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Controlled Nanoscale Motion

Nobel Symposium 131

Springer

NOBEL SYMPOSIA

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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 experimental 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.

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