PERSONALIA

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Aleksandr Viktorovich Gurevich (on his 90th birthday)

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September 19, 2020 was the 90th birthday of the remarkable theoretical physicist, Academician of the Russian Academy of Sciences (RAS) Aleksandr Viktorovich Gurevich.

A V Gurevich's scientific activity began in 1954 at the Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation of the Academy of Sciences (IZMIRAN), where he worked at the laboratory of Ya L Alpert. In 1957, at the invitation of V L Ginzburg, he began working at the Department of Theoretical Physics of the P N Lebedev Physical Institute of the Academy of Sciences (FIAN), with which all his further scientific life has been connected and where he carried out his outstanding studies in radio physics, astrophysics, the kinetic theory of plasma, and mathematical physics.

Already A V Gurevich's first studies on the theory of runaway electrons became world renowned. In the 1950s, experiments on plasma confinement showed a considerable excess of high-energy electrons compared to the amount that would be observed upon their equilibrium velocity distribution. Carrying away a considerable part of the energy, these electrons hampered effective plasma heating. The phenomenon needed theoretical interpretation. A V Gurevich considered the problem of the formation of the distribution function of fast electrons under the action of a constant electric field with allowance for their collisions with thermal electrons and ions of plasma. A specific feature of such collisions is the decrease in the scattering cross sections and, therefore, of the braking force with increasing particle energy. A V Gurevich formulated a consistent kinetic theory of the effect by describing quantitatively a fast particle flux from the thermal-energy to the high-energy region. The theory gave an exponentially strong divergence from simple analytical estimates. Unexpected was the fact that even in a very weak electric field a nonequilibrium state occurs in plasma with a non-Maxwellian distribution function. This is what makes an essential difference between plasma and gas.

Earlier, kinetic energy was mainly considered an auxiliary way to obtain transport coefficients in the framework of the hydrodynamic approach (S Chapman and D Enskog). The construction of the theory of runaway electrons was an important stage in the development of plasma kinetics, the kinetic theory being not an auxiliary instrument of hydrodynamics, but a direct tool for describing the essence of the physical phenomenon. In particular, the kinetic approach underlay A V Gurevich's pioneering work on the theory of flow around a body moving in the ionosphere plasma, which was timed to coincide with the launch the first satellite in 1957. The above-mentioned theory, developed in mutual paper with Ya L Alpert and L P Pitaevskii, was further widely applied.

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Aleksandr Viktorovich Gurevich

In 1992, on the basis of the concept of runaway electrons, A V Gurevich proposed a new mechanism of gas breakdown. The idea was that in an electric field a bare 'runaway' electron ionizes the neutral gas through collisions, thus producing, together with a large number of low-energy electrons, a certain number of electrons with an energy sufficient to compensate for the ionization loss. The newly produced fast electrons will in turn be accelerated by the electric field and will ionize the gas. The avalanche of fast electrons will thus increase. The kinetic theory of such a breakdown, constructed together with K P Zybin, G M Milikh, and R Russell-Dupree, showed that the threshold electric field is 10 times lower for the given phenomenon than in an ordinary breakdown, whereas the spatial scale of avalanche increase at atmospheric pressure amounts to about hundreds of meters. The above-mentioned studies became widely popular among specialists in atmospheric electricity. It is the only theory today providing insight into such phenomena as the observed bursts of intense X-ray radiation during thunderstorms and powerful gamma-ray bursts coming from Earth and registered by artificial Earth satellites (TGF). It is also of importance that the measurements of electric fields in thunderstorm clouds always yielded values insufficient for breakdown from the viewpoint of the traditional mechanism. A V Gurevich suggested that electrons of secondary cosmic rays might be bare particles for a runaway electron breakdown; a massive program was developed of simultaneous observations of extensive air showers of cosmic rays and gamma-ray and radio-emission bursts, as well as fast electron fluxes typical of lightning discharges. Studies undertaken at the initiative of A V Gurevich at the Tyan-Shan Mountain Scientific Station of P N Lebedev Physical Institute of the Russian Academy of Sciences (TShMSS LPI) revealed a correlation among the above-mentioned phenomena, predicted by the runaway breakdown theory.

A special place in A V Gurevich's creative activities is taken by issues in radiophysics and the physics of nonlinear phenomena. As far back as 1960, he wrote, together with V L Ginzburg, the review "Nonlinear phenomena in plasma" for the journal *Uspekhi Fizicheskikh Nauk* (*Soviet Physics Uspekhi*), which became widely known and is cited to date. Studies of ionospheric and cosmic plasma are important for A V Gurevich, not only because plasma is the ground state of matter beyond Earth's atmosphere, but also because it is there, as he thought, that plasma shows its properties in a more pure form, and this paves the way for the development of clear theoretical notions (as distinct from laboratory setups, where boundaries substantially affect the physics of the process). In a large series of studies, he formulated the theory of nonlinear modification of the ionosphere affected by high-power radio waves. It was predicted that such waves must induce resonance instability, resulting in a nonlinear radio wave absorption, electron heating, and an artificial ionospheric glow. The nonlinearity causes heating region splitting into narrow prolonged inhomogeneities with a lowered plasma density. An incident wave is nonlinearly self-focusing on the small-scale inhomogeneities generated by it. Various plasma waves are generated in the region perturbed by the radio wave, which leads to the development of nonlinear plasma turbulence. It shows up in electron acceleration and in the occurrence of artificial radio emission and stable plasma structures.

The theoretical work done by A V Gurevich on the interaction of plasma with high-power microwave radiation stimulated in the USSR, the USA, and northern Europe the construction of special radio stands to affect the ionosphere, as well as complexes of diverse equipment for its diagnostics. The studies of nonlinear phenomena in the ionosphere brought world fame to A V Gurevich. He was awarded the 1990 Eplton Prize of the Royal Society and the International Scientific Radio Union (URSI).

