

E. coli in Motion

The bacterium *Escherichia coli*—*E. coli* for short—has long been the organism of choice for unraveling biochemical pathways, deciphering the genetic code, learning how DNA is replicated and read, and even for manufacturing proteins of commercial interest. For some thirty years, it also has been a model for studying the molecular biology of behavior: *E. coli* swims in a purposeful manner, propelled by long, thin helical filaments, each driven at its base by a reversible rotary engine. As a microscopic organism immersed in an aqueous environment, it has mastered physical constraints utterly different from any that we know, devising sensors, comparators, and motors on the nanometer scale.

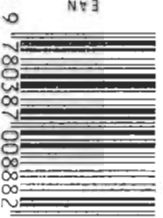
This cross-disciplinary monograph describes these feats in a manner accessible to scientists, engineers, and others not trained in microbiology who would like to learn more about living machines. It treats the history of the subject, the physiology, physics, biochemistry, and genetics, largely from first principles. It is all about a small but remarkably sophisticated friend who lives in your gut.

Topics discussed include:

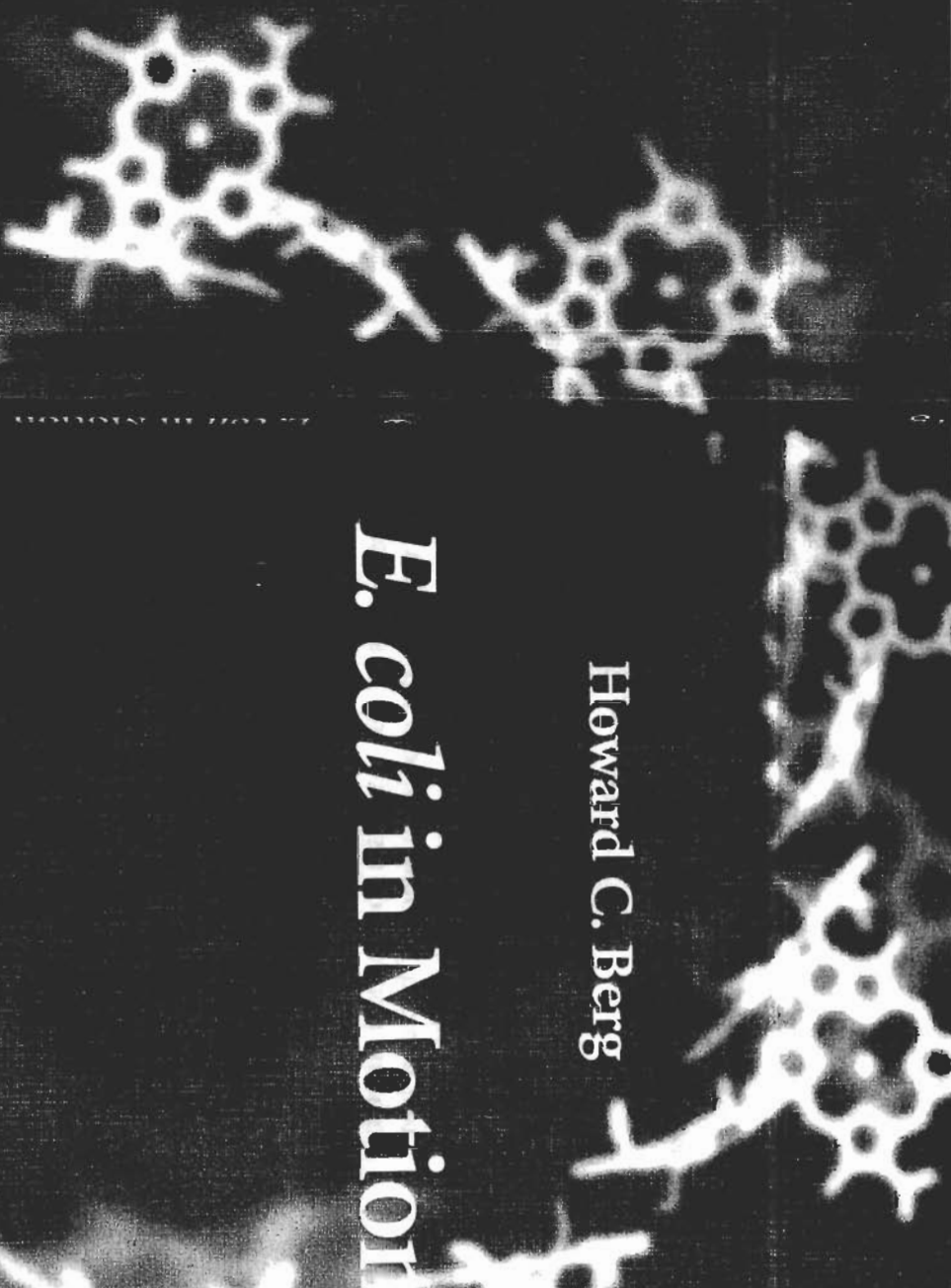
- How does *E. coli* move about?
- How do cells decide whether life is getting better or worse?
- What is the machinery that makes this behavior possible?
- How is the construction of this machinery programmed?
- How does this machinery work?
- What remains to be discovered?

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Preface

Most bacteria are small, about one micrometer in diameter: ten thousand cells laid out side by side span the width of one's finger. Nevertheless, many species are motile. They swim using propellers (called flagella) that extend out into the external medium or, in the case of spirochetes, that rotate within the cell envelope. One marine bacterium appears to use submicroscopic external oars. Other common bacteria, equipped with large numbers of flagella, swarm rapidly over surfaces. Some bