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Book Review: *Nonequilibrium Phase Transitions in Lattice Models*

Nonequilibrium Phase Transitions in Lattice Models. J. Marro and R. Dickman, Cambridge University Press, Cambridge, 1999, xv + 327 pp.

This book illustrates recent progress in the study of nonequilibrium phenomena by lattice models. To this end, the chosen strategy is to present a variety of characteristic situations such as field-driven lattice gases, lattice gases with interacting spins, models with quenched and annealed disorder or with impurities giving rise to conflicting dynamics and particle reaction models defined via single- and multiparticle rules. In each chapter, a physically motivated model is first dealt with in detail. Several variants of the model displaying new or additional features are next presented and briefly discussed. For further details on each variant, the reader is provided with an extensive list of bibliographical references. The analysis contains some exact results, although it is primarily based on analytical mean-field (MF) approaches like kinetic cluster theories and MC simulations. Due to lack of space, field theoretical and renormalization group methods are almost completely left aside and only occasionally refered to.

The book consists of a preface, a short introductory chapter, and 8 full-length chapters. Chapter 1 is a brief appetizer which aims to emphasize the importance of nonequilibrium phenomena in nature and gives an intuitive definition of far-from-equilibrium phase transitions. The need for microscopic models to study criticality is pointed out, since hydrodynamic approaches often do not incorporate fluctuation effects which may be non-negligible near transition points. A rough classification of nonequilibrium systems is also given: Hamiltonian systems out of equilibrium, "perturbed equilibrium" models for which thermodynamic quantities like temperature or internal energy can still be defined and models with no equilibrium counterparts. In order to give some of the flavor of the models considered later on, two generic examples are used: a simple branching process exhibiting a phase transition and a lattice gas model displaying a nonequilibrium anisotropic steady state with phase separation. Important

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concepts of modern theory like universality and scaling are introduced and motivated on the basis of these examples.

Chapters 2 and 3 are devoted to the driven lattice gas (DLG), a non-equilibrium anisotropic version of the usual lattice gas. In Chapter 2, the basic model is introduced via a Master equation approach with transition rates satisfying local detailed balance. Its relevance for the description of surface growth processes and fast or superionic conductors (FIC) is discussed. The authors argue that the model incorporates the main basic features of FIC materials, since it allows for "nonequilibrium steady states in a collection of driven interacting particles." They also argue that one and two dimensional models of FIC materials do not lack physical interest, since FIC materials often exhibit low dimensional effects due to layered and channel-like conducting structures. The dynamics and the morphology of the steady state in 1D and 2D is discussed on the basis of MC simulations. In 2D, phase segregation and complex anisotropic static behavior occur, while the early-time dynamics is characterized by multistrip particle structures. A layered model with an extra degree of freedom is subsequently discussed. The chapter closes with a meticulous review of computations for correlations and critical and scaling properties. In Chapter 3, a more theoretical description of the above phenomena is provided. The starting point is a MF theory of "minimum domains" which generalizes the familiar Bethe–Peierls approximation of equilibrium. An alternative hydrodynamic approach is developed. The 1D and 2D standard DLG models and the layered DLG are extensively treated and the results compared with MC simulations. Previous calculations for special limiting situations are generalized with the help of Ω-expansion techniques.

Chapter 4 is devoted to a stochastic lattice gas model with competing reaction-diffusion kinetics (RDLG). The dynamics of the RDLG is mapped into a spin model in which the reaction processes are represented by spin flips and the diffusion processes are equivalent to NN spin exchanges. A relationship between microscopic and hydrodynamic levels of description is established, in particular a derivation by de Masi *et al.* of a macroscopic equation for the local magnetization from the corresponding Master equation after suitable scaling is outlined. The RDLG model turns out to exhibit an extremely rich static behavior in both 1D and 2D. The steady state undergoes different kinds of phase transitions depending on the parameter values and the form of the microscopic transition rates. The MF theory for the DLG is extended to the RDLG.

The next chapter is devoted to catalysis models. Most of it focuses on the Ziff–Gulari–Barshad (ZGB) model for the oxidation of CO on a catalytic surface. This system exhibits two phase transitions from an active steady state into absorbing states in which the surface is poisoned either by

CO molecules (discontinuous transition) or by oxygen atoms (continuous transition). Several MF approaches and simulation results are presented.

Chapter 6 deals with the contact process (CP), a simple (but not exactly solvable) lattice model for epidemics which also displays a transition into an absorbing (disease-free) state. The phase diagram is shown and several statistical quantities (mean number of affected individuals, infection spreading from a local seed) are computed. A hyperscaling property for the critical exponents is derived. The analogies between directed percolation (DP) and CP-related models are analyzed in detail and thus interesting physical insight is provided. The closing sections of the chapter deal with the diffusive CP, a quantum mechanical operator method and the effect of quenched and annealed disorder on the CP.

The role of disorder and conflicting dynamics is the object of the next two chapters. Chapter 7 presents a variety of models in which a superposition of local spin processes "conspire" to drive the system into a non-equilibrium steady state. These models are relevant for the behavior of disordered materials and dilute magnetic systems. In such systems, diffusion of impurities cannot in general be neglected. This is the physical motivation for kinetic disorder models like the nonequilibrium random-field Ising model (NRFM). Several generalizations of the NRFM are presented. Under certain conditions (short range interactions and global detailed balance), an *effective Hamiltonian* can be defined for these systems. Chapter 8 deals partly with a selection of the spin systems introduced in the previous chapter, but also with voter models and other models relevant for proton glasses and neural networks. It also includes an interpretation of the concept of thermal bath which might have better been placed at the end of Section 7.2.

The final chapter of the book explores the role of many-body effects in particle reaction models involving creation and annihilation. In a modified version of the CP studied in Chapter 6, it is shown that the interplay between a pairwise annihilation rule and diffusion may change qualitatively the phase diagram of the CP. If one substitutes the annihilation of pairs by a triplet annihilation rule, one surprisingly finds that, in a certain parameter regime, particles actually avoid extinction by reproducing at a lower rate! According to numerical evidence, the critical behavior of this family of CP-related models falls into the DP universality class. The next sections present several single-component models exhibiting discontinuous phase transitions and some examples of catalysis-related models with multiple absorbing configurations. The effect of conservation laws on lattice dynamics is discussed explicitly for the branching annihilating random walk (BAW). A parity-conserving BAW with an even number of particles turns out to exhibit non-DP behavior. A variety of systems belonging to this new universality class, e.g., the kink cellular automaton, are briefly illustrated. The closing Section 9.6 deals with cyclic dynamics; it discusses shortly the properties of a three-state Lotka–Volterra lattice model.

On the whole, Marro and Dickman have written an interesting, well documented review on nonequilibrium lattice problems. The authors have taken special care in separating controversial issues from well established facts. The idea of organizing each chapter around an illustrative, characteristic example is a good one, although the number of variants presented might probably have been reduced for the sake of compactness, since it is sometimes hard for the reader to keep in mind the quantitative details of each one. This specially holds for some parts of Sections 2.6, 3.2, 3.5, 4.6, 7.6, 7.8, and 8.3. In contrast, Chapters 5, 6, and 9 are particularly well organized and provide clear physical insight and many valuable bibliographical references. Another bonus of the book is that it nicely illustrates the importance of MF approaches in a variety of different contexts (epidemics, condensed state theory, RD systems, etc.). On the other hand, the structure of the book might have been considerably simplified if Chapters 2 and 3 had been combined into a single one with more emphasis on qualitative aspects. The same holds for Chapters 7 and 8. It also seems natural to place Chapter 9 immediately after Chapter 6, since it mostly deals with a multiparticle generalization of the CP. For didactic purposes and the sake of clarity, it would be desirable to include more illustrative pictures.

In its current form, the book can hardly be recommended as an introduction to nonequilibrium lattice problems. However, it is an excellent source of references for students and researchers working on population models, cellular automata and theory and experiments of reaction-diffusion systems. Some chapters (specially those devoted to lattice gases and models of disorder) require a good command of the subtleties of equilibrium statistical mechanics, while others are more accesible to graduate students.

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