Contents

Preface IX

1	Fundamentals-Small-Scale Propulsion 1
1.1	Introduction 1
1.2	Nanomachines History 3
1.3	Challenges to Nanoscale Propulsion 4
1.4	Low Reynolds Number Hydrodynamics 7
	References 9
2	Motion of Natural Nanoswimmers 13
2.1	Introduction 13
2.2	Chemically Powered Motor Proteins 14
2.2.1	Biological Motors: Active Workhorses of Cells 15
2.2.2	Protein Motors: Basic Operation 16
2.2.3	Kinesins 17
2.2.3.1	Function and Structure 17
2.2.3.2	Kinesin Movement 18
2.2.4	Myosins 19
2.2.5	Dyneins 21
2.2.6	Biomotor-based Active Nanoscale Transport in Microchip
	Devices 21
2.3	Rotary Biomotors 24
2.4	Swimming Microorganisms 26
2.4.1	Bacterial Flagella - Escherichia coli 27
2.4.2	Sperm Motility 28
2.4.3	Cilia-Driven Swimming of Paramecium 29
2.4.4	Bacteria Transporters and Actuators 30
	References 31
3	Molecular Machines 35
3.1	Stimuli-Responsive Rotaxane, Pseudorotaxane, and Catenane
	Nanomachines 37
3.2	Molecular Rotary Motors 43
	•

-					
Co	m	te	n	ts	

3.3	Light-Driven Molecular Machines based on <i>cis-trans</i> Photoisomerization 44
221	Azobenzene-based Nanomachines 45
3.3.1	Nanocars 47
3.4	DNA Nanomachines 50
3.5	Autonomous Enzyme-Assisted DNA Nanomachines 53
3.5.1	DNA Spiders 54
3.5.2	pH and Light Switchable DNA Machines 55
3.5.3	References 57
	References 37
4	Self-Propelling Chemically Powered Devices 61
4.1	Self-Propelling Catalytic Nanowires 63
4.1.1	Propulsion Mechanism of Catalytic Nanowire Motors 67
4.1.2	Magnetically Directed Movement of Catalytic Nanowire Motors 68
4.2	Catalytic Tubular Microengines 69
4.2.1	Bubble-Propulsion Mechanism of Tubular Microengines 71
4.2.2	Preparation of Tubular Microengines 73
4.2.2.1	Rolled-up Fabrication of Tubular Microengines 73
4.2.2.2	Membrane-Template Electrodeposition of Tubular Microengines 75
4.3	Catalytic Janus Microparticles: Spherical Motors 76
4.3.1	Preparation of Catalytic Janus Particle Motors 77
4.3.1.1	Janus Capsule Motors 79
4.3.2	Propulsion Mechanisms of Catalytic Janus Spherical Motors 79
4.4	Controlled Motion of Chemically Powered Nano/Microscale
	Motors 81
4.4.1	Thermally Controlled Nanomotors 82
4.4.2	Light Control of Catalytic Motors 83
4.4.3	Potential Control of Catalytic Motors 84
4.5	Alternative Fuels for Chemically Powered Micro/Nanoscale Motors 84
4.6	Collective Behavior: Toward Swarming and Chemotaxis 86
4.6.1	Triggered Self-Organization of Microparticles 86
4.6.2	Chemotaxis: Movement along Concentration Gradients 89
4.7	Biocatalytic Propulsion 91
4.8	Motion Based on Asymmetric Release of Chemicals 93
4.9	Polymerization-Induced Motion 95
	References 95
5	Externally Powered Nanomotors – Fuel-Free Nanoswimmers 101
5.1	Magnetically Driven Nanomotors 101
5.1.1	Helical Propellers 102
5.1.2	Flexible Swimmers 106
5.1.3	Surface Walkers 107
5.1.4	Magnetically Actuated Artificial Cilia Array 109
5.2	Electrically Driven Nanomotors 110
5.2.1	Motion of Miniature Diodes 110

5.2.2	Micromotors Driven by Bipolar Electrochemistry	110
5 3	Illtragound Actuated Micromotore 112	

Light-Driven Micromotors 113 5.4

5.5 Hybrid Nanomotors 114 References 115

6

Applications of Nano/Microscale Motors 119

6,1 Cargo Towing: Toward Drug Delivery 119

6.1.1 Cargo-Loading Schemes 119

6.1.2 Cargo Release Strategies 122

Drug Delivery: Realizing the Fantastic Voyage Vision 124 6.1.3

6.2 Biosensing and Target Isolation 126

6.2.1 Biomotor-Driven Sensing: Toward "Smart Dust" Devices 126

Motion-based Signal Transduction 128 6.2.2

6.2.3 Isolation of Biological Targets: "Swim-Catch-Isolation" 130

Active Nanoscale Transport by Synthetic Motors in Microchip 6.3 Devices 134

Nanomotor-based Surface Patterning and Self-Assembly 135 6.4

Use of Micro/Nanoscale Motors for Environmental Monitoring and 6.5 Remediation 137 References 138

Conclusions and Future Prospects 141

7.1 Current Status and Future Opportunities 141

7.1.1 Future Micro/Nanoscale Machines in Medicine 143

7.2 Future Challenges 144

Concluding Remarks 146 7.3 References 147

> Glossary 149 Index 155