Physics – Uspekhi **53** (9) 963 – 965 (2010)

PERSONALIA

PACS number: **01.60. + q**

Aleksandr Viktorovich Gurevich (on his 80th birthday)

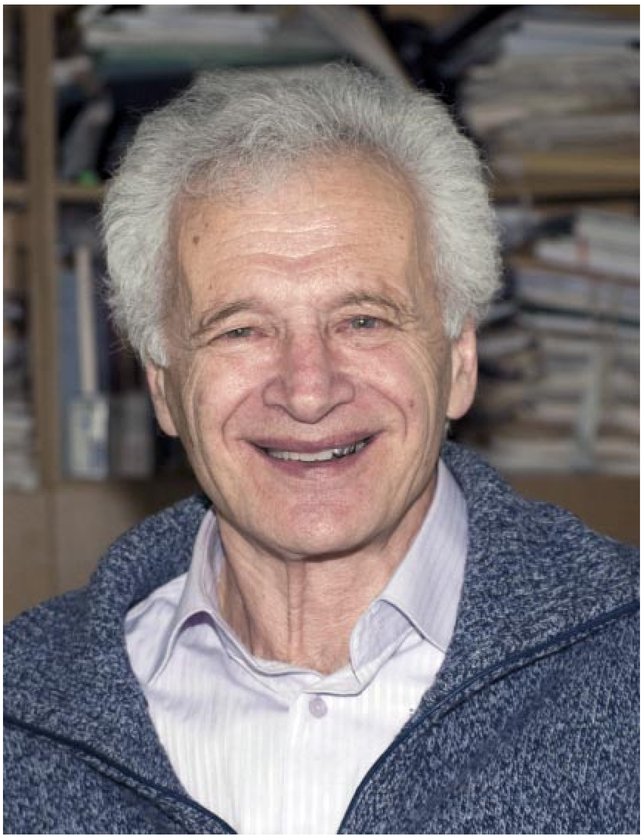
DOI: 10.3367/UFNe.0180.201009l.1005

19 September 2010 marked the 80th birthday of the well-known theoretical physicist and Full Member of the Russian Academy of Sciences, Aleksandr Viktorovich Gurevich. His scintillating talent has manifested itself in diverse areas of modern physics, such as radio physics, astrophysics, the kinetic theory of plasma, and mathematical physics.

We begin our brief outline of A V Gurevich's achievements in science with his work on the theory of runaway electrons. Pioneering experiments on plasma confinement in the 1950s exposed the significant excess of high-energy electrons in comparison with the quantities that were expected for the equilibrium distribution of velocities. These electrons removed considerable amounts of energy and thus hindered efficient heating of the plasma. The phenomenon required theoretical interpretation. A V Gurevich considered the problem of motion of a group of fast electrons in a constant electric field, taking into account their collisions with thermal electrons and ions of the plasma. One feature of these collisions is the drop in the scattering cross sections and, consequently, a friction force which diminishes as particle energy increases. A V Gurevich constructed a consistent kinetic theory of the effect, having quantitatively described the flow of fast particles from the range of thermal energies to that of high energies. He found an unexpected result: the nonequilibrium state arises in the plasma even in very weak electric fields and has a non-Maxwellian distribution function. This is the fundamental difference between plasma and gas.

This work of A V Gurevich became an important step in developing the kinetic theory. In contrast to a traditional application of the method of the kinetic equation used to derive hydrodynamic equations and to calculate transport coefficients in them (this approach goes back to S Chapman and D Enskog), he was able to find essentially nonhydrodynamic solutions. The role that kinetic theory plays in it is not that of an auxiliary tool of hydrodynamics, but a direct tool for describing the essence of a physical phenomenon. In particular, the kinetic approach underlies A V Gurevich's pioneering paper on the theory of flow around bodies moving in the ionospheric plasma; it was completed in 1957 forestalling the launch of Sputnik. This theory, developed jointly with Ya L Alpert and L P Pitaevskii, has thereafter received wide acceptance.

In 1992, A V Gurevich suggested a new mechanism of gas breakdown based on the concepts of runaway electrons. The idea was that in the electric field a seed 'runaway' electron ionizes the neutral gas through collisions, and at the same time creates not only a large number of low-energy electrons but also some number of electrons with an energy sufficient



Aleksandr Viktorovich Gurevich

for overcoming ionization losses. These new fast electrons will in turn be accelerated by the electric field and ionize the gas. This chain produces a rapidly growing avalanche of fast electrons. The kinetic theory of this phenomenon, developed jointly with K P Zybin, G M Milikh, and R Russel-Dupré, demonstrated that the threshold electric field required for this phenomenon is only a tenth of what is needed for ordinary breakdown, while the spatial scale of the rise of the avalanche at atmospheric pressure runs to hundreds of meters. This work became widely popular with specialists in atmospheric electricity; breakdown in terms of the concept of runaway electrons leads to an understanding of such phenomena as the observed bursts of intense X-ray emission during storms and powerful flashes of gamma radiation of terrestrial origin (TGF) recorded by instruments on board artificial satellites. It is particularly important that measurements of electric fields in thunderclouds had always given strengths of electric fields that are insufficient for breakdown in terms of the conventional mechanism. A V Gurevich came up with a hypothesis that the seed particles for runaway electron breakdown could be electrons of secondary cosmic rays; he developed an extensive program of simultaneous observations of incoming extensive air showers of cosmic rays and

Uspekhi Fizicheskikh Nauk **180** (9) 1005 – 1006 (2010)
DOI: 10.3367/UFNr.0180.201009l.1005
Translated by V I Kisin

gamma-ray, radio emission, and fast-electron flux bursts typical of thunderstorm discharges. The studies he initiated at LPI's Tien-Shan Mountain Cosmic Ray Station (TSMCRS) confirmed correlations between these phenomena in agreement with predictions of the theory of runaway electron breakdown.

Issues in radiophysics and the physics of nonlinear phenomena occupy a special place in A V Gurevich's work. Beginning with the work of 1960 on nonlinear waves in plasmas (jointly with V L Ginzburg), he has continued to be engrossed in the rich field of challenges and opportunities opening up in this area. A V Gurevich's work largely formed two avenues of inquiry in nonlinear physics: the theory of processes occurring in the ionosphere under the action of powerful radio waves, and the theory of dissipationless shock waves.

For A V Gurevich, the study of ionospheric and space plasmas is important not only because plasma is the predominant state of matter beyond the confines of the terrestrial atmosphere, but also because, in his opinion, plasmas display their properties in that environment in a considerably purer form than in terrestrial research facilities, and this opens the way to developing clearer theoretical approaches. In an extended series of papers, A V Gurevich constructed a theory of nonlinear modification of the ionosphere exposed to powerful radio waves. It was predicted that such waves should cause resonance instability in ionospheric plasma, leading to nonlinear absorption of radio waves, the heating of electrons, and artificial airglow. Nonlinearity results in breaking the region of heating into narrow elongated nonuniform striations of low-density plasma. This produces nonlinear self-focusing of the incident wave by the small-scale irregularities it has generated. Various plasma waves are generated in the perturbed radiowave zone, leading to a fully developed nonlinear plasma turbulence. It manifests itself in the acceleration of electrons, the formation of artificial radio emission and stable plasma structures.

As a result of the stimulating effect of A V Gurevich's ideas, special radio stands for affecting the ionosphere and diversified complexes of apparatus for its diagnostics were built in the USSR, the USA, and in Northern Europe. Work on nonlinear phenomena in the ionosphere brought A V Gurevich international renown. In 1990, he was awarded the Appleton Prize of the Royal Society and the International Union of Radio Science (IURS).

In the 1970s, A V Gurevich and L P Pitaevskii formulated and solved the problem of the structure of dissipationless shock waves in a dispersive medium. A perturbation of the nondissipative medium in the absence of dispersion is known to become a singular one after a finite period of time. It was shown that in the presence of dispersion this mode is replaced with an expanding area of oscillations. The solution was constructed by Whitham averaging of the Korteweg–de Vries equation. The authors demonstrated the advantages of this averaging method for constructing multisoliton solutions, as compared with the inverse scattering problem method. This circumstance attracted the attention of mathematicians and generated a whole new area in the study of exactly integrable equations.

In the 1990s, A V Gurevich and co-authors posed and solved the problem of description of turbulence in nondissipative media with dispersion. It has been shown that a large class of deterministically defined initial perturbations dynamically evolve in this environment into a chaotic state whose statistical characteristics are calculated on the basis of the initial perturbation. This new kind of the emergence of chaos in dynamics is a result of multiple turn-over of maxima of the initial wave propagating in an infinite nonlinear dispersive medium. But A V Gurevich's interest in the problem of turbulence is not limited to the nondissipative case. He has recently initiated work on the theory of classical hydrodynamical turbulence, in which together with K P Zybin, V A Sirota, and A S Ilyin he has made significant progress in understanding the structure of developed turbulence.

In the 1980s, A V Gurevich, V S Beskin, and Ya N Istomin developed a theory of pulsar magnetospheres and of their radio emission. Even now, many years hence, it remains one of the most profound, consistent, and closed theories in the physics of radio pulsars. This series of papers is very characteristic of A V Gurevich's scientific style: he loves concrete physics based on experiments and observations but, being a theoretical physicist, approaches it primarily as a source of new theoretical problems, not as an area on which to test previously constructed models. Hence, he insists on what he calls a 'closed formulation of a problem'. In this case, this meant a refusal to follow the path of constructing a phenomenological model of the magnetosphere of a neutron star by incorporating into it the observational data on the pulsar from the very beginning — the approach that continues to be excessively popular in astrophysical theories. A V Gurevich invariably emphasizes that one must strive for a coherent and self-consistent theoretical model that starts with the 'physics of the case'. The observable characteristics of the phenomenon after this should be derivable as a natural consequence of the theory.

The authors succeeded in developing a closed theory of physical phenomena that occur in the vicinity of highly magnetized rotating neutron stars. It turned out that the most important element of the resulting picture is the spatial structure of the currents flowing in the magnetosphere and reconnecting on the surface of the star. For example, it is the ponderomotive action of surface currents that results in slowing down the rotation of the pulsar (which obviously reveals itself in the observable increase in the rotation period). This statement now seems trivial, but 25 years ago astrophysicists were up in arms against it.

Then was constructed for the first time the kinetic theory of the production of relativistic electron–positron plasma near the magnetic poles of a neutron star. Finally, the authors developed a theory of the generation of coherent radio emission by pulsars; it was based on an analysis of the nonlinear stage of development of instability of this kind of plasma when moving in a strong curved magnetic field of the star. In this way it proved possible for the first time to go all the way from a consistent physical theory of the magnetosphere of the neutron star, particle creation, and the generation of radio emission to comparing the theory's quantitative predictions with observational data and obtaining good agreement. The importance of this theory increases as new observational data are accumulated.

Finally, we will point to a series of papers by A V Gurevich and K P Zybin on the nonlinear stage of gravitational (Jeans) instability of nondissipative self-gravitating cold matter and the spatial structure of its distribution. Dark matter, which, according to modern concepts, determines the observed structure of galaxies and their clusters, does possess these properties. According to the kinetic theory developed in 1988, the evolution to equilibrium goes through the emergence of density singularity. Multistream flow develops behind the singularity and both the number of streams and the number of singularities grow with time. In addition, it was found that the neighborhood of those points where density perturbations reach the critical level are the first to enter the nonlinear stage of instability. It is the universal nature of any differentiable function near a local maximum that dictates the universal character of the asymptotically appearing stirred kinetic state. The analytically obtained equilibrium distribution is singular and is described well by a radial power-law function, whose exponent is close to that observed in galaxies and clusters of galaxies. Therefore, an extended self-gravitating object forms at the final stage of the instability development. As numerical methods grew more sophisticated and the power of computers increased, it became possible to obtain such singular distributions in numerical experiments as well.

Since the initial density fluctuations in the Universe had different scales, a hierarchical structure of self-gravitating objects consisting of dark matter consecutively evolved as perturbations developed further. Later progress in the theory elaborated in collaboration with M I Zel'nikov allowed them to describe this structure.

The singular character of the potential at the center of the halo of dark matter is a natural cause for the nucleation and further growth of a black hole, but this requires that baryonic matter also be absorbed. A V Gurevich and his team proposed a mechanism for the growth of a central supermassive black hole as it absorbs dark matter and stars. The calculated growth rate of giant black holes agrees with available observations.

A V Gurevich is one of those theoretical physicists who is not satisfied with developing a theory in the cause of theory. For him, it is important to see in the ideas of the theory a reflection of real natural processes. The reality, however, is richer and more complex than a theory. It is far from simple to single out a purely physical effect, such as the electric breakdown via runaway electrons, which is doubtless from theoretical standpoints, from the richest variety of spurious phenomena accompanying thunderstorm discharges. In fact, this is the problem on which A V Gurevich has concentrated his efforts in recent years. In addition to large-scale experiments at TSMCRS, he proposed a laboratory experiment at LPI for studying the role of runaway electrons in the ionization wave. Furthermore, A V Gurevich acts as the science supervisor of the project for launching the Chibis microsatellite (SRI RAS, SINP MSU, and LPI Collab.) for TGF research. We wish Aleksandr Viktorovich Gurevich health and success in his endeavors!

V S Beskin, M A Vasil'ev, A V Gaponov-Grekhov,
L M Zelenyi, K P Zybin, Ya N Istomin,
L V Keldysh, O N Krokhin, G A Mesyats,
L P Pitaevskii, M O Ptitsyn, V I Ritus