

PERSONALIA

PACS number: **01.60.+q**

Vladimir Evgen'evich Zakharov (on his 80th birthday)

DOI: https://doi.org/10.3367/UFNe.2019.08.038655

August 1, 2019 marked the 80th birthday of the outstanding theoretical physicist and academician of RAS, Vladimir Evgen'evich Zakharov. His name is inseparably linked with the occurrence and development of modern nonlinear physics and mathematics. His achievements in this area long ago became classical and acknowledged by the world scientific community, a reflection of which is the highest rating of his scientific papers (his citation index amounts to more than 42,000).

V E Zakharov graduated from the physical faculty of Novosibirsk State University (NSU) in 1963. He is one of the remarkable pleiad of first NSU graduates, a student of academician R Z Sagdeev. V E's scientific activity began at the famous Budker Institute — the Institute of Nuclear Physics of the Siberian Branch of the Academy of Sciences. Since 1974, he has been working at the L D Landau Institute of Theoretical Physics of RAS. For over 10 years from 1992, he was director of this institute. Since 2004, V E has been working at the P N Lebedev Physical Institute of RAS, where he is head of the Laboratory of Mathematical Physics.

V E has made a considerable contribution to practically all fields of modern physics: nonlinear plasma theory, hydrodynamics, solid state physics, nonlinear optics, oceanology, the theory of general relativity, field theory, and mathematical physics. The pioneering results in the theory of integrable systems associated with the development of the inverse scattering transform method, which are pearls of 20th-century mathematical physics, brought him recognition from not only physicists, but also mathematicians.

The main contribution of V E to science is related to the development of the three most important avenues of nonlinear physics and mathematics — the theory of wave collapses, the soliton theory, and the theory of wave turbulence.

The prediction of Langmuir wave collapse in plasma as a new physical phenomenon and the theory formulated by him are remarkable achievements of V E in the field of nonlinear plasma physics. The theory of Langmuir turbulence based on the random phase approximation which existed before V E's paper of 1972 predicted the appearance of Langmuir condensate for $k = 0$. This could in no way explain numerous experimental facts. V E established that such a scenario of the development of plasma turbulence is impossible because of so-called modulation instability of condensate. Being a nonlinear stage of the development of this instability, the collapse of Langmuir waves leads to compression of Langmuir packets to sizes of several Debye radii, which is accompanied by fast electron generation. The Langmuir collapse theory is based on the averaging method that

Vladimir Evgen'evich Zakharov

allowed him to derive the equations of interaction of Langmuir and ion oscillations in plasma (in particular, the interaction of high-frequency and low-frequency sound type waves), now referred to as Zakharov equations. This work changed radically the concept of plasma turbulence and of the mechanisms of dissipation of high-frequency wave turbulence under collective methods of plasma heating, such as heating by electron beams or by a high-frequency electromagnetic field. This work proved to be very important for nonlinear studies not only in plasma physics, but also in nonlinear optics and hydrophysics related to turbulence of sea waves.

The formulation of the wave collapse theory, beginning with V E's studies of the Langmuir collapse theory, self-focusing of light in two- and three-dimensional geometry, and up to the studies of interactions between collapses and weak wave turbulence and the influence of plasma collapse upon particle spectra is his fundamental contribution to the physics of nonlinear wave processes. The term 'wave collapse' itself was introduced by V E in his papers and is now widely used in the scientific community. According to the conception formulated by V E and his students, the physical realization of

Uspekhi Fizicheskikh Nauk **189** (10) 1127 – 1128 (2019)
DOI: https://doi.org/10.3367/UFNr.2019.08.038655
Translated by M V Tsaplina

wave collapse or solitons depends critically on boundedness or unboundedness from below of the Hamiltonian of the wave system. The case of the bounded Hamiltonian made it possible to discover stable solitons, whereas unboundedness began to serve as one of the criteria of wave collapse. This was precisely how stable three-dimensional ion-acoustic solitons in magnetized plasma were found as solutions of the Zakharov–Kuznetsov equation.

The formulation of the theory of Kolmogorov wave turbulence spectra, now referred to as Kolmogorov–Zakharov spectra, is one of V E's main achievements in the theory of turbulence. These are power-like spectra corresponding to a constant flux of energy or the number of quasiparticles, which are exact solutions of kinetic equations for waves that are found using special conformal transformations, called Zakharov transformations. These spectra describe wave pumping into the short-wave region (direct cascade) or to a large-scale region (inverse cascade). V E's theory of Kolmogorov spectra of wave turbulence that manifest themselves in wind-driven seas, acoustic turbulence, and the excitation of plasma oscillations became a considerable contribution to oceanology and plasma physics, which influenced substantially their contemporary representation. For the outstanding contribution to the turbulence theory, in particular, for predicting the inverse cascade, Zakharov was awarded the 2003 International Dirac Medal.

V E Zakharov is one of the founders of the mathematical theory of solitons based on the application of refined mathematical methods of integration of nonlinear differential equations in partial derivatives with the help of the formalism of the inverse scattering problem. The inverse scattering transform was formulated by V E with co-authors as a theory of integrable systems with an infinite number of degrees of freedom. In his pioneering paper of 1972, together with A B Shabat, he integrated the nonlinear Schrödinger equation, one of the most universal equations of nonlinear waves. This equation has a wide spectrum of applications, namely, it describes in nonlinear dielectrics and plasma self-focusing and self-modulation of light at superlow temperatures the dynamics of Bose–Einstein gas condensates, the behavior of rough seas, and the propagation of optical pulses in light fiber communication lines. It is also applied as a quantum model of interacting Bose point particles. The mathematical basis of this work is connected with the solution of the inverse problem for a linear operator — the Zakharov–Shabat operator — whose spectrum remains constant in time. Solitons are set by the position of the discrete spectrum of the Zakharov–Shabat operator. For this reason, solitons, as nonlinear coherent localized structures, turn out to be structurally stable — their form remains unchanged under scattering by solitons and by nonsoliton excitations.

This theory paved the possibility for the application of optical solitons in optical fiber communication lines as a bit of information. Owing to the work of V E and the representatives of his school, this area has recently been intensely developed and has found numerous applications in the latest techniques and technologies of telecommunications. At the present time, intense studies are being carried out to create future generations of optical fiber lines based on a direct coding of the spectrum of the Zakharov–Shabat operator, called coherent communications.

The Zakharov–Shabat dressing method of 1974–1979 exerted a decisive influence upon the state-of-the-art of the theory of nonlinear waves and solitons. This method, developed in the framework of the theory of integrable systems, is based on the way of constructing soliton and any other solutions of nonlinear equations through deformation of an arbitrary initiating solution. Another approach proposed and developed by V E together with his students is based on the solution of a nonlocal Riemann spectral problem and its modifications. The jewel in the crown of this activity was V E's solution to the classical problem of the description of orthogonal curvilinear coordinate systems in a Euclidian space of arbitrary dimensions, which was stated at the beginning of the nineteenth century and was associated with the names of the great mathematicians Riemann, Bianchi, and others. The development of these methods showed their efficiency in solving a number of problems in field theory, gravitation, nonlinear optics, and hydrodynamics. In 1978, he solved, together with V A Belinskii, an important general relativistic problem of integrating Einstein equations for two-dimensional metrics, which allowed the classification of their solutions by spectral methods using variable spectral parameters. In particular, the simplest solution in the form of a black hole is an analog of the soliton solution. Using the inverse scattering transform, he completely solved, together with his students, the problem of superfluorescence, in particular, asymptotical states are found, i.e., increasing pulses propagating through an inversely populated two-level medium, which are analogs of the precursor for stable media. V E's work of 1981 on integrating Benni equations describing wave propagation on shallow water for the nonpotential velocity field exerted considerable influence on the development of the inverse scattering transform. This work pointed out for the first time the method of examining multidimensional hydrodynamic-type systems. In recent years, V E has formulated a new direction in the theory of classical integrable systems: integrable turbulence. This direction is now being intensely developed both in numerical experiments and in experiments on incoherent wave propagation in fiber optics.

