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Dr. Christian Caron  
Springer Heidelberg  
Physics Editorial Department I  
Tiergartenstrasse 17  
69121 Heidelberg/Germany  
[christian.caron@springer.com](mailto:christian.caron@springer.com)

Heiner Linke Alf Månsson (Eds.)

# Controlled Nanoscale Motion

Nobel Symposium 131

 Springer



NOBEL SYMPOSIA



## Editors

Heiner Linke  
Physics Department  
University of Oregon  
Eugene, OR 97403-1274  
USA  
E-mail: linke@uoregon.edu

Alf Månsson  
Department of Chemistry  
and Biomedical Sciences  
University of Kalmar  
SE-391 82 Kalmar  
Sweden  
E-mail: alf.mansson@hik.se

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## Preface

When the size of a machine approaches the nanometer scale, thermal fluctuations become large compared to the energies that drive the motor. The mechanism and control system for directed nanoscale motion must allow for, or even make use of, this stochastic environment. Controlled motion at the nanoscale therefore requires theoretical descriptions and engineering approaches that are fundamentally different from those that were developed for man-made, macroscopic motors and machines.

Over the past decade, a need to understand and to control directed motion at the nanoscale has arisen in several areas of biology, physics and chemistry. Most notably, the advent of single-molecule techniques in biophysics has given access to detailed information about the performance of molecular motors in biological cells. Combined with a variety of techniques from molecular biology, this information allows conclusions about the physics of biological machines. Even more recently, a variety of approaches including nanofabrication and synthetic chemistry have been used to create artificial nanoscale motors or to control the motion of individual molecules, for example using nanofluidic systems. Many of these approaches were triggered by novel theoretical methods designed to understand how the interplay of stochastic thermal motion and non-equilibrium phenomena can be harnessed to generate an output of useful work.

The present volume is based on selected contributions to the Nobel Symposium 131 on *Controlled Nanoscale Motion in Biological and Artificial Systems*, held on June 13–17, 2005 at Bäckaskog Slott in Sweden. The peer-reviewed chapters in this book are designed to be tutorial and self-contained and provide insight into the state of the art in the following three areas:

*Biophysics of molecular motors and single molecules.* Molecular motors are proteins or protein complexes that transduce chemical free energy into work through processes generally believed to involve substantial changes in protein structure. This section describes the physical and biochemical principles of molecular motor function together with an account of some important exper-

imental techniques for their study. The section begins with an overview of the regulation and function of a complex bacterial flagellar motor (Chap. 1). The focus is then shifted towards molecular motors in eukaryotes and the biophysical principles by which they produce force and linear transport. Chapters 2, 3 and 5 consider the mechanisms of operation of members of the myosin motor family, which interact with the actin cytoskeleton, and of kinesins and dyneins, which interact with microtubules. The multitude of biological roles of motors in living cells include tasks of biomedical relevance, such as axonal transport and embryonal development. Chapters 4 and 5 exemplify these functions together with accounts of how such diverse tasks can be achieved by a limited set of motors and cytoskeletal filaments. Chapter 7 describes the role of molecular motors in nanotube dynamics in living cells, including a theoretical treatment of the physics of membrane nanotubes. Chapters 6 and 8, finally, consider nanoscale motion in macromolecules not traditionally counted as molecular motors, including nucleic acid and nucleic acid-binding proteins (Chap. 6) and polysaccharide modifying enzymes (Chap. 8).

*Theory of controlled nanoscale motion.* Nanoscale motors and machines typically operate far from thermal equilibrium in an environment characterized by substantial thermal motion. In addition, thermal fluctuations of the protein conformational state around a free energy minimum can contribute to the stochastic nature of experimental data. The theory of Brownian motion in and out of thermal equilibrium therefore plays an important guiding role in the design of artificial motors and in the analysis of single-molecule experiments. Chapter 9 describes improved mathematical models of Brownian motion and their use to calibrate optical tweezers. Chapter 10 represents a tutorial introduction to the Jarzynski equation that allows extraction of information about equilibrium processes from data taken under non-equilibrium conditions. Finally, Chap. 11 describes theoretical approaches and methods for the accurate determination of diffusion constants from noisy data.

*Controlled motion in nanotechnology.* The ability to fabricate and manipulate nanoscale structures offers an impressive array of methods for the control of the motion of nanoscale objects, giving access to a new realm of experimental physics. Chapters 12 and 13 provide tutorial introductions to the physics of nanomechanical and nanofluidic devices for detection and study of single biomolecules. The subsequent three chapters describe two representative approaches to the construction of artificial molecular motors using self-assembly techniques, as well as a synthetic nanopore system that allows control of ion flow similar to a biological ion channel. The final two Chapters (17 and 18) tie together nanotechnology and biological motors by discussing the physics and methods of controlling biological motors using nanofabricated structures.

Nobel Symposium 131, on which this volume is based, was sponsored by the Nobel Foundation through its Nobel Symposium Fund. We thank all speakers and participants for their contributions and the Nobel Foundation for generous financial support.