In the 1970s, A V Gurevich and L P Pitaevskii stated and solved the problem of the structure of a dissipativeless shock wave in a dispersive medium (the Gurevich–Pitaevskii problem). For their work, they received the 1980 L D Landau Prize of the USSR Academy of Sciences. It is a known fact that the perturbation of a dissipativeless medium in the absence of dispersion becomes singular in some finite time. It was shown that in the presence of dispersion an expanding region of oscillations occurs instead. These oscillations carry away energy, and an additional deceleration takes place. The solution was constructed through an averaging of the Korteweg–de Vries equation by the Whitham method. The authors demonstrated the advantage of his method for constructing multisoliton equations over the method of the inverse scattering problem. This circumstance attracted mathematicians' attention and was the starting point of a whole direction in the study of exactly integrable equations.

In the 1990s, A V Gurevich and his co-authors stated and solved the problem of turbulence description in a dissipativeless medium with dispersion. It was shown that a wide class of deterministically defined initial perturbations in exactly integrable equations will dynamically evolve into a chaotic state whose statistic characteristics are calculated from the initial perturbation. Such a new type occurrence of chaos from dynamics results from a multiple umklapp of maxima of the initial wave propagating in an infinite nonlinear dispersive medium. A V Gurevich's interest in the problem of turbulence is not restricted to the dissipativeless case; in the 2000s, he initiated studies of the theory of classical hydrodynamic turbulence, which he carried out together with K P Zybin, V A Sirota, and A S Il'in and advanced substantially the understanding of the structure of developed turbulence.

In the 1980s, A V Gurevich, V S Beskin, and Ya N Istomin formulated the theory of the pulsar magnetosphere and radio emission that even now, after many years, remains topical in the understanding of processes proceeding in the environment of neutron stars. The proposed consistent theory of physical processes in the environment of rotating neutron stars revealed the spatial structure of currents running in the magnetosphere and closed on the star surface. The ponderomotive action of these currents leads to the observed deceleration of pulsar rotation. This statement now seems trivial, but 30–40 years ago it encountered an almost hostile reception from astrophysicists. At that time, it was believed that the electromagnetic loss is due to simple magnetodipole radiation of a magnetized body in a vacuum. In particular, the theory predicted that the angle between the star rotation axis and the magnetic axis evolves towards the equator. Unfortunately, it is hitherto impossible to verify directly the validity of this prediction, but new observational indications of the validity of such a prediction constantly appear.

Constructed further was the theory of coherent pulsar radio emission generation, according to which, during plasma motion in a curved magnetic field of a star, an instability develops, generating radio emission at its nonlinear stage; this theory now remains, in fact, the only theory of radio emission investigating the nonlinear stage in detail. Also, the kinetic theory of relativistic electron-positron plasma production near neutron star magnetic poles was formulated long before the contemporary numerical simulations. Thus were the processes in the magnetosphere of a neutron star — particle production and the generation of radio emission — first considered to be interrelated. In 1994, the authors received the L I Mandelstam Prize of RAS.

Note finally a series of studies by A V Gurevich and K P Zybin concerning the nonlinear stage of gravitational (Jeans) instability of dissipativeless self-gravitating cold matter and the spatial structure of its distribution. Such properties are inherent in the dark matter that is currently considered to determine the observed structure of galaxies and their clusters. Ya B Zel'dovich pointed out that in a considered medium the density singularity ('Zel'dovich pancake') emerges in a finite time interval. However, the hydrodynamic approach he used does not make it possible to obtain a solution beyond the singularity and, therefore, to find the established distribution of matter. In 1988, A V Gurevich and K P Zybin formulated a kinetic theory, which showed that the process of establishing equilibrium proceeds through the development behind a singularity of a multi-stream flow, and the number of streams, as well as the number of singularities, grows over time. Moreover, it has turned out that the first to enter the nonlinear stage of the instability were the neighborhoods of those points where perturbations in the density maxima reach their critical value. The universal character of any differentiable function near its local maximum dictates the universal character of the mixed kinetic state that occurs at asymptotically large times. The equilibrium distribution obtained analytically is singular and is described well by the radial power-law function with the exponent close to that observed in galaxies and their clusters. Thus, at the final stage of the development of instability, an extended self-gravitating object emerges. Later, with the development of numerical methods and an increase in computer power, similar singular distributions began to be obtained in numerical experiments. This series of studies received the 2005 A A Friedmann Prize of RAS.

The singular character of the potential in the center of the dark matter halo is the natural cause of the birth and further growth of a black hole, for the occurrence of which, however, it is necessary that baryon matter also be absorbed. A V Gurevich and his team proposed the growth mechanism of the central supermassive black hole owing to its absorption of dark matter and stars. The calculated growth rate of giant black holes agrees with observations.

A V Gurevich is particularly interested in the relation between theoretical notions and actual natural phenomena. For this reason, he has always tried to be involved in theoretical problems associated with observations and experiments rather than examine what he called ''pursuing illusory subjects.'' So, in addition to the above-mentioned ionospheric research, A V Gurevich took part in planning natural studies of atmospheric discharges at TShMSS LPI and in interpreting the data obtained. Moreover, he collaborated with the Institute of Electrophysics of the Ural Branch of RAS, where laboratory studies of the role of runaway electrons in an ionization wave were conducted. He also supervised the Chibis microsatellite project (of the Space Research Institute of RAS, the Scientific Research Institute of Nuclear Physics of Moscow State University, LPI) for the study of high-altitude atmospheric discharges.

We wish Aleksandr Viktorovich good health and high spirits!

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