SOVIET PERSPECTIVES ON TURBULENCE AND CHAOS

Nonlinear Physics: From the Pendulum to Turbulence and Chaos

R. Z. Sagdeev, D. A. Usikov and G. M. Zaslavsky
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Reviewed by Yves Pomeau, Eric Siggia and Uriel Frisch

A crucial point in the history of science was the discovery by Galileo of the law of the simple pendulum in the limit of small-amplitude oscillations. The corresponding equation of motion is the simplest example of an integrable system, having only one periodic behavior in the absence of damping or external forcing. There are many situations showing integrability as well as regularity in elementary classical physics, for example, dissipationless dynamics with one degree of freedom (position and momentum together make up this unique degree of freedom). Another classical example is the regular Keplerian motion of a planet in the gravitational field of the Sun. Mathematicians and physicists have longed to know what happens in more complex situations. Such situations are not hard to come up with: the finite-amplitude motion of a classical electron disturbed by a passing electromagnetic wave, the three-body problem in astronomy and so on.

Let us start from an integrable dynamical system with one degree of freedom as defined before, and thus having periodic oscillations only. Let us consider now a time-dependent perturbation imposed on this system. If the perturbation is weak, an important theorem by Andrei Kolmogorov, Vladimir Arnol'd and Jürgen Moser tells us that, for most initial conditions, the long-term dynamics of the perturbed system are quasiperiodic; that is, the dynamics depend on combinations of the two frequencies (that of the unperturbed motion and that of the external perturbation). The KAM theorem answers an old and deep question, posed first by Joseph Louis Lagrange about the global stability of the motion of the Moon under perturbations due to the Sun. But this is not the whole story, as Boris Chirikov and Michel Hénon understood quite early in their numerical studies. If the perturbation becomes too large, the phenomenon of "resonance overlap" occurs, which basically destroys the KAM structure of the phase space. When this happens, the dynamics become truly chaotic and may be described by the methods of statistical physics.

Roald Sagdeev and George Zaslavsky have been among the pioneers in this field of study. Together with Daniel Usikov they have now written *Nonlinear Physics: From the Pendulum to Turbulence and Chaos* as volume 4 in the series Contemporary Concepts in Physics.

After describing how physicists were frustrated for many years by their inability to tackle nonlinear problems, the authors write: "As a sort of compensation, physicists made great advances in constructing some purely linear theories: electromagnetic-field theory and quantum theory. The success achieved in these fields somewhat distracted scientists' attention from the genuine nonlinearities." The authors make it clear that one of the main inspirations for their studies of nonlinearity has been plasma physics. In plasmas waves carrying an electric field and a magnetic field often are unstable, and so reach finite amplitudes. These waves then affect the motion of individual charged particles in a strongly nonlinear fashion. Even though no calculation of plasma instability *per se* is to be found in the book, this plasma background is important. However, some other physical situations are mentioned, such as the origin of comets and chaotic super-radiance. Among all the books published so far on nonlinear phenomena and chaos, this one is closest to *Regular and Stochastic Motion* by A. J. Lichtenberg and M. A. Lieberman (Springer-Verlag, New York, 1983). *Nonlinear Physics*, however, has a much wider scope and aims at a larger audience. It includes such topics as wave-interaction phenomena, soliton theory and super-radiance, none of which are discussed by Lichtenberg and Lieberman.

Although this is never explicitly stated, one might say that this book was written to put forward a central thesis, in the classical sense of the word. The key is in the subtitle, *From the Pendulum to Turbulence and Chaos*. The pendulum the authors have in mind is a strongly nonlinear one. This is best exemplified by imagining oneself on a swing that can go all the way around, such as can be found in many amusement parks. Suppose you work it up until it swings just barely past the top. Now gently and regularly wave your hand; the swing (assumed to be well lubricated) will respond by going chaotic: Successive times of passage near the ground become essentially unpredictable. This is one of the few known instances where quantitative predictions can be made about a chaotic conservative dynamical system. Indeed, more than 20 years ago, Nataly Filonenko, Sagdeev and Zaslavsky tackled a problem of this type arising in their plasma studies. They constructed a simple area-preserving map characterizing successive returns near the ground. This "stan-

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dard map" is nonintegrable. Using results of Chirikov, they predicted that chaos sets in for arbitrarily weak perturbations and found how the width in phase space of the chaotic—or stochastic—layer scales with the strength of the perturbation. Such results, discussed at length in part 2 of the book, are of considerable physical interest because many systems are mathematically isomorphic to the nonlinear pendulum or variants thereof. In part 3 the authors take great care to present a wide spectrum of applications: in plasmas, mechanics, optics, atomic physics, solid-state physics and astrophysics.

Part 4, which concludes the book, is devoted to a lively presentation of numerical experiments due to Usikov that concern various Poincaré maps with one pair of action-angle variables. This clever presentation is very well documented and will be interesting to students as well as research workers in other fields. It starts with a set of color pictures, follows these with a set of demonstrations on floppy discs (for any IBM-compatible PC) and finally gives the original program (in BASIC). Particularly fascinating are the presentations of maps displaying structures with quasicrystal-type symmetries. (See the article by Alexander Chernikov, Sagdeev and Zaslavsky in PHYSICS TODAY, November 1988, page 27.) Clever computer studies have become important in recent times for the study of dynamical systems. No doubt this welcome part of the book will trigger new insights and ideas among readers. It is a pity that these numerical experiments seem split off from the rest of the book. For instance, there are no specific references to them in the text to motivate the analytic reasoning.

The book is informal: Most developments of topics are self-contained, with no claims made as to mathematical rigor; and order of magnitude estimates more than once replace detailed analytical derivations. This style is in the modern Russian tradition of Lev Landau and Evgenii Lifshitz. Although as physicists we prefer this style, this *parti pris* of informality sometimes leads the authors to skip important points. Except for one special case, frequency locking is not covered. Similar remarks could be made regarding the presentation of Serge Aubry's theory of the ground state of one-dimensional classical chains of atoms. In a later chapter on "strong" turbulence, the Kolmogorov–Obukhov $-5/3$ power law is never mentioned and ordinary neutral fluids are mentioned only to motivate various scenarios for the onset of turbulence.

The authors are at their best when discussing areas in which they have actually worked. Dissipative problems such as those encountered in fluid turbulence are treated in a haphazard or sketchy manner. (These include much of what is called "dynamical systems" in the West.) For instance, the universality of the period-doubling route to chaos as developed by Mitchell Feigenbaum is only briefly touched upon. No hint of an explanation is given and the word "renormalization" is not to be found. By contrast the treatment of the nonlinear Korteweg–de Vries equation by inverse-scattering techniques is well presented.

The physical appearance of the book leaves much to be desired. New chapters are signaled in characters no larger than those of the text. Chapter numbers are not designated on every page. The numbering of equations is itself chaotic and there are many misprints, particularly in equations and mathematical symbols, which are sometimes barely decipherable. It would be most desirable to have a new edition with fewer typos and a better reference system.

This book deserves wide reading and will be a rich source of inspiration to the growing community of scientists interested in nonlinear science. It also can be read profitably by graduate students in plasma physics, applied mathematics and theoretical physics. It is not organized as a textbook, however, and contains no exercises.

Vospominania ob Igore Vasilieviche Kurchatove [Recollections about Igor Vasilievich Kurchatov]

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Anatolii Aleksandrov
Nauka, Moscow, 1988.
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A man came for the first time to the horse races. Approaching the track, he stopped to tie a loose shoelace. Suddenly, a saddle was tightened on his back, irons were forced into his mouth, and he was pushed out onto the track. So he raced. He did not win first prize, but he did come in second.

That is how Vasilii Emelianov, a specialist in metallurgy and one of the managers of the Soviet Atomic project, described his and his colleagues' situation in the fall of 1945 to Igor Kurchatov, father of the Soviet A- and H-bombs. This account appears in a book of memoirs about Kurchatov, edited by Anatolii Aleksandrov, former president of the Soviet Academy of Sciences and a close friend and collaborator of Kurchatov's. The book contains approximately 60 essays in Russian, 40 of which appear here for the first time; the remaining 20 are reprinted from Soviet literary and scientific magazines as well as from a previous, smaller collection of memoirs on Kurchatov published in the USSR in 1983.

Kurchatov (1903–60) was a first-rate physicist who combined qualities of J. Robert Oppenheimer and Edward Teller. This blend enabled him to find the right language for dealing with such disparate personalities as his Soviet colleagues, captive German nuclear physicists, marshals of the Soviet Army and such "tough cookies" as Stalin and his henchman Lavrenti Beria, overlord of the Soviet Atomic project.

Memoirs collected in this volume, particularly those under the subtitle "The Problem of Uranium," examine significant phases of the Soviet A- and H-bomb projects. The memoirs of Georgi Flerov describe the events that led to the Soviet decision on 10 March 1943 to restart nuclear research in the USSR, under Kurchatov's leadership. Three crucial tests are described in considerable detail in other essays. In the first Soviet A-bomb test, on 29 August 1949 the bomb was lifted to the top of a steel tower by means of a specially constructed elevator. The second A-bomb test, was conducted at the same site in August 1951; the bomb was dropped from a plane. The first H-bomb test, which took place on 12 August 1953, also occurred at this test site. The "product" was the same size as the first Soviet A-bomb. There were no separate special storage places for cryogenic technology or liquid deuterium. The bomb was put on a 30-meter-high metal tower. At a distance of over 30 kilometers, the shock wave almost knocked the observers to the ground. Within a 5-km radius of the epicenter of the explosion, the surface was baked into a ceramic-like, dark mirror.

Just these few examples should show that the book is extremely interesting and merits translation into English. Still, one would expect under the conditions of *glasnost* a more frank and complete account of one of the major achievements of Soviet science and technology. Nowhere does the book recall the participation in the Soviet nuclear project of such German physicists as Gustav Hertz and Nikolaus Riehl, nor does it