V E and colleagues (V S L'vov, S S Starobinets, et al.) are the authors of the theory of parametric wave excitation by a coherent source, the so-called S-theory. It is based on the original idea of the description of a above threshold turbulent state with the help of normal and anomalous pair correlators. This theory became in a sense an analog of the BCS theory for superconductivity. Its important consequence was the prediction of a singularity of stationary spectra of turbulence confirmed in experiments on parametric excitation of spin waves in ferromagnets. In the course of developing these studies, V E and his students formulated a theory of singular spectra of plasma turbulence distributed as jets or even concentrated at separate points of k-space under induced scattering of electromagnetic waves in plasma.

In recent years, V E obtained some fundamental results on the theory of collapse, integrability of hydrodynamics with a free boundary, and the development of the inverse scattering transform. The most important achievements are his theory of the occurrence of sea rogue waves — a problem of practical importance for navigation and the construction of sea platforms and the theory of rough sea spectra aimed at forecasting and based on analytical investigations and the direct numerical integration of complicated integro-differential kinetic equations for waves. In recent years, the study of rogue waves elaborated by V E has been under development, predicting risks for navigation and for modern fiber communication lines.

It is impossible to imagine the scientific activity of V E without his school. During the whole V E's life in science, he has given attention to his students and also to the students of his students. This large group of talented scientists trained by him is well-known in the scientific community as 'Zakharov's school' — the school of nonlinear physics and mathematics. At the present time, many of his students are fruitfully working in many countries all over the world.

He has never been indifferent to the fate of Russian science. This applies to his great efforts to save science in Russia, both at the beginning of the post-Soviet period and at present. It was his initiative to organize scholarships for outstanding Russian scientists and support for research schools, which was very important in the 1990s. During the 2014 reorganization of RAS, he was one of the organizers of the '1st of July' club of RAS scientists disagreeing with the RAS reform. This club, of which V E remains an informal leader, continues its constructive activity in organizing science in RAS, for the revival of Russian science. One should also notice his active civic position in the struggle against pseudo-science.

Speaking of V E's scientific and organizational activity, one should first of all emphasize that for over 25 years he has been head of the Academic Council of RAS for the problem of 'nonlinear dynamics'. Vladimir Evgen'evich is the editor-in-chief of the journals *East European Journal of Physics* (since 2004) and *Journal of Nonlinear Science* (1991–2001), editor of the journals *Journal of Turbulence* (since 2001), *Physics of Life* (since 2002) and *Physica D*, *Nonlinear Phenomena* (1980–1997), and chair of the organizing committees and program committees of the most prestigious international conferences, symposia, and scientific schools on nonlinear physics. In 2010, V E was given a scientific megagrant from the Russian government and opened a laboratory of nonlinear wave processes at Novosibirsk State University and now in Skolkovo. In 1987 and 1993, for his scientific achievements in fundamental studies of nonlinear phenomena in physics, he was awarded State Prizes. He was elected to the European Academy of Sciences, the American Mathematical Society, the Optical Society of America, and the American Geophysical Union.

We would like to note his talent as a poet, very highly appreciated by professional poets and writers. This hypostasis is a continuation of his scientific activity. He is a well-known poet and member of the Union of Russian Writers. V E's rhymes and poems, published in various years in the journals *Novyi Mir* and *Arion* and in literary collections and in his books, are accordant with our times. The most recent of his achievements was the issue of a six-volume collection of his poetry.

The exclusive energy inherent in V E, his goodwill, decency, and honesty attract many quite different people to him. His friends, colleagues, and students heartily wish Vladimir Evgen'evich all the best on his jubilee and wish him sound health, simple human happiness, longevity, and success in various undertakings in his diverse activity for the benefit of Russia and world science.

A V Gurevich, L M Zelenyi, E A Kuznetsov,
G A Mesyats, A V Mikhailov, S L Musher,
S P Novikov, V A Rubakov, A M Rubenchik,
R Z Sagdeev, Ya G Sinai, V E Fortov