

CISM International Centre for Mechanical Sciences

Courses and Lectures

Volume 577

Series editors

The Rectors

Friedrich Pfeiffer, Munich, Germany

Franz G. Rammerstorfer, Vienna, Austria

Elisabeth Guazzelli, Marseille, France

The Secretary General

Bernhard Schrefler, Padua, Italy

Executive Editor

Paolo Serafini, Udine, Italy



The series presents lecture notes, monographs, edited works and proceedings in the field of Mechanics, Engineering, Computer Science and Applied Mathematics. Purpose of the series is to make known in the international scientific and technical community results obtained in some of the activities organized by CISM, the International Centre for Mechanical Sciences.

More information about this series at <http://www.springer.com/series/76>

David J. Steigmann
Editor

The Role of Mechanics in the Study of Lipid Bilayers

 Springer

Editor

David J. Steigmann
Faculty of Mechanical Engineering
University of California, Berkeley
Berkeley, CA
USA

ISSN 0254-1971 ISSN 2309-3706 (electronic)
CISM International Centre for Mechanical Sciences
Courses and Lectures
ISBN 978-3-319-56347-3 ISBN 978-3-319-56348-0 (eBook)
DOI 10.1007/978-3-319-56348-0

Library of Congress Control Number: 2017937266

© CISM International Centre for Mechanical Sciences 2018

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

This volume consists of Lecture Notes based on lectures delivered at the Advanced Summer School entitled “The Role of Mechanics in the Study of Lipid Bilayers” held at the International Centre for Mechanical Sciences (CISM) in Udine, Italy, during the period July 11–15, 2016. The course was presented by six lecturers, from Germany, Mexico, Spain, the UK and the USA (2).

The purpose of the six chapters comprising the volume is to provide a state-of-the-art account of the continuum theory underpinning the mechanics and physics of lipid bilayers and its applications.

Chapter “[Mechanics and Physics of Lipid Bilayers](#)” outlines an approach to the theory of lipid bilayers through an appeal to three-dimensional liquid-crystal theory. This provides an over-arching framework that encompasses the classical theory while facilitating its extension to embrace nonstandard effects associated with lipid tilt and distension, dissipative processes involving flow and diffusion, and electromagnetic interactions.

Chapter “[Elasticity and Hereditariness](#)” is devoted to the study of the energetics of lipid membranes, the nature and origin of the line tension accompanying phase transitions, and the role played by viscoelastic effects.

Chapter “[Lipid Membranes: From Self-Assembly to Elasticity](#)” delves into the physical basis of lipid bilayer arrangements, their self-assembly and associated thermodynamics, their elastic moduli, and the physical origins of lipid tilt.

In Chapter “[The Geometry of Fluid Membranes: Variational Principles, Symmetries and Conservation Laws](#)” the theory of lipid membranes is cast in a variational and differential-geometric setting, facilitating a development of the notion of membrane stress and its role in the associated mathematics. Included here are the consequences of reparametrization invariance and Euclidean invariance and the systematic treatment of constraints.

Chapter “[On the Computational Modeling of Lipid Bilayers Using Thin-shell Theory](#)” is devoted to the numerical analysis of lipid membrane behavior by advanced finite element methods. This provides an opportunity, through several examples, to exhibit the potential of the theory of lipid bilayers to predict of the emergence of various geometric features such as filaments and buds.

Chapter “[Onsager’s Variational Principle in Soft Matter: Introduction and Application to the Dynamics of Adsorption of Proteins onto Fluid Membranes](#)” describes a far-ranging investigation into Onsager’s variational principle with applications to chemo-mechanical problems in soft matter and the dynamics of protein adsorption.

These chapters combine to provide a unique perspective on this important branch of bio-physics from the vantage point of mechanics and applied mathematics.

It is a pleasure to acknowledge the efforts of my colleagues, Profs. Arroyo, Deseri, Deserno, Guven and Sauer, for presenting their lectures and for preparing the chapters of this volume, and the students for attending the lectures and contributing to the discussions.

I particularly thank the Rector, officers and staff at CISM for their encouragement, enthusiasm, assistance, and warm hospitality, which were essential to the success of the School. I am also grateful to Prof. Paolo Serafini, Executive Editor of CISM, for his guidance and encouragement in the preparation of these lecture notes.

Berkeley, USA

David J. Steigmann

Contents

Mechanics and Physics of Lipid Bilayers	1
David J. Steigmann	
Elasticity and Hereditariness	63
Luca Deseri	
Lipid Membranes: From Self-assembly to Elasticity	105
M. Mert Terzi and Markus Deserno	
The Geometry of Fluid Membranes: Variational Principles, Symmetries and Conservation Laws	167
Jemal Guven and Pablo Vázquez-Montejo	
On the Computational Modeling of Lipid Bilayers Using Thin-Shell Theory	221
Roger A. Sauer	
Onsager’s Variational Principle in Soft Matter: Introduction and Application to the Dynamics of Adsorption of Proteins onto Fluid Membranes	287
Marino Arroyo, Nikhil Walani, Alejandro Torres-Sánchez and Dimitri Kaurin	