Kalmar and Eugene  
January 2007

*Alf Månsson*  
*Heiner Linke*

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## List of Contributors

**J.-F. Allemand**

Laboratoire de Physique Statistique  
and Dept. Biologie  
Ecole Normale Supérieure  
France  
allemand@lps.ens.fr

**John Allingham**

University of Wisconsin  
Department of Biochemistry  
USA  
jallingham@biochem.wisc.edu

**J.L. Arlett**

Division of Physics  
Mathematics and Astronomy  
arlett@cco.caltech.edu

**Robert H. Austin**

Department of Physics  
Princeton University  
USA  
austin@princeton.edu

**D. Bensimon**

Laboratoire de Physique Statistique  
and Dept. Biologie  
Ecole Normale Supérieure  
France  
david.bensimon@lps.ens.fr

**Howard C. Berg**

Departments of Molecular and  
Cellular Biology and of Physics  
Harvard University  
USA  
hberg@mcb.harvard.edu

**K. Berg-Sørensen**

Department of Physics  
Technical University of Denmark  
Denmark

**G. Charvin**

Laboratoire de Physique Statistique  
and Dept. Biologie  
Ecole Normale Supérieure  
France  
gilles.charvin@lps.ens.fr

**Edward C. Cox**

Department of Molecular Biology  
Princeton University  
USA  
ecox@princeton.edu

**H.G. Craighead**

Applied and Engineering Physics  
Cornell University  
USA  
hgcl@cornell.edu

**V. Croquette**

Laboratoire de Physique Statistique  
and Dept. Biologie  
Ecole Normale Supérieure  
France  
croquette@lps.ens.fr

**M.C. Cross**

Division of Physics  
Mathematics and Astronomy  
California Institute of Technology  
USA

**András Czövek**

Department of Biological Physics  
Eötvös University  
Hungary  
czigor@angel.elte.hu

**Gaudenz Danuser**

Departments of Cell Biology  
The Scripps Research Institute  
USA

**Imre Derényi**

Department of Biological Physics  
Eötvös University  
Hungary  
derenyi@angel.elte.hu

**Marileen Dogterom**

FOM Institute for Atomic and  
Molecular Physics (AMOLF)  
The Netherlands  
dogterom@amolf.nl

**Martijn M. van Duijn**

Department of Bioengineering  
University of California Berkeley  
USA  
vanduijn@berkeley.edu

**Henrik Flyvbjerg**

Biosystems Department  
and Danish Polymer Centre  
Risø National Laboratory  
Denmark  
henrik.flyvbjerg@risoe.dk

**S.E. Fraser**

Kavli Nanoscience Institute  
and Division of Biology and  
Division of Engineering and  
Applied Science  
California Institute of Technology  
USA

**Lawrence S.B. Goldstein**

Departments of Cellular and  
Molecular Medicine  
University of California of San Diego  
USA  
lgoldstein@ucsd.edu

**P.H. Hagedorn**

Biosystems Department  
Risø National Laboratory  
Denmark  
peter.hagedorn@risoe.dk

**Henry Hess**

Department of Materials Science  
and Engineering  
University of Florida  
USA  
hhess@mse.ufl.edu

**Nobutaka Hirokawa**

Department of Cell Biology  
and Anatomy  
Graduate School of Medicine  
University of Tokyo  
Japan  
hirokawa@m.u-tokyo.ac.jp

**Robert D. Horansky**

Department of Physics  
University of Colorado  
USA  
Robert.Horansky@Colorado.edu

**Christopher Jarzynski**

Theoretical Division  
 Los Alamos National Laboratory  
 and  
 Department of Chemistry  
 and Biochemistry  
 Institute for Physical  
 Science and Technology  
 University of Maryland  
 USA  
 cjarzyns@umd.edu

**Gerbrand Koster**

Institut Curie  
 France  
 and  
 FOM Institute for Atomic and  
 Molecular Physics (AMOLF)  
 The Netherlands  
 gerbrand.koster@curie.fr

**N.B. Larsen**

Danish Polymer Centre  
 Risø National Laboratory  
 Denmark  
 and  
 Biosystems Department  
 Risø National Laboratory  
 Denmark  
 niels.b.larsen@risoe.dk

**G. Lia**

Harvard University  
 Chemistry and Chemical Biology  
 USA  
 lia@fas.harvard.edu

**T. Lionnet**

Laboratoire de Physique Statistique  
 and Dept. Biologie  
 Ecole Normale Supérieure  
 France

**Thomas F. Magnera**

Department of Chemistry  
 and Biochemistry  
 University of Colorado  
 USA  
 magnera@eefus.colorado.edu

**Alf Månsson**

School of Pure and Applied  
 Natural Sciences  
 University of Kalmar  
 Sweden  
 alf.mansson@hik.se

**Dietmar J. Manstein**

Institute for Biophysical Chemistry  
 Germany  
 manstein@bpc.mh-hannover.de

**Charles R. Martin**

Department of Chemistry  
 University of Florida  
 USA  
 crmartin@chem.ufl.edu

**Josef Michl**

Department of Chemistry  
 and Biochemistry  
 University of Colorado  
 USA  
 michl@eefus.colorado.edu

**Lars Montelius**

Division of Solid State Physics and  
 The Nanometer Consortium  
 University of Lund  
 Sweden  
 lars.montelius@ftf.lth.se

**S. Mosler**

Danish Polymer Centre  
 Risø National Laboratory  
 Denmark

**K.C. Neuman**

Laboratoire de Physique Statistique  
 and Dept. Biologie  
 Ecole Normale Supérieure  
 France



**Ian A. Nicholls**

School of Pure and  
Applied Natural Sciences  
University of Kalmar  
Sweden  
ian.nicholls@hik.se

**Kazuhiro Oiwa**

Kobe Advanced CT Center  
(KARC)  
National Institute of Information  
and Communications Technology  
(NICT)  
Japan  
oiwa@nict.go.jp

**Pär Omling**

Division of Solid State  
Physics and The Nanometer  
Consortium  
University of Lund  
Sweden  
par.omling@vr.se

**M.R. Paul**

Department of Mechanical  
Engineering  
Virginia Polytechnic Institute  
and State University  
USA  
mrp@vt.edu

**John C. Price**

Department of Physics  
University of Colorado  
USA  
john.price@colorado.edu

**Jacques Prost**

Institut Curie  
France  
and  
ESPCI  
France  
jacques.prost@curie.fr

**Ivan Rayment**

Department of Biochemistry  
University of Wisconsin  
USA  
Ivan.Rayment@biochem.wisc.edu

**M.L. Roukes**

Kavli Nanoscience Institute  
and Division of Physics  
Mathematics and Astronomy and  
Division of Engineering and  
Applied Science  
California Institute of Technology  
USA  
roukes@caltech.edu

**O.A. Saleh**

Materials Department and  
Biomolecular Science and  
Engineering Program  
University of California  
USA  
saleh@engineering.ucsb.edu

**K.T. Samiee**

Applied and Engineering Physics  
Cornell University  
USA  
kts3@cornell.edu

**E. Schäffer**

Center of Biotechnology  
Technical University  
Germany

**D. Selmeczi**

Danish Polymer Centre  
Risø National Laboratory  
Denmark  
and  
Department of Biological Physics  
Eötvös University  
Hungary  
david.selmeczi@risoe.dk

**Sameer B. Shah**

Department of Bioengineering  
 University of Maryland  
 USA  
 sameer@umd.edu

**Zuzanna S. Siwy**

Department of Physics and  
 Astronomy  
 University of California  
 USA  
 and  
 Department of Chemistry  
 Silesian University of Technology  
 Poland  
 zsiwy@uci.edu

**Gudmund Skjåk-Bræk**

Department of Biotechnology  
 The Norwegian University of Science  
 and Technology  
 Norway  
 gudmund.skjaax-braek  
 @biotechntnu.no

**Marit Sletmoen**

Biophysics and Medical Technology  
 Department of Physics  
 The Norwegian University of Science  
 and Technology  
 Norway  
 marit.sletmoen@phys.ntnu.no

**J.E. Solomon**

Division of Physics  
 Mathematics and Astronomy  
 California Institute of Technology  
 USA

**S.M. Stavis**

Applied and Engineering Physics  
 Cornell University  
 USA  
 sstavis@gmail.com

**Bjørn Torger Stokke**

Biophysics and Medical Technology  
 Department of Physics  
 The Norwegian University of Science  
 and Technology  
 Norway  
 bjorn.stokke@phys.ntnu.no

**Sven Tågerud**

School of Pure and  
 Applied Natural Sciences  
 University of Kalmar  
 Sweden  
 sven.tagerud@hik.se

**Reiko Takemura**

Okinaka Memorial Institute for  
 Medical Research  
 Japan

**S. Tolić-Nørrelykke**

Max Planck Institute for the Physics  
 of Complex Systems  
 Germany  
 tolic@nbi.dk

**Viola Vogel**

Department of Materials  
 Swiss Federal Institute of Technology  
 (ETH)  
 Switzerland  
 viola.vogel@mat.ethz.ch

**Y.M. Wang**

Department of Physics  
 Princeton University  
 USA  
 ymwang@wuphys.wustl.edu

**Ge Yang**

Departments of Cell Biology  
 The Scripps Research Institute  
 USA

**H. Yokota**

Department of Molecular Physiology  
The Tokyo Metropolitan Institute  
of Medical Science  
Japan  
[hiroaki\\_yokota@rinshoken.or.jp](mailto:hiroaki_yokota@rinshoken.or.jp)

**Bernard Yurke**

Bell Laboratories  
USA  
[yurke@lucent.com](mailto:yurke@lucent.com)