Physics – Uspekhi **41** (7) 731 – 732 (1998)

PERSONALIA PACS number: **01.60.+q**

Boris Valerianovich Chirikov (on his seventieth birthday)

Professor and full member of the Academy of Sciences, Boris Valerianovich Chirikov, chair of the theoretical division of the G I Budker Nuclear Physics Institute of the Siberian Branch of the Russian Academy of Sciences, was 70 on June 6, 1998.

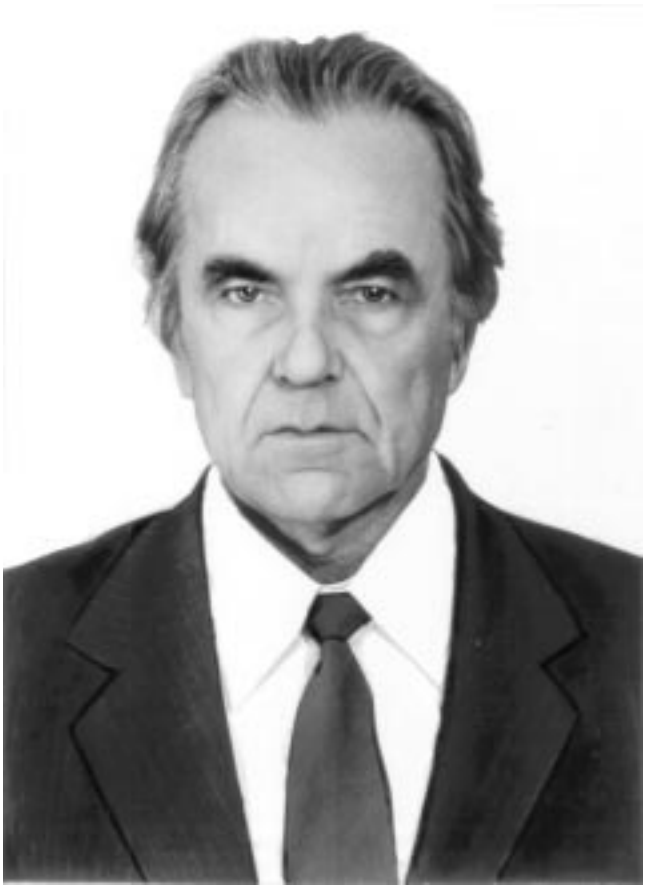
His name is familiar to anyone who has dealt with dynamic chaos — the phenomenon of the random behavior of deterministic classical and quantum systems. The principal significance of the physical theory of dynamic chaos, whose founding father Boris V Chirikov definitely was, is first of all that it brings to the surface the mechanism and the conditions under which statistical laws arise in nature, and gives it a consistent deterministic explanation.

Boris V Chirikov was among the first group of graduates of the physico-technical faculty of Moscow University (later transformed to the Moscow Physico-Technical Institute). While still a student, he participated in experimental studies at the Thermal Research Laboratory (which evolved into the Institute of Theoretical and Experimental Physics (ITEP)). Andreĭ M Budker, head of the Laboratory of Novel Acceleration Methods and future full member of the Academy of Sciences, invited the young physicist in 1954 to LIPAN (currently the Russian Research Center 'Kurchatov Institute'). At LIPAN Chirikov chose as his field the pressing problems of accelerator and plasma physics. In 1958, Budker organized the Nuclear Physics Institute of the Siberian Branch of the Academy of Sciences at the Akademgorodok settlement near Novosibirsk. Chirikov became a very active member.

The early period of Chirikov's research life is connected with two problems formulated by Budker. The first problem was an analysis of ionic compensation of a high-intensity relativistic electron beam in the process of formation and decay of a virtual cathode (1957). The result of this study was the design and construction of the B-3 betatron, with parameters that still hold the record even against today's standards. Later (1968) Chirikov published a paper that was to become a classic, in which he extended Budker's theory to coherent transverse instability of an annular ion-compensated electron beam.

The second problem was an analysis of the effect of nonlinear resonances on the accuracy of maintaining the adiabatic invariant in open magnetically plugged traps, suggested by Budker for hot plasma confinement. Experiments pointed unambiguously to an exotic mechanism of particle loss due to their random behavior. To describe the new phenomena, new approaches were needed, and Chirikov started developing his theory of chaos; the theory stated that chaotic motion may arise in completely deterministic systems and be described by conventional laws of statistical mechanics.

Already the first publication in this series (1959) introduced the physical criterion of generation of random oscillations in nonlinear Hamiltonian systems. Now widely known as the Chirikov criterion, it was based on the concept of overlapping of nonlinear resonances and allowed a relatively straightforward calculation of the conditions of transition to the statistical description of a system's dynamics. Chirikov used this criterion to interpret the experimental results obtained in Budker's laboratory on electron confinement in open traps; this was the first application of a physical theory of chaos to experimental data.



Boris Valerianovich Chirikov

The analytical methods developed by Chirikov allowed him to solve, among other things, the famous Poincaré problem of the last century on the dimensions of the randomized layer in the neighborhood of the separatrix of nonlinear resonance (1979). This result formed the basis for developing an effective evaluation of Arnold diffusion — the universal instability mechanism of nonlinear oscillations that had been predicted by V I Arnold in 1964. This phenomenon plays a decisive role in such dissimilar processes as Solar system dynamics (including the motion of asteroids, comets and even planets) and proton confinement in storage rings of modern colliders. Later (1988) Chirikov predicted and then numerically confirmed a novel mechanism of fast Arnold diffusion whose rate is a power-law rather than exponential function of the perturbation parameter.

In 1979 Chirikov published a large review paper [*Phys. Rep.* **52** 263 (1979)] in which he presented the fundamentals of the

Uspekhi Fizicheskikh Nauk **168** (7) 813 – 814 (1998)
Translated by V I Kisin

theory of dynamical chaos in classical Hamiltonian systems, developed by himself and his co-workers, and its applications. This paper soon became known among specialists as the 'Chaos Bible'.

The key feature of Chirikov's scientific approach is a combination of rigorous analytical methods and approximate physical evaluations, plus extensive numerical experiments on simple but never trivial models. One of these models (the standard Chirikov map) is substantive to such an extent that it serves as both the cornerstone and the touchstone for the theoretical description of various properties of dynamic chaos. With this integrated approach, a numerical experiment often plays the decisive role, dictating the direction of theoretical and experimental studies of novel physical phenomena and physical laws.

Using the theory of dynamical chaos, Chirikov and his colleagues were able to solve a number of important physical problems:

— It was shown that the maximum particle energy in the dynamic Fermi acceleration model is bound and follows from the condition of resonance overlap (1964).

— The Fermi – Pasta – Ulam problem was solved: the conditions of random behavior of a string of coupled nonlinear oscillators were found analytically and then confirmed by numerical experiments.

— A transient chaos phenomenon was discovered in models with dissipation; an explanation was found and its 'lifetime' evaluated. The conditions of random attractor generation in nonlinear dissipative maps were derived (in 1973, which was several years before the strange attractor boom exploded worldwide).

— The Budker problem of long-time confinement of charged particles in an adiabatic trap was solved (1978), which made a significant contribution to the general theory of adiabatic invariants.

— Modulation diffusion was predicted (1981) — a new important type of weak diffusion in oscillatory systems; it was later analyzed in detail theoretically and numerically in various physical applications.

— It was shown that the 'internal dynamics' of the classical long-wavelength non-Abelian Yang – Mills-type field (in the Martinyan model) can be chaotic, that is, in the general case the equations of this field are nonintegrable (1981).

— The universal mode was discovered for the power-law decay of Poincaré recurrences and correlation functions in dynamic Hamiltonian systems with split phase space. These statistical anomalies were explained in terms of the hierarchical renorm structure of the phase space at the chaos boundary (1988).

— It was demonstrated that the dynamics of the Halley comet are chaotic. An evaluation was obtained for its residence time in the Solar system and the anomalies in its early visit dates (in the BC era) were explained (1989).

In the mid-1970s Chirikov and his group began to analyze dynamic chaos in quantum systems. This work has in fact created a new field of theoretical physics: quantum chaos, which has now been detected in atoms, nuclei, complex molecules and some other physical objects.

Even the first publications in this series (1979 – 1981) revealed strikingly unexpected properties of quantum chaos, which required reconsideration of the correspondence principle for systems with chaotic behavior at the classical limit. It was thus shown that the correspondence in the behavior of classical and quantum systems depends dramatically on the time interval over which the comparison is carried out, even in a deeply quasi-classical region. Numerical experiments on the simplest models demonstrated that in addition to the familiar, relatively short, ballistic time scale (which corresponds to the motion of initial packets over classical trajectories), there exists a different long-period diffusion time scale. Quantum diffusion is quite close to the classical one on this scale but its mechanism is found to be very different, unrelated to the instability of the classical system involved. One can say, therefore, that quantum diffusion is only a good imitation of classical diffusion, nevertheless allowing a modified quasi-classical description.

The limitations of this imitation result in a striking phenomenon of dynamic localization of wave packets, which Chirikov and his group discovered in 1979. An impressive manifestation of this localization is the increasing with time deviation of quantum diffusion from classical diffusion over times greater than the diffusion scale. An analog of this localization is the famous Anderson localization which arises in solid state models with a random potential. However, Anderson localization owes its formation to the random external potential, while dynamic localization is caused by quantum chaos resulting in pseudo-random behavior of the Hamiltonian matrix elements in a nonperturbed basis. The similarity of these two phenomena allows the application of a number of results for dynamic systems to the physics of disordered systems.

Using the theory of dynamic localization, Chirikov and his co-workers were able to predict and provide a detailed description of specific features of the diffusion photoeffect for Rydberg states of the hydrogen atom in microwave fields. These predictions, and the dynamic localization effects, were recently demonstrated experimentally.

We wish to emphasize again the specifics of Chirikov's approach to physics: in 1977 he proposed an immensely rich model that is widely known as the quantum rotator, and then used it to generate most of his results on quantum chaos. Numerous publications were devoted to this model, and it keeps attracting physicists and mathematicians who work on new paths in quantum chaos theory.

The analysis of quantum systems led Chirikov to a paradoxical conclusion: the quantum world does not live as 'true chaos'! In reality, what we typically see in quantum mechanics is a pseudochaos which often gives a fairly good imitation of the familiar classical chaos. Even though the manifestations of pseudochaos often appear to be practically indistinguishable from 'true chaos', the difference becomes substantial in certain circumstances. The latest work published by Chirikov extends the concept of quantum pseudochaos; it discusses largely unexpected applications of the theory of chaos to such fundamental aspects as the nature of the irreversibility of the laws of statistics and the role played by quantum measurements.

Boris Valerianovich Chirikov always combined intense research with teaching and lecturing to various audiences. His masterful lectures and highly nonstandard textbooks helped several generations of students of Novosibirsk University to begin their lives in physics.

Friends and colleagues warmly congratulate Boris Valerianovich on this anniversary and wish him rugged health, much happiness and many creative years of life.

V E Balakin, L M Barkov, N S Dikanskiĭ,
G I Dimov, E P Kruglyakov, G N Kulipanov,
I N Meshkov, V V Parkhomchuk,
V A Sidorov, A N Skrinskiĭ