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Bogolyubov Institute for Theoretical Physics, Nat. Acad. of Sci. of Ukraine  
(14b, Metrolohichna Str., Kyiv 03680, Ukraine)**OLEKSANDR SERGIYOVYCH DAVYDOV  
(1912–1993)**

Oleksandr Serhiyovych Davydov was born on December 26, 1912 in a town of Yevpatoria, in worker's family. He finished the secondary school in 1930 and moved to Moscow in the spring of 1931, where he started to work as a grinder at the AMO automobile plant.

Thirst for knowledge, which revealed itself in the young man as early as his school days, brought him in 1932 to workers' courses at the Moscow State University (MSU). In a year, Oleksandr Serhiyovych became a first-year student at the Faculty of Physics of the MSU. Being yet a student, O.S. Davydov showed his unordinary abilities of a physicist-theorist. In the fifth-year of the study, he carried out, under the supervision of Prof. V.S. Fursov, his first scientific work on the statistical theory of light scattering in condensed media and attracted attention of the university lecturers.

In 1939, O.S. Davydov graduated with distinction from the university, where he obtained the qualification in the speciality "theoretical physics", and was accepted as a postgraduate student to an outstanding Soviet scientist, the future Nobel laureate, the Head of the Department of theoretical physics at P.N. Lebedev Physical Institute of the Academy of Sciences of the USSR (FIAN) Academician Igor Evgen'evich Tamm. Already during the first years of independent work, O.S. Davydov showed a diversity of his scientific interests. After statistical physics, he became interested in the problems of nuclear theory and elementary particles. The researches of the young scientist were devoted, in particular, to the theoretical study of the phenomena of internal conversion in and decay of atomic nuclei.

In 1941, Oleksandr Serhiyovych prepared, ahead of time, his Ph.D. thesis. Its presentation was planned for the autumn of that year. However, the extraordi-

nary events interrupted those plans: the Great Patriotic War began.

Being in the reservation as a physicist, Oleksandr Serhiyovych was commissioned to the Narkomat (Ministry) of aviation industry, where he was appointed the Head of the x-ray and, afterwards, spectral laboratory at one of the plants in a town of Ufa (Russia). The young scientist revealed himself as a high-skilled and hard-working expert capable of successfully managing a team of scientific collaborators. In 1942, he was appointed the Head of the Department of Physical Methods of Research, which included all physical laboratories of the plant. O.S. Davydov worked at this position till the last months of the war.

In 1943, the FIAN was in Kazan', and Oleksandr Serhiyovych, possessing the single copy of the manuscript, defended his dissertation for the scientific degree of Ph.D. in Physics and Mathematics. The dissertation was entitled *Theory of Electron Emission by a Radioactive Substance*.

When working at the plant, O.S. Davydov managed to combine the production and the scientific activity with the pedagogical one. In particular, in 1942–1945, he taught the general physics course to students at the evening department of the Aviation Institute.

In April 1945, Oleksandr Serhiyovych was invited to work at the Institute of Physics of the Academy of Sciences of the Ukrainian SSR (AS UkrSSR), where the spectroscopic researches of aromatic compounds, pioneering at that time, were carried out. After having moved to Kyiv, O.S. Davydov worked first at the position of Senior scientific researcher, then as the Deputy Director for scientific work of the Institute of Physics of the AS UkrSSR. The scientific activity of Oleksandr Serhiyovych in those years was associated with the study of molecular crystal properties.

In 1949, on the basis of the results obtained, O.S. Davydov wrote and defended a thesis for the doctoral degree entitled *Theory of Light Absorp-*

*tion in Molecular Crystals.* In parallel with his work at the Institute of Physics of the AS UkrSSR, O.S. Davydov started his pedagogical activity at the T.G. Shevchenko State University of Kyiv. As the Head of the chair, he lectured courses in quantum mechanics, statistical physics, thermodynamics, electrodynamics, the theory of chemical bond, and some other domains of physical science.

In 1951, O.S. Davydov was awarded the academic rank of Professor and elected the Corresponding Member of the AS UkrSSR. He was no more than 40 years of age at that time.

In 1953, by the order of the government of the USSR, O.S. Davydov was appointed the Head of the theoretical department at the Institute of Physics and Power Engineering in Obninsk (Russia). At the same time, Oleksandr Sergiyovych occupied the Professor position at the chair of theoretical physics and, afterwards, the Head of the chair of quantum-mechanical theory at M.V. Lomonosov Moscow State University.

In 1956, O.S. Davydov changed to a permanent position at the MSU. Simultaneously, he occupied the position of the Head of the theoretical sector of the Laboratory of atomic nucleus at the FIAN. Within this time period, the scientist returned back to researches in nuclear physics and developed the theory of collective excitations in atomic nuclei.

In 1964, Oleksandr Sergiyovych came back to Kyiv to head the Department of nuclear theory at the Institute of Physics of the AS of UkrSSR. The same year, he was elected the Academician of the AS of UkrSSR.

In 1966, O.S. Davydov transferred to the Institute for Theoretical Physics (ITP) (recently organized by M.M. Bogolyubov) of the NAS of Ukraine. First, he worked there as the Head of the Department of nuclear theory (later, the Department of multiparticle systems); later, from 1973 to 1987, he was the Director of this institute.

Oleksandr Sergiyovych published about three hundreds of scientific works, including eight monographs and four popular science books. He was an excellent lecturer; he successfully spoke to various audiences ranging from leading experts-physicists to people who are only interested in the problems of modern science. The lectures and scientific reports of Oleksandr Sergiyovych had a steady success at the largest scientific centers in many countries.

In 1966, O.S. Davydov together with a group of his colleagues was awarded the highest Soviet scientific award, the Lenin Prize, for theoretical and experimental researches of excitons in crystals. In 1969, he was awarded the State Prize of the Ukrainian SSR for a cycle of works on the nuclear theory and, in 1972, the honorary title of Honored worker in science of the Ukrainian SSR.

The scientific works of O.S. Davydov were deservedly recognized by physicists in the whole world. The Davydov splitting effect and the Davydov–Filippov theory of nonaxial nuclei are well-known. In the last years of Davydov’s life, the term “Davydov’s solitons” became widely propagated. The monographs written by the scientist were translated into many languages and published in UK, Germany, the USA, Italy, Poland, Japan, and other countries. Being published many times, they have not lost their actuality till now. O.S. Davydov’s books *The Theory of Atomic Nucleus* and *Quantum Mechanics* served – and we may say “continue to serve” – for the whole generation of physicists both in the USSR and abroad as a basis to become proficient in the fundamentals of modern science.

O.S. Davydov executed a large piece of the scientific managerial and editorial work. He was an assistant of the Editor-in-Chief of the journal “Dopovidi AN URSR” (“Reports of the AS of the UkrSSR”, from 1980), a member of editorial-publishing council of the AS UkrSSR, a member of editorial boards of the journals “Teoreticheskaya i Matematicheskaya Fizika” (“Theoretical and Mathematical Physics”, from 1972), “Yadernaya Fizika” (“Nuclear Physics”, from 1965), and “Ukrains’kyi Fizychnyi Zhurnal” (“Ukrainian Journal of Physics”, from 1967), the Editor-in-Chief of the transactions of Bogolyubov Institute for Theoretical Physics of the NAS of Ukraine “Fizika Mnogochastichnykh Sistem” (“Physics of Many-Particle Systems”, from 1979). Oleksandr Sergiyovych was also a member of the Presidium and the Chairman of the Physics Section of the Committee on State Prizes of the Ukrainian SSR in science and engineering at the Council of Ministers of the UkrSSR (1969–1987), a member of scientific councils of the AS of the USSR in the problems “Solid State Theory”, “Nuclear Spectroscopy”, and “Nuclear Reactions”.

The diversified activity of O.S. Davydov was distinguished by high awards of his Motherland: the Or-

ders of Lenin, the medals “For Valiant Labor in the Great Patriotic War 1941–1945”, “For Labor Valor” “For Valiant Labor in Commemoration of the 100th Anniversary since the Birth of Vladimir Il’ich Lenin”, “Thirty Years of Victory in the Great Patriotic War 1941–1945”. At last, in 1982, O.S. Davydov was awarded the rank of the Hero of Socialist Labor.

Talking about Oleksandr Sergiyovych Davydov as a scientist, one cannot but mention a specific property of his thinking manner – a simplicity, which originated from a profound comprehension of the basis and the essence of physical phenomena and became a characteristic feature of his scientific style. The works of O.S. Davydov and the logic of his scientific (and not only scientific!) thinking manner are free of philosophizing. The science always deals with specific objects. This is one of the important criteria that enable the true logic to be discerned from scientism, which Oleksandr Sergiyovych actively counteracted.

The love of experiments and the comprehension of their capabilities were inherent to Davydov as a theorist. Carried out at a high modern level, his works were free of multilevel abstract constructions, which often frighten off experimenters. O.S. Davydov’s scientific credo, which he steadily followed in his works, consisted in the tending to maximum clearness and concreteness. The same rule served as a basis of requirements that the scientist put before his numerous disciples. He run seminars at the ITP of the AS UkrSSR attended by both theorists and experimenters. The main principle for each lecturer at the seminar was “The audience knows nothing”. Such an approach made it impossible to use the highly specialized information and terminology without a preliminary and – this is important! – clear explanation.

O.S. Davydov was distinguished by a high adherence to the principles of his scientific positions. Oleksandr Sergiyovych consistently defended his viewpoint concerning physical problems under discussion. His belief was based on the extremely high scientific erudition and the profound understanding of the physical essence of phenomena.

Those who communicated with O.S. Davydov knew him as an excellent, even passionate, polemist. His scientific arguments were always connected with the essence of a problem, they were weighty and convincing. Nevertheless, Oleksandr Sergiyovych never abused his authority and the name of world-rank scientist. He remained a patient enough listener, did

not nitpick, and did not make pedantic remarks on non-essential or formal issues.

