplishments augmented.