# Phase Transition Dynamics

Phase transition dynamics is of central importance in current condensed matter physics. Akira Onuki provides a systematic treatment of a wide variety of topics including critical dynamics, phase ordering, defect dynamics, nucleation, and pattern formation by constructing time-dependent Ginzburg–Landau models for various systems in physics, metallurgy, and polymer science.

The book begins with a summary of advanced statistical–mechanical theories including the renormalization group theory applied to spin and fluid systems. Fundamental dynamical theories are then reviewed before the kinetics of phase ordering, spinodal decomposition, and nucleation are covered in depth in the main part of the book. The phase transition dynamics of real systems are discussed, treating interdisciplinary problems in a unified manner. New topics include supercritical fluid dynamics, boiling near the critical point, stress–diffusion coupling in polymers, patterns and heterogeneities in gels, and mesoscopic dynamics at structural phase transitions in solids. In the final chapter, theoretical and experimental approaches to shear flow problems in fluids are reviewed.

*Phase Transition Dynamics* provides a comprehensive treatment of the study of phase transitions. Building on the statics of phase transitions, covered in many introductory textbooks, it will be essential reading for researchers and advanced graduate students in physics, chemistry, metallurgy and polymer science.

AKIRA ONUKI obtained his PhD from the University of Tokyo. Since 1983 he has held a position at Kyoto University, taking up his current professorship in 1991. He has made important contributions to the study of phase transition dynamics in both fluid and solid systems.

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# Contents

# Preface

This book aims to elucidate the current status of research in phase transition dynamics. Because the topics treated are very wide, a unified phenomenological time-dependent Ginzburg–Landau approach is used, and applied to dynamics near the critical point. Into the simple Ginzburg–Landau theory for a certain order parameter, we introduce a new property or situation such as elasticity in solids, viscoelasticity in polymers, shear flow in fluids, or heat flow in $^4$He near the superfluid transition. By doing so, we encounter a rich class of problems on mesoscopic spatial scales. A merit of this approach is that we can understand such diverse problems in depth using universal concepts.

The first four chapters (Part one) deal with static situations, mainly of critical phenomena, and introduce some new results that would stand by themselves. However, the main purpose of Part one is to present the definitions of many fundamental quantities and introduce various phase transitions. So it should be read before Parts two and three which deal with dynamic situations. Chapter 5 is also introductory, reviewing fundamental dynamic theories, the scheme of Langevin equations and the linear response theory. Chapter 6 treats critical dynamics in (i) classical fluids near the gas–liquid and consolute critical points and (ii) $^4$He near the superfluid transition. Chapter 7 focuses on rather special problems in complex fluids: (i) effects of viscoelasticity on composition fluctuations in polymer systems; and (ii) volume phase transitions and heterogeneity effects in gels. Chapters 8 and 9 (in Part three) constitute the main part of this book, and consider the kinetics of phase ordering, spinodal decomposition, and nucleation. Motions of interfaces and vortices are examined in the Ginzburg–Landau models. Chapter 10 focuses on dynamics in solids, including phase separation, order–disorder and martensitic transitions, shape instability in hydrogen–metal systems, and surface instability in metal films. These problems have hitherto been very inadequately studied and most papers are difficult to understand for those outside the field, so it was important to write this chapter in a coherent fashion, though it has turned out to be a most difficult task. I believe that many interesting dynamical problems remain virtually unexplored in solids, because such phenomena have been examined either too microscopically in solid-state physics without giving due respect to long-range elastic effects or with technologically-oriented objectives in engineering. Chapter 11 is on shear flow problems in fluids, a topic on which a great number of theoretical and experimental papers appeared in the 1980s and 1990s. This book thus covers a wide range of phase transition dynamics. Of course, many important problems had to be omitted.

I have benefited from discussions with many people working in the fields of low-temperature physics, statistical physics, polymer science, and metallurgy. Particularly

useful suggestions were given by H. Meyer, Y. Oono, K. Kawasaki, T. Ohta, M. Doi, T. Hashimoto, H. Tanaka, M. Shibayama, T. Miyazaki, T. Koyama, and Y. Yamada. Thanks are due to R. Yamamoto, K. Kanemitsu, and A. Furukawa for drawing some of the figures. It is with deep sadness that I record the deaths of T. Tanaka and K. Hamano. It is a great pleasure to be able to acknowledge their memorable contributions to Chapters 7 and 11, respectively. Finally, I apologize to my students, colleagues, and family, for any difficulty they may have experienced because I have been so busy with this extremely time-consuming undertaking.

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