O.S. Davydov gave much attention and time to the pedagogical activity, the training of the scientific staff. He was able to discuss the work of a student or a post-graduate student, by thoroughly and comprehensively drilling down into the details of a derivation and calculations. One can hardly overestimate advantages that young physicists obtained from such discussions.

The scientific school of O.S. Davydov includes many known physicists. He was a supervisor of 36 Ph.D. thesis, and the authors of the majority of them became Doctors of science later. However, the idea of the scientific school includes not only the number but, first of all, the quality of its disciples. The school of O.S. Davydov satisfies this criterion. Among his disciples, there are such well-known physicists-theorists as the winners of Lenin Prize A.F. Lubchenko and E.I. Rashba, the winners of the State Prize the UkrSSR in science and engineering Yu.B. Gaididei and V.M. Loktev, the winners of the K.D. Sinelnikov Prize of the AS UkrSSR V.M. Loktev, V.I. Ovcharenko, and G.F. Filippov, the winner of the O.S. Davydov Prize of the NASU O.O. Eremko, the winner of the M.M. Bogolyubov Prize of the NASU V.M. Loktev; this is L.S. Bryzhyk, who first won the prestigious Gold medal of I. Prigogine not only among physicists in post-Soviet countries but also in the Eastern Europe, as well as the well-known physicists V.M. Agranovych, V.Ya. Antonchenko, V.N. Ermakov, O.V. Zolotaryuk, E.M. Myasnikov, B.M. Nitsovych, V.A. Onishchuk, I.S. Osad’ko, A.A. Chaban, and others.

O.S. Davydov gained a sincere respect of his colleagues and disciples not only as an outstanding scientist but also as an accessible person, simple in communication, permanently correct, capable of creating the atmosphere of goodwill and interest in science around himself. The volume of this paper does not allow us to consider completely all scientific problems that O.S. Davydov was interested in. Therefore, we will shortly characterize only his main achievements.

As was mentioned above, Oleksandr Sergiyovych was a physicist-theorist with a wide range of scientific interests. However, we can distinguish those directions of theoretical physics, in which his basic interests prevailed and the corresponding contribution

was the most pronounced. These are the solid state theory, nuclear theory, and quantum biophysics. The story of scientist's activity can be conditionally divided into long enough periods, during which he intensively worked in a certain branch of theoretical physics. Below, a short review of the results obtained will be made, mainly, on the basis of their subjects.

O.S. Davydov carried out his first scientific research as early as he was a student. It was devoted to the development of the statistical theory of scattering of electromagnetic waves in condensed media. On the basis of standard methods of the statistical mechanics of condensed systems, the intensity of scattered light in nonideal gases at the condensation and at the transition from the gaseous into the liquid state through the critical point was calculated. Those works did not lose their scientific value and are often cited in the modern physical literature.

O.S. Davydov made a great contribution to the theory of elementary excitations in solids. He created the theory of molecular excitons, collective currentless electronic excitations, in molecular crystals. The concept of exciton was introduced into the crystal physics by the outstanding Soviet physicist Ya.I. Frenkel more than 80 years ago. O.S. Davydov generalized and extended this concept onto molecular crystals with a complicated structure. He pointed out a crucial role of molecular excitons in such important processes as light absorption, luminescence, energy transfer, and photoconductivity in molecular crystals and some organic polymers, as well as in plenty of biological processes. When estimating O.S. Davydov's contribution to the theory of molecular excitons, the well-known physicist from Japan Y. Tanaka marked that "The research of electron structure in complicated molecules in the crystalline state was rather scarce until Davydov had developed the theory of excitons in molecular crystals".

Let us formulate the principal ideas of the theory of molecular excitons developed by O.S. Davydov. Molecular crystals are solids consisting of molecules (or atoms of inert gases), with the interaction forces between the latter being of the Van der Waals type. Typical molecular crystals include crystals composed of anisotropic molecules of aromatic compounds: anthracene, benzene, naphthalene, and others. The molecular interaction energy in such crystals is relatively low in comparison with the energy of electrons in the molecules. However, as O.S. Davydov

showed, even the small intermolecular interaction can give rise in most cases to a modification of the energy spectrum in real crystals, if we compare them with a crystal, in which such interaction is absent (the model of "oriented gas"). This phenomenon manifests itself most strongly in crystals that contain a few molecules in a unit cell. Just such crystals were studied by O.S. Davydov for the first time.

