POLYMERS, LIQUIDS AND COLLOIDS IN ELECTRIC FIELDS

Interfacial Instabilities, Orientation
and Phase Transitions

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Interfacial Instabilities, Orientation and Phase Transitions

edited by Yoav Tsori and Ullrich Steiner

Series in Soft Condensed Matter **Vol. 2**

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and Phase Transitions

Editors

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Foreword

The study of Soft Condensed Matter has stimulated fruitful interactions between physicists, chemists, and engineers, and is now reaching out to biologists. A broad interdisciplinary community involving all these areas of science has emerged over the last 30 years, and with it our knowledge of Soft Condensed Matter has grown considerably with the active investigations of polymers, supramolecular assemblies of designed organic molecules, liquid crystals, colloids, lyotropic systems, emulsions, biopolymers and biomembranes, among others. Taking into account that research in Soft Condensed Matter involves ideas coming from physics, chemistry, materials science as well as biology, this series may form a bridge between all these disciplines with the aim to provide a comprehensive and substantial understanding of a broad spectrum of phenomena relevant to Soft Condensed Matter.

The present Book Series, initiated by the late Pierre-Gilles de Gennes, comprises independent book volumes that touch on a wide and diverse range of topics of current interest and importance, covering a large number of diverse aspects, both theoretical and experimental, in all areas of Soft Condensed Matter. These volumes will be edited books on advanced topics with contributions by various authors and monographs in a lighter style, written by experts in the corresponding areas. The Book Series mainly addresses graduate students and junior researchers as an introduction to new fields, but it should also be useful to experienced people who want to obtain a general idea on a certain topic or may consider a change of their field of research. This Book Series aims to provide a comprehensive and instructive overview of all Soft Condensed Matter phenomena.

The present volume of this Book Series, edited by Yoav Tsori and Ullrich Steiner, impressively demonstrates that electric fields play an important role in Soft Condensed Matter phenomena. Due to their comparatively strong influence and long range, electric fields are particularly relevant when the system size becomes small like in block copolymer mesophases or at interfacial structures. Electric fields can induce phase transitions, provoke

interfacial instabilities, govern wetting properties or allow tuning ordering processes in block copolymer systems.

Within the next few years, our *Series on Soft Condensed Matter* will grow continuously and eventually cover the whole spectrum of phenomena in Soft Condensed Matter. We hope that many interested colleagues and scientists will profit from these endeavors.

David Andelman and Günter Reiter
Series Editors

Preface

The aim of this book is to survey phenomena in soft matter systems that are triggered by electric fields. Strong electric fields are easily generated and cause stronger interactions in most materials compared to magnetic fields or to gravity. In confinement, electric fields exceeding 10 MV/m are readily produced by low-voltage sources. The manipulation of liquid and soft materials by electric fields is therefore well suited for nanotechnological and microfluidic applications.

The topics covered in this book include field-induced phase transitions in simple liquids and polymers, liquid interfacial instabilities, electrowetting, and orientational and order-order phase transitions in block-copolymers. The level of text is adequate for graduate students and researchers alike. The rich static and dynamical behavior described in the chapters are explained invoking simple physical mechanisms and physical quantities, such as the dielectric properties and conductivity of the liquids or polymers.

The chapters are organized as follows. The first chapter, by D. Andelman and R. Rosensweig, is an introductory review of modulated phases. It surveys several examples of self-organizing materials, such as magnetic garnet films, two-dimensional ferromagnetic layers, and Langmuir dipolar films. It also describes in detail the well-known instabilities of ferrofluids subjected to magnetic fields (e.g. the Rosensweig instability).

The second chapter by A. Onuki deals with solvation effects in polar fluids. By using a Ginzburg-Landau theory, he shows how to calculate the equilibrium ion and electric field distributions near an interface. The surface tension between two phases and the structure factor in the one-phase region near a critical point are given. The following chapter, by K. Orzechowski, is closely related. It gives a concise account of the changes occurring in the phase diagram of mixtures in uniform electric fields. The comparison with the theories of Landau and Lifshitz and the more recent theory by Onuki is also given.

Chapters 4 and 5 describe the behavior of two immiscible liquids in electric fields. T. Russell and J. Bae describe the electrohydrodynamic interfacial instability which develops when a liquid film is subjected to a normal electric field. Here the instability occurs because the electrostatic energy is at a maximum when the external field is perpendicular to a dielectric interface. A fastest-growing wavelength is obtained by a linear stability analysis of pure dielectric liquids. According to the “leaky dielectric” model of G. I. Taylor, the existence of residual conductivity leads to the appearance of large viscous stresses, which lead to a faster dynamics and smaller values of the dominant wavelength. Related phenomena are discussed by F. Mugele in his review of electrowetting. Dissolved ions help to decrease the contact angle of a droplet placed on a solid substrate. The chapter presents the theory and experiments of contact angle saturation, the dynamics of droplets in microfluidics channels, droplet breakup, and various interfacial instabilities.

Q. Tran-Cong-Miyata and H. Nakanishi’s chapter deals with phase separation transitions in polymer systems driven by light. They show that chemical reactions can be used to select the fastest-growing mode in the phase-separation process of polymer mixtures. Hierarchical structures, morphologies with multiple length-scales, and spatio-temporal control of the system can also be obtained.

Chapter 7, written by M. Schick, presents a fundamental approach to the thermodynamics of purely dielectric self-assembled phases in electric fields. This chapter first explains in detail how the electrostatic energy of such systems should be calculated. As examples, it discusses order-order, order-disorder, and orientational phase transitions which occur in block-copolymers.

A. Boeker and K. Schmidt describe the influence of electric fields on block-copolymers in solutions. Their unique experimental method allows them to record the dynamical orientation process, which is found to depend on the distance to the critical point. In addition, they describe an intriguing phenomenon, the reversible change in spacing of a lamellae-forming system induced by an electric field. The last chapter, by A. Zvelindosky and G. Sevink gives an account of the forefront of numerical methods used to calculate orientation and phases of block-copolymers in external fields. They show that dynamical density functional approaches can be used to obtain the dynamics of phase ordering as well as the long-time steady-state.

We believe this book will be useful to people entering the field (no pun intended) as well as to active researchers. We hope the book will

stimulate further innovation in this lively and fruitful interdisciplinary domain.

We would like to thank the Series Editors, D. Andelman and G. Reiter, for their active and very positive role in bringing this book to life. Y. Tsori would like to express his gratitude to L. Leibler and P.-G. De Gennes, with whom he had numerous discussions and collaborations on the subject of electric fields in liquids and polymers.

Yoav Tsori, Beer-Sheva
Ullrich Steiner, Cambridge

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