Preface to the First Edition

During the last decade each of the authors has regularly taught a graduate or senior undergraduate course in statistical mechanics. During this same period, the renormalization group approach to critical phenomena, pioneered by K. G. Wilson, greatly altered our approach to condensed matter physics. Since its introduction in the context of phase transitions, the method has found application in many other areas of physics, such as many-body theory, chaos, the conductivity of disordered materials, and fractal structures. So pervasive is its influence that we feel that it now essential that graduate students be introduced at an early stage in their career to the concepts of scaling, universality, fixed points, and renormalization transformations, which were developed in the context of critical phenomena, but are relevant in many other situations.

In this book we describe both the traditional methods of statistical mechanics and the newer techniques of the last two decades. Most graduate students are exposed to only one course in statistical physics. We believe that this course should provide a bridge from the typical under-graduate course (usually concerned primarily with noninteracting systems such as ideal gases and paramagnets) to the sophisticated concepts necessary to a researcher.

We begin with a short chapter on thermodynamics and continue, in Chapter 2, with a review of the basics of statistical mechanics. We assume that the student has been exposed previously to the material of these two chapters and thus our treatment is rather concise. We have, however, included a substantial number of exercises that complement the review.

In Chapter 3 we begin our discussion of strongly interacting systems with a lengthy exposition of mean field theory. A number of examples are worked out in detail. The more general Landau theory of phase transitions is developed and used to discuss critical points, tricritical points, and first-order phase transitions. The limitations of mean field and Landau theory are described and the role of fluctuations is explored in the framework of the Landau–Ginzburg model.

Chapter 4 is concerned with the theory of dense gases and liquids. Many of the techniques commonly used in the theory of liquids have a long history and are well described in other texts. Nevertheless, we feel that they are sufficiently important that we could not omit them. The traditional method of viral expansions is presented and we emphasize the important role played in both theory and experiment by the pair correlation function. We briefly describe some of the useful and still popular integral equation methods based on the Ornstein–Zernike equation used to calculate this function as well as the modern perturbation theories of liquids. Simulation methods (Monte Carlo and molecular dynamics) are introduced. In the final section of the chapter we present an interesting application of mean field theory, namely the van der Waals theory of the liquid-vapor interface and a simple model of roughening of this interface due to capillary waves.

Chapters 5 and 6 are devoted to continuous phase transitions and critical phenomena. In Chapter 5 we review the Onsager solution of the two-dimensional Ising model on the square lattice and continue with a description of the series expansion methods, which were historically very important in the theory of critical phenomena. We formulate the scaling theory of phase transitions following the ideas of Kadanoff, introduce the concept of universality of critical behavior, and conclude with a mainly qualitative discussion of the Kosterlitz–Thouless theory of phase transitions in two-dimensional systems with continuous symmetry.

Chapter 6 is entirely concerned with the renormalization group approach to phase transitions. The ideas are introduced by means of technically straightforward calculations for the one- and two-dimensional Ising models. We discuss the role of the fixed points of renormalization transformations and show how the theory leads to universal critical behavior. The original ϵ-expansion of Wilson and Fisher is also discussed. This section is rather detailed, as we have attempted to make it accessible to students without a background in field theory.

In Chapter 7 we turn to quantum fluids and discuss the ideal Bose gas, the weakly interacting Bose gas, the BCS theory of superconductivity, and the phenomenological Landau–Ginzburg theory of superconductivity. Our treatment of these topics (except for the ideal Bose gas) is very much in the spirit of mean field theory and provides more challenging applications of the formalism developed in Chapter 3.

Chapter 8 is devoted to linear response theory. The fluctuation-dissipation theorem, the Kubo formalism, and the Onsager relations for transport coefficients are discussed. This chapter is consistent with our emphasis on equilibrium phenomena — in the linear response approximation the central role is played by equilibrium correlation functions. A number of applications of the formalism, such as the dielectric response of an electron gas, the elementary excitations of a Heisenberg ferromagnet, and the excitation spectrum of an interacting Bose fluid, are discussed in detail. The complementary approach to transport via the linearized Boltzmann equation is also presented.

Chapter 9 provides an introduction to the physics of disordered materials. We discuss the effect of disorder on the quantum states of a system and introduce (as an example) the notion of localization of electronic states by an explicit calculation for a one-dimensional model. Percolation theory is introduced and its analogy to thermal phase transitions is elucidated. The nature of phase transitions in disordered materials is discussed and we conclude with a very brief and qualitative description of the glass and spin-glass transitions. These subjects are all very much at the forefront of current research and we do not claim to be at all comprehensive in our treatment. In compensation, we have provided a more extensive list of references to recent articles on these topics than elsewhere in the book.

We have found the material presented here suitable for an introductory graduate course, or with some selectivity, for a senior undergraduate course. A student with a previous course in statistical mechanics, some background in quantum mechanics, and preferably, some exposure to solid state physics should be adequately prepared. The notation of second quantization is used extensively in the latter part of the book and the formalism is developed in detail in the Appendix. The instructor should be forewarned that although some of the problems, particularly in the early chapters, are quite straightforward, those toward the end of the book can be rather challenging.

Much of this book deals with topics on which there is a great deal of recent research. For this reason we have found it necessary to give a large number of references to journal articles. Whenever possible, we have referred to recent review articles rather than to the original sources.

The writing of this book has been an ongoing (frequently interrupted) process for a number of years. We have benefited from discussion with, and critical comments from, a number of our colleagues. In particular, Ian Affleck, Leslie Ballentine, Robert Barrie, John Berlinsky, Peter Holdsworth, Zoltán Rácz, and Bill Unruh have been most helpful. Our students Dan Ciarniello, Victor Finberg and Barbara Frisken have also helped to decrease the number of errors, ambiguities, and obscurities. The responsibility for the remaining faults rests entirely with the authors.

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Preface to the Second Edition

During the five years that have passed since the first edition of this book was published, we have received numerous helpful suggestions from friends and colleagues both at our own institutions and at others. As well, the field of statistical mechanics had continued to evolve. In composing this second edition we have attempted to take all of this into account. The purpose of the book remains the same: to provide an introduction to state-of-the-art techniques in statistical physics for graduate students in physics, chemistry and materials science.

While the general structure of the second edition is very similar to that of the first edition, there are a number of important additions. The rather abbreviated treatment of computer simulations has been expanded considerably and now forms a separate Chapter 7. We have included an introduction to density-functional methods in the chapter on classical liquids. We have added an entirely new Chapter 8 on polymers and membranes. In the discussion of critical phenomena, we have corrected an important omission of the first edition and have added sections on finite-size scaling and phenomenological renormalization group. Finally, we have considerably expanded the discussion of spin-glasses and have also added a number of new problems. We have also compiled a solution manual which is available from the publisher.

It goes without saying that we have corrected those errors of the first edition that we are aware of. In this task we have been greatly helped by a number of individuals. In particular, we are grateful to Vinay Ambegaokar, Leslie Ballentine, David Boal, Bill Dalby, Zoltán Rácz, Byron Southern and Philip Stamp.

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Preface to the Third Edition

In the third edition we have added a significant amount of new material. There are also numerous corrections and clarifications throughout the text. We have also added several new problems.

In Chapter 1 we have added a section on magnetic work, while in Chapter 2 we have added to the discussion of the maximum entropy principle, emphasizing the importance of the assumption that the entropy is extensive in a normal thermodynamic system.

In Chapter 3 we have replaced the derivation of the Bragg Williams approximation from the density matrix, to a more intuitive one, stressing the mean field assumption of statistical independence of spins at different sites. We have also added a section on the Potts model. The sections on the Maier-Saupe model for liquid crystals, the Blume-Emery-Griffiths model for ^{3}He-^{4}He mixtures and van der Waals fluid have been moved to a new chapter called "Applications of Mean Field Theory" that includes a section on an insect infestastion model in ecology and also includes a non-equilibrium system: the two species asymmetric exclusion model. This section illustrates the application of mean field theory outside the scope of equilibrium statistical mechanics.

The new Chapters 5 and 6 only contain relatively minor changes to the old Chapters 4 and 5. In Chapter 7, the section on the epsilon expansion in the old Chapter 6 has been rewritten, and we have added a section on the Ising model on the diamond fractal.

Because of the growing importance of the field we have added a new Chapter 8 on stochastic processes. We start with a description of discrete birth and death processes, and we return to the insect infestation model of Chapter 4. Most of the remainder of the chapter is concerned with the Fokker-Planck equation for both discrete and continuous processes. We apply the theory both to a genetics problems and diffusion of particles in fluids. Other applications involve the rate of excape from a metastable state and problems of heterogeneous diffusion. Finally we show how the Fokker-Planck equation can be transformed into a form similar to the Schrödinger equation, allowing the application of techniques familiar from quantum mechanics.

In Chapter 9 (old Chapter 7) we have rewritten the section on molecular dynamics and added a subsection on Brownian dynamics. There are only relatively minor changes to Chapters 10 and 11 (old Chapters 8 and 9) except that we have updated the references to the literature in view of important new developments in superconductivity and Bose condensation. A section on rigidity percolation has been added to Chapter 13 (old Chapter 11).

Helpful comments and suggestions from Ian Affleck, Marcel Franz, Michel Gingras, Margarita Ifti, Greg Lakatos, Zoltán Rácz, Fei Zhou and Martin Zuckermann are gratefully acknowledged.

Updated information of interest to readers will be displayed on our website http://www.physics.ubc.ca/~birger/equilibrium.htm.

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