Let a crystal have  $\sigma$  molecules in a unit cell, and the position of molecules are determined by two indices,  $\mathbf{n}$  and  $\alpha$ , where the vector  $\mathbf{n}$  points to the place of the unit cell, and  $\alpha = 1, \dots, \sigma$  characterizes the position and the orientation of a molecule in this cell. Molecules with the same index  $\alpha$  form the  $\alpha$ -th sublattice of the crystal. The operator of crystal energy  $H$  can be written down in the form

$$H = \sum_{\mathbf{n}\alpha} \left( H_{\mathbf{n}\alpha} + \frac{1}{2} \sum_{\mathbf{m}\beta \neq \mathbf{n}\alpha} V_{\mathbf{n}\alpha\mathbf{m}\beta} \right),$$

where  $H_{\mathbf{n}\alpha}$  is the energy operator for a molecule that occupies the site  $\mathbf{n}\alpha$ , and  $V_{\mathbf{n}\alpha\mathbf{m}\beta}$  is the operator of interaction energy between the  $\mathbf{n}\alpha$ -th and  $\mathbf{m}\beta$ -th molecules. When studying the crystal states with only one excited molecule, O.S. Davydov suggested the wave functions

$$\psi_{\alpha}(\mathbf{k}) = \frac{1}{\sqrt{N}} \sum_{\mathbf{n}} \exp(i\mathbf{k}\mathbf{n}) \psi_{\mathbf{n}\alpha}$$

to be used, where  $\psi_{\mathbf{n}\alpha}$  is the wave function describing the state where one molecule is in the excited electron state,  $\mathbf{k}$  is the wave vector, and  $N$  is the number of unit cells in the crystal. From the physical viewpoint, the wave functions  $\psi_{\alpha}(\mathbf{k})$ , where  $\alpha = 1, 2, \dots, \sigma$ , correspond to collective states of a molecular crystal, in which excitons "wander" over the sublattices, "paying no attention to one another". O.S. Davydov proved that making allowance for the interaction between the sublattices results in that not a single band but  $\sigma$  bands of excited excitonic states (Fig. 1) with the energies

$$E_{\mu}(\mathbf{k}) \quad (\mu = 1, 2, \dots, \sigma)$$

correspond to the non-degenerate excited state of a free molecule in crystals that contain  $\sigma$  molecules in a unit cell. The energy distances between those bands are determined by the matrix elements of the operator of intersublattice interaction

$$\langle \psi_{\alpha}(\mathbf{k}) | H | \psi_{\beta}(\mathbf{k}) \rangle \quad (\alpha \neq \beta).$$

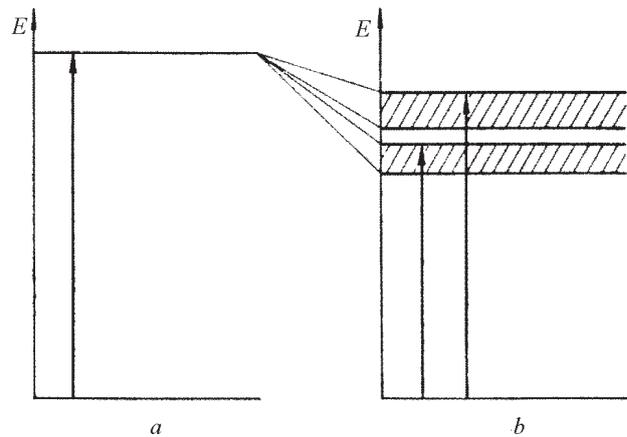
This splitting of nondegenerate molecular terms in crystals was called the *Davydov splitting* in the world literature and was registered by the State Committee for Inventions and Discoveries at the Council of Ministers of the USSR as a discovery with the same name.

Excitations that correspond to different excitonic states not only possess different energies, but they are excited by electron waves with mutually perpendicular polarizations. This circumstance emphasizes the collective character of excitonic states associated with the molecular interaction. If a molecular crystal were a simple set of oriented isotropic molecules, the aforementioned polarization, as well as the splitting, would be absent (Fig. 2).

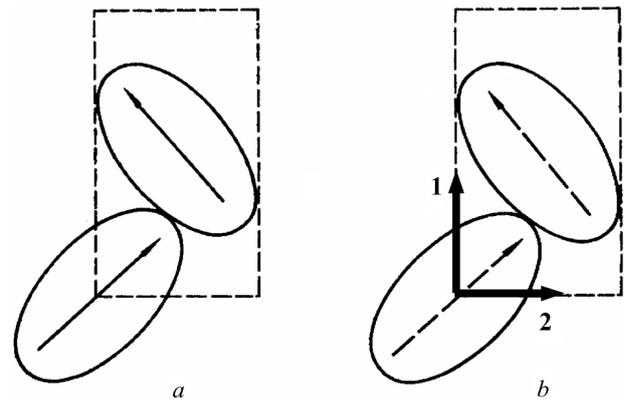
The Davydov splitting was experimentally observed in many molecular crystals, such as anthracene, benzene, naphthalene and others. It allows the excited electron states of involved molecules (the symmetry of their wave functions, oscillator forces of quantum transitions, and properties of intramolecular vibrations) to be studied, being an additional method for researching the crystal structure and its changes at transitions from one crystal modification to another one. The effect of polarized excitonic bands enabled O.S. Davydov to explain the phenomenon of pleochroism in molecular crystals and to find the origins of some specific features in their luminescence.

Exceptional attention was paid by O.S. Davydov to the development of the theory of molecular excitons with regard for vibrations of the crystal lattice. He was the first who introduced the concept of deforming (localized) excitons, the appearance or the motion of which is accompanied by a deformation of the crystal lattice near the excited site, into the scientific lexicon. Together with his disciples, O.S. Davydov carried out calculations of the width and the shape of the exciton absorption line taking both strong and weak interactions between excitons and phonons into account.

An important place in modern solid state physics belongs to O.S. Davydov's works devoted to the study of impurity-induced light absorption in crystals. He revealed, for the first time, a characteristic feature of impurity-induced excitonic excitations in crystals and demonstrated that their generation at the light absorption or the disappearance at the luminescence is usually associated with multiphonon processes. O.S. Davydov developed a theory that allows one to determine the shape of absorption and luminescence lines of impurity electron excitations, as well as the



**Fig. 1.** Energy spectrum of a crystal with two molecules in the unit cell: in the model of "oriented gas" (a) and with regard for the intermolecular interaction (b)



**Fig. 2.** Diagram of dipole transitions in a molecular crystal with two molecules in the unit cell: in the model of noninteracting molecules (a) and for excitonic states (arrows 1 and 2 show the directions of the dipole moments of their transitions) (b)

dependence of the absorption band shape on the temperature. His theory considers the variations in both the equilibrium positions of molecules in the impurity crystal and the frequencies of normal molecular vibrations when the impurity transits into an excited electron state. The theory developed by O.S. Davydov with the collaborators allows the data concerning the coefficient of impurity light absorption as a function of the frequency of an incident electromagnetic wave to be determined near the maximum of the absorption curve and on its wings. In particular, his results contain data on the temperature dependences

of position, intensity, and width of a phonon-free line, which can be used as a basis for the explanation of the Shpolskii effect.

Among O.S. Davydov's works on the theory of impurity-induced light absorption, an important place is occupied by a cycle of researches carried out together with A.F. Lubchenko and aimed at the theoretical substantiation of the so-called Urbach rule. At the beginning of the 1950s, the German experimenter F. Urbach, when studying the light absorption in silver halide crystals as a function of the photon frequency  $\omega$  and the crystal temperature  $T$ , found an empirical dependence

$$\chi(\omega) = \chi(\omega_0) \exp \left\{ -\chi \frac{\omega - \omega_0}{T} \right\}$$

for the light absorption coefficient  $\chi(\omega)$  in the frequency interval  $\omega < \omega_0$ , where  $\omega_0$  is the frequency of a phonon-free transition, and  $\chi$  is a parameter that weakly depends on the temperature and the frequency. Many attempts were made to explain the Urbach rule theoretically, but all of them failed. In this connection, R.S. Knox noticed in his monograph "Theory of Excitons" (1963) that "The rule remains a challenge to theorists as of the present writing".

The main idea proposed by O.S. Davydov consisted in that the long-wave edge of the absorption band is formed by quantum transitions from vibrational sublevels of the crystal lattice onto the electron excitation level. O.S. Davydov showed that the Urbach rule is satisfied in condensed media with a considerable number of phonon states that interact with electron excitations and are thermally excited at the given temperature following the Boltzmann law. The nature of the electron excitation is not essential in this case; the only necessary condition is the existence of a coupling between the electron excitation and phonons belonging to the quasicontinuous vibration spectrum of the crystal.

A cycle of works written by O.S. Davydov in the co-authorship with O.O. Eremko, E.M. Myasnikov, and O.O. Serikov and devoted to the study of kinetic spectral characteristics of the electromagnetic wave propagation in crystals in the excitonic frequency range became an important contribution to the modern theory of light absorption in crystals. In those works, the exciton-phonon interaction and the dispersion and the relaxation of excitonic excitations were taken into account in order to determine the application limits of

some key points of classic crystallography. A number of features in the low-temperature light absorption by crystals with dispersion were predicted, such as a deviation of the dependence of the crystal absorption coefficient on the thickness from the Bouguer–Lambert exponential law, the dependence of the integral (over the frequency) absorption on the temperature, and some others. Those effects were afterward confirmed experimentally many times dispersion in both domestic and foreign laboratories.

The fact that the works of O.S. Davydov in solid-state theory were recognized both in the Soviet Union and abroad is testified by not only their numerous citations in the scientific literature. In particular, his ideas were extended onto antiferromagnetically ordered insulators, in which the Kharkiv physicists (V.V. Eremenko and others) detected the effect of *magnetic Davydov splitting*. This effect was intensively studied in the laboratories throughout the world. The corresponding theory was developed at the ITP of the AS UkrSSR by E.G. Petrov. In solid oxygen, another, *biexcitonic*, splitting of polarized bands was observed experimentally by A.F. Prikhot'ko and L.Yo. Shans'kyi, which is also based on the collective character of excited electron states in crystals (Yu.B. Gaididei and V.M. Loktev). Moreover, the two-sublattice structure of a honeycomb lattice and the Davydov character of the electron spectrum in graphene, which is considered to be a material of the future, are eventually responsible for such a peculiarity of its quasiparticles as their massless character.

Recently, a substantial role of collective excitonic processes in biological phenomena – in particular, in the energy migration – was repeatedly emphasized and has been practically proved. Therefore, it is not surprising that O.S. Davydov's works are also widely cited in the biophysical literature. The estimation of a large contribution by O.S. Davydov to the solid state theory was summarized in the "Bolshaya Sovetskaya Entsiklopediya" (the "Great Soviet Encyclopedia") as follows: "The theory of molecular crystal spectra developed by O.S. Davydov forms a basis for interpreting the results of numerous works in spectroscopy". At last, one cannot but say that O.S. Davydov's outstanding researches of exciton properties were distinguished, as was mentioned above, by the Lenin Prize. Oleksandr Sergiyovych was also nominated for the Nobel Prize.

Some of O.S. Davydov's works were devoted to the theory of nuclear radioactive decay and the theory of elementary particles. In particular, while developing the theory of internal conversion, he succeeded in considering the influence of an atomic electron shell on the probability of the gamma quantum emission by an atomic nucleus for an arbitrary multipolarity of emitted radiation. Earlier, the American physicists R. Taylor and N. Mott studied only the case of quadrupole emission. A theory describing the beta-decay of nuclei was developed under the assumption that the neutrino's spin is equal to  $3/2$ , and the rest mass to zero. O.S. Davydov proposed a new vector-spinor form for the equations describing particles with spin  $3/2$ . This allowed those equations and their solutions to be written down in a much simpler form. Later, the vector-spinor form of equations began to be used by many Soviet physicists and foreign theorists while studying the beta-decay.

The works of O.S. Davydov in the theory of atomic nuclei form a basis for the phenomenological theory of the structure of heavy nonspherical nuclei. They substantially affected the notions about the shape of nuclei that dominated in nuclear physics at that time. In the paper "Rotational states of nonaxial nuclei" (1958), O.S. Davydov together with his disciple G.F. Filippov formulated and developed the basic concepts of the model of a rigid nonaxial rotator. This model allowed many regularities in the spectra of low-energy excitations of a large group of nonspherical nuclei to be explained from a common viewpoint. According to this rotator model, after the corresponding choice of energy measurement units has been made, the Hamiltonian of rotational excitations looks like

$$H_{\alpha} = \frac{1}{2} \sum_{\lambda=1}^3 \frac{I_{\lambda}^2}{\sin^2(\gamma - \frac{2\pi\lambda}{3})},$$

where  $\gamma$  is an empirically determined parameter, and  $I_{\lambda}$  are the projections of the operator of nuclear angular momentum on the Cartesian axes that coincide with the main axes of the nuclear inertia tensor. At  $\gamma \rightarrow 0^{\circ}$  or  $60^{\circ}$ , the energies of some excited states of the system with the Hamiltonian  $H_{\alpha}$  remain finite and, when passing to the limit, coincide with the energy levels of a rigid symmetric top. The sequence of those levels forms the basic band. The energies of other excited rotational states tends to infinity when  $\gamma \rightarrow 0^{\circ}$  or  $60^{\circ}$ . These excited states form *abnormal*

*rotational bands*. Even the first comparison of the experimental data obtained for the widths and the spins of collective states with the theory showed that the model of rigid nonaxial rotator correctly reproduced the main regularities in the excitation spectra of plenty of even-even nuclei. If the energies of collective excitations are expressed in terms of the energy of the first excitation with spin 2, the theory contains only one parameter  $\gamma$ , which is to be determined from experiment. This simple parameter is determined from the observed ratio between the energies of levels with spin 2 of the first abnormal and basic rotational bands and looks like

$$R_{22} = \frac{\varepsilon_{22}}{\varepsilon_{21}} = \frac{3 + \sqrt{9 - 8 \sin^2 3\gamma}}{3 - \sqrt{9 - 8 \sin^2 3\gamma}}.$$

When  $\gamma$  changes from  $0^{\circ}$  to  $30^{\circ}$ , the ratio  $\varepsilon_{22}/\varepsilon_{21}$  monotonously decreases from infinity to 2. A possibility to use the parameter  $R_{22}$  for the determination of  $\gamma$  is associated, on the one hand, with a high sensitivity of the ratio to the variation of  $\gamma$  and, on the other hand, with the fact that the positions of energy levels  $\varepsilon_{21}$  and  $\varepsilon_{22}$  are known rather well for a lot of even-even nuclei. By experimentally measuring the ratio  $\varepsilon_{22}/\varepsilon_{21}$  and using the expression for  $R_{22}$ , it is possible to calculate the quantity  $g$  and, hence, the spins and the positions of other levels for the main rotational and abnormal bands. Therefore, the theory allows the energy ratio  $\varepsilon_{22}/\varepsilon_{21}$  for every collective excitation of the quadrupole type (even states with  $I \neq 0$ ) to be expressed in terms of the single experimental ratio  $R_{22}$ .

According to the model concerned, the spectrum of excited states has the following features:

1. The effective (or actual) deviation of the nucleus shape from an ellipsoid of revolution results in that the interval rule, which is typical of axial nuclei, becomes violated in the main rotational band. Before O.S. Davydov's works, all nuclei were believed to possess the axial symmetry, and deviations of experimental relations for the energy from the interval rule of an axial nucleus were tried to be explained by the violation of adiabaticity conditions.

2. Besides the change of the interval rule for the levels belonging to the main rotational band, the account of effective (or actual) nonaxiality gives rise to the appearance of new "abnormal" bands, which are considered as rotational excitations in the theory of

nonaxial nuclei. Those excitations are grouped into several bands: the first abnormal group is formed by levels with spins equal to 2, 3, 4, 5, 6, 7...; the second by levels with spins equal to 4, 5, 6, 7...; the third by levels with spins equal to 6, 7... and so forth.

Simultaneously with the energies of excited states, the model allows one to determine the wave functions and, respectively, makes it possible to find (i) the probability of transitions with different multiplicities between excited states, (ii) the relative probabilities of the  $\alpha$ - and  $\beta$ -cascades of the parent nucleus with the excitation of the daughter nucleus onto various rotational levels, (iii) the probability of the excitation of a nucleus by the Coulomb field of fast charged particles, and others.

In subsequent works by O.S. Davydov and his collaborators, the issue "How much can the results of the nonaxial nucleus model change if, instead of the Hamiltonian  $H_a$ , the Hamiltonian with three arbitrary principal moments of inertia is used?", as well as other consequences of this model, was examined.

In 1960, O.S. Davydov together with A.A. Chaban developed a model of collective excitations, which, unlike the model of nonaxial rotator, was not based on the adiabatic approximation. Instead, the rotational and vibrational excitations of nonspherical nuclei were studied on the basis of a Hamilton operator containing four dynamic collective variables. The model considers the stretching of a nucleus at the rotation and allowed a deformation of nuclei with respect to longitudinal vibrations to relate with the energy of spinless  $\beta$ -vibrations. As to the transverse  $\gamma$ -vibrations of the nuclear surface, they were taken into account by introducing an effective parameter  $\gamma = \gamma_{\text{eff}}$ .

The nonadiabatic model of rotational and vibrational excitations in even-even atomic nuclei contains an extra, in comparison with the theory of rigid rotator, phenomenological parameter  $\mu$  that characterizes the deformation of a nucleus with respect to longitudinal vibrations. The introduction of  $\mu$  not only made it possible to explain a deviation of the rotational level arrangement from the interval rule, but also to establish the origin of many even excited states, which belong to the vibrational and rotational-vibrational types.

Together with his disciples, O.S. Davydov also developed the theory of electromagnetic transitions in atomic nuclei, which took longitudinal and transverse

deformations of the nuclear surface into account. It was proved that the stretching of nuclei owing to centrifugal forces very much increases the probability of electric quadrupole transitions between rotational states with high spin values. Rather general sum rules for the probabilities of electric quadrupole transitions were found. On the basis of the theory that considers the deformed state of a nucleus, the average values for the electric quadrupole momenta in the first excited states of even-even nuclei were calculated. The corresponding results agreed well with available experimental data obtained at various laboratories. The research of those quantities allowed the scientists to draw important conclusions about the shape of atomic nuclei. In particular, it turned out that plenty of nuclei, which were considered earlier spherical, are actually nonspherical. As a result, the nonspherical nuclei became interesting objects for physical researches.

The results obtained by O.S. Davydov found a convincing experimental confirmation at the laboratories in the USSR, the USA, and other countries. A lot of basic results were obtained by Kyiv physicists at the Institute for Nuclear Research of the NASU. The fundamental contribution by the scientist to the theoretical nuclear physics stimulated and continues to stimulate new experimental researches.

Later, O.S. Davydov's disciples carried out intensive researches of the microscopic theory of nuclei on the basis of the idea of the nucleon-nucleon interaction.

When estimating the contribution made by O.S. Davydov to the modern physics of atomic nuclei, Academician M.M. Bogolyubov wrote: "O.S. Davydov's works on the nuclear theory are one of the most outstanding achievements in theoretical physics".

The eighties of the last century were devoted by O.S. Davydov to one of the branches in natural sciences that developed most rapidly, namely, theoretical biophysics. Here, one of the most challenging problems was – and, probably, remains – the explanation of a high efficiency of energy and charge transfer in protein molecules. The high efficiency of energy transport in biological systems did not find an explanation in the conventional theory of transport processes that was based on the exciton mechanism. O.S. Davydov and his colleagues L.S. Bryzhyk, O.O. Eremko, M.I. Kyslukha, and V.Z. Enol's'kyi developed a different approach, which was based on the

concept of special collective states in biopolymers, solitons. According to O.S. Davydov' idea, solitons in biomolecules are bound states of electron (or vibrational) excitations and deformation ones that accompany them. Deformation excitations are localized in a certain region of the molecular chain and move along it at a constant velocity. The energy of this bound state is lower than the sum of energies of excitation components. This is one of the primary reasons of why solitons are highly stable. They can be excited only when undergoing local actions. In particular, these can be chemical reactions, for example, the decomposition of adenosine triphosphoric (ATP) acid molecules. O.S. Davydov showed that an exclusively high stability of solitons and their motion along the  $\alpha$ -helical sections of protein molecules without losses provide a high efficiency of energy and charge transfer, with the corresponding carriers being called *Davydov's solitons* or, sometimes, *Davydov's electrosolitons*. A possibility for a Davydov's soliton to be formed in  $\alpha$ -helical protein molecules found its convincing confirmation in numerous subsequent experiments carried out at the Los-Alamos National laboratory (USA) and at the research centers of Denmark and Scotland.

The concept of soliton was also applied by O.S. Davydov to a basically new explanation of the mechanism of contraction of cross-striated muscles. This problem was researched by a lot of scientists. A considerable body of experimental data was accumulated, which allows a number of hypothetical ideas to be put forward, which could explain the phenomenon of muscular fiber contraction on the basis of the interaction and the transformation of protein molecules. The models of other authors available at that time adequately described specific experimental facts (the mutual motion of myosin and actin chains at the muscle contraction, the absorption of the decomposition energy of ATP molecules in the course of contraction, the efficiency of the contraction of muscle fibers with different compositions, and its dependence on the medium acidity) but had substantial shortcomings. The main ones were the absence of an explanation for mutual relations among a wide complex of processes that accompany the contraction of muscular fibers, their physically unconvincing character, and unreal microscopic scenarios of the phenomenon.

The theory proposed by O.S. Davydov was based on the representation of excited soliton states in  $\alpha$ -

helical myosin molecules taking the specific structure of myosin into account. The energy of ATP molecule hydrolysis is spent for the generation of solitons in a myosin molecule, where they move from molecule's head, where they emerged, to molecule's tail. The motion of solitons along the myosin molecules forming thick threads is accompanied by a substantial bending of the latter. In the region of excitations that run along the bundle of myosin molecules, the thick thread expands, and the heads of myosin molecules become pressed to neighbor thin threads. In the expanded region, the heads of myosin molecules push thin threads a small distance forward and depart from them. Therefore, when the expanded region moves along the thick thread, the head of the molecule pulls thin threads after itself. Therefore, the motion of thin and thick threads in such a manner with respect to one another results in a variation of the muscular fiber length. The theory of muscular fiber contraction proposed by O.S. Davydov was accepted with a high enthusiasm and supported by leading biophysicists. Undoubtedly, it can be regarded as a significant achievement of the scientist-physicist.

Even a short list of scientific results enables one to estimate a great contribution made by the outstanding Soviet scientist, Academician of the AS UkrSSR O.S. Davydov to the modern theoretical physics.

Oleksandr Sergiyovych devoted the last years of his life to studying the phenomenon of high-temperature superconductivity discovered in 1986. As a physicist, he believed that the high temperature of the superconducting transition cannot be an occasional result of a "parameter combination" and suggested that the corresponding compounds should be characterized by "special features". Having come to know that the structure of one of them – the first true high-temperature superconductor  $\text{YBa}_2\text{Cu}_3\text{O}_7$  – contains copper-oxygen conducting chains, Oleksandr Sergiyovych drew a conclusion that it is they that are responsible for this surprising phenomenon and made an attempt to develop the so-called bisoliton theory of superconductivity; further researches (after O.S. Davydov's death) showed however that this theory was wrong. Nevertheless, the corresponding activity testified that Oleksandr Sergiyovych maintained a considerable interest to everything new (we may also include here his attempts to interpret experiments on cold nuclear fusion, which remained unjust

tified) and his creative potential at the highest level up to his last days.

The National Academy of Sciences of Ukraine issued a bibliographic guide *Oleksandr Serhiyovych Davydov* (Kyiv, Naukova Dumka, 1982), which contained a complete list of more than 200 publications of the scientist. The basic original results were expounded in the following monographs translated into many languages:

– *Excited States of Atomic Nuclei* (Atomizdat, Moscow, 1967),

– *Theory of Molecular Excitons* (Nauka, Moscow, 1968),

– *Biology and Quantum Mechanics* (Naukova Dumka, Kyiv, 1979),

– *Solitons in Molecular Systems* (Naukova Dumka, Kyiv, 1988),

– *High-Temperature Superconductivity* (Naukova Dumka, Kyiv, 1990).

Those books, as well as the textbooks written by him and known throughout the world, kept their scientific value up to nowadays and can be found at any university library.

One cannot but indicate that, in 2000, the National Academy of Sciences of Ukraine, in order to perpetuate Oleksandr Serhiyovych's memory, founded the O.S. Davydov Prize of the NAS of Ukraine for outstanding works in theoretical physics and biophysics. The outstanding Soviet physicist-theorist, Academician of the NAS of Ukraine O.I. Akhiezer became its first winner. The O.S. Davydov Prize was also awarded to Academician of the NAS of Ukraine M.F. Shulga, Corresponding Members of the NAS of Ukraine G.M. Zinoviev, E.M. Ganapols'kyi, B.O. Ivanov, E.G. Petrov, and other outstanding theorists from the NAS and universities of Ukraine. Every year, the ITP holds the Davydov readings timed to the date of his birthday (December 26), in which the scientists from the ITP and other scientific institutions of the NAS of Ukraine and higher school institutions participate. Hence, we may say that the name of O.S. Davydov continues to live and his scientific heritage to develop.

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