# Statistical physics

**Statisticheskaya Fizika Otkrytykh Sistem (Statistical physics of open systems)**
Yu L Klimontovich (Moscow: Yanus, 1995) 624 pp

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Self-organization and phase transitions in far-from-equilibrium open systems appear to be the most interesting fields of application for statistical physics. There is a broad spectrum of open macroscopic systems exchanging energy and matter with the environment including those investigated not only in physics but also in chemistry, biology, and even sociology. As are other sectors of the theory of non-equilibrium processes, statistical physics is expected to formulate and substantiate a universal approach to the description of open macroscopic systems to be further used for the construction of special theories. Although this programme will take much time to be completed, the investigations of the last few decades have already demonstrated many common features in the behavior of open systems which can be naturally described in terms of non-equilibrium statistical mechanics.

Many authors have contributed to the development of the theory of open systems which is today elaborated almost as well as more traditional areas of non-equilibrium statistical mechanics, such as the theory of linear processes and kinetic theory. This makes it imperative to have a systematic exposition of the physical theory of open systems intelligible to senior and postgraduate university students and researchers having no special expertise in non-equilibrium statistical mechanics but working in allied fields. The book being reviewed is the first in the world literature expounding the subject at the 'physical level'. The author avoids cumbersome mathematical calculations and follows a constructive plan to illustrate the application of the theory to the solution of special problems. From a stylistic point of view, the monograph may be regarded as a textbook. The author is a leading expert in the theory of non-equilibrium processes, and the reader has an opportunity to obtain a first-hand knowledge of it. This is especially important for a book dealing with a theory which continues to be developed. It is well known that authors of textbooks on the statistical physics of non-equilibrium systems who have no personal research experience in the field sometimes treat many key problems in a way that is either questionable or entirely wrong.

The book consists of 23 chapters. Chapters 1–8 are devoted to basic concepts of statistical physics including equilibrium and non-equilibrium Gibbs statistical ensembles, informational and thermodynamic entropy, and distribution and correlation functions of fluctuations. Unlike standard manuals on statistical physics, this book pays much attention to the 'physically infinitesimal scale' concept for various modes of the description of macroscopic systems and the related problem of differentiation between small and large scale fluctuations which play different roles in the evolution of non-equilibrium systems. Chapters 6–8 are concerned with kinetic theory and contain a detailed discussion of the important and non-trivial problem of the origin of the dissipation mechanism and irreversibility at the kinetic scale.

Chapters 9 and 10 deal with the kinetic fluctuation theory for non-equilibrium systems. The author considers two approaches which are both interesting for practical purposes. One is based on the Leontovich dissipative equation for $N$-particle distribution and the other on the Langevin non-equilibrium method. In addition, the behavior of entropy in a system is discussed taking into account kinetic fluctuations.

Important problems of the transition from the kinetic to semimacroscopic (hydrodynamic) description are considered in Chapters 11–14. The traditional Chapman–Enskog method well-known from the theory of Boltzmann equation is applicable to states approximating local equilibrium. At the same time, far-from-equilibrium open systems often undergo situations which require processes at kinetic and hydrodynamic scales to be taken into account. In such situations, some local parameters (e.g. temperature) lose their usual thermodynamic sense, and the local equilibrium can not serve as a starting point for the construction of transfer equations. The author proposes an alternative method for the transition from kinetic to hydrodynamic description by smoothing distribution functions over a physically infinitesimal volume and introducing the *Knudsen physical parameter*. This parameter is actually the ratio of the 'point' size in the medium for the selected way of defining the non-equilibrium state to the characteristic scale of the problem. Using perturbation theory with the Knudsen physical parameter, the author derived a generalized kinetic equation for the universal description of kinetic and hydrodynamic processes and considered the physical corollaries of this equation, e.g. entropy behavior and the transition to macroscopic transfer equations.

The next three chapters (15–17) deal with those aspects of the theory of open systems which are not directly related to macroscopic models. The evolution of non-equilibrium states is described by the master equation for the probability of transition in the space of approximate variables, the Fokker–Planck equation for the distribution function of these variables or non-linear stochastic equations (Langevin equations) for fluctuations. Collectively, these problems of special importance for chemistry, biology, and sociology constitute a far-reaching generalization of the theory of Brownian motion of macroscopic particles in liquids and gases. It is worthwhile to note, however, that the microscopic approach discussed in previous chapters and disregarded in Chapters 15–17 remains apparent in certain principles which have to be introduced into the semimacroscopic theory. Specifically, they include the relationship between dissipation and fluctua-

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tions as well as general properties of Langevin random sources describing non-equilibrium noise. It is essential that, in addition to fundamental problems, e.g. different forms of the Fokker – Planck equation, their relation to physical properties of the processes in a system, and reciprocated effects of equilibrium and non-equilibrium phase transitions, the book provides a number of interesting examples from various fields of physics and biology (partially ionized plasma, segnetoelectrics, liquid crystals, lasers, population dynamics). This gives the reader the idea of how the theory 'works' in the solution of specific problems.

In Chapters 18 and 19, kinetic theory is applied to the investigation of active media characterized by the appearance of macroscopic dissipative structures in case of remodeling the so-called driving parameters which describe the degree of deviation of the system from equilibrium. Of late, active media have been extensively studied in physics, chemistry, and biology, but as a rule many authors use very crude models based on phenomenological equations of the 'reaction – diffusion' type. The book under consideration appears to be the first in which the kinetic approach to active media is employed, thus allowing for the discussion of the important problem of fluctuations in such media. These chapters are equally interesting for physicists, chemists, and biologists involved in active media studies.

A separate chapter is devoted to low-energy flicker noise ($1/f$ noise), arising in systems of different nature and having a number of surprising properties, viz. the growing spectral function of fluctuations at decreasing frequency, independence of temporal correlations of the system's dimension, etc. Flicker noise remains in many aspects an enigma even though it has been known for a long time and extensively studied for about 70 years. The author regards flicker noise as an example of anomalous diffusion in a bounded medium. This viewpoint is in line with the general theory of open systems presented in the book. The author provides an elegant explanation of certain mechanisms underlying flicker noise and demonstrates the characteristic features of Langevin sources responsible for this noise.

The last three chapters deal with the theory of non-equilibrium open systems in relation to the self-organization criterion. Because self-organization processes may in a way be interpreted as a chain of non-equilibrium phase transitions leading to the appearance of dissipative structures, there is a natural question of what physical principle (similar to the second law of thermodynamics) reflects the degree of order in open system states at different driving parameter values. The main criterion formulated by the author in the form of the *S-theorem* (*S* stands for self-organization) consists in that entropy of an open system decreases with the progress of self-organization which means that a state with dissipative structures is better ordered than the original. The *S*-theorem is illustrated throughout the book by specific examples; its general formulation is presented in Chapter 21. The non-trivial nature of the *S*-theorem becomes well apparent in Chapter 22 where the turbulence problem is discussed in the framework of the statistical theory of open systems. According to the self-organization criterion suggested by the author, the transition from laminar to turbulent motion may be interpreted as the non-equilibrium phase-transition 'from chaos to order' even though the assertion of the opposite seems more natural from the 'naive' point of view.

The last chapter is a concise introduction to the theory of quantum open systems. The transition to irreversible equations in quantum theory as well as reciprocal effects of non-equilibrium and typical quantum events is closely related to such crucial and so far unsolved problems as the completeness of quantum mechanics, the role of interactions between quantum systems and the macroscopic environment, etc. The preliminary exposition in terms of the theory of open systems prepares the reader for the discussion of these problems in the second volume of the book.

The "Statistical theory of open systems" is an interesting combination of a monograph and a textbook on a debated problem. It should be emphasized that such an organization of the book reflects the current state of the statistical theory of far-from-equilibrium systems having far more 'blank spaces' and unsolved problems than well-established principles and reliable findings. The book being intended not only for specialists but also for students, the author encountered the complicated task of selecting appropriate materials. On the whole, he has managed to achieve a reasonable equilibrium between 'the old' and 'the new'. As for previous books of the same author, this one is distinguished for the original, clear, and deep exposition of its physical content. It will be of great value to those interested in one of the most important problems of the theory of non-equilibrium processes.

In conclusion, the book is published both in Russia and abroad (Doedrecht, Boston: Kluwer Academic Publishers, 1995). The ideas discussed in the book have been further developed in the author's paper [*Physics – Uspekhi* **166** 1231 (1996)] where he addresses the problem of formulating the 'physics of open systems' as a new interdisciplinary area of research. At present volume 2 of the monograph is in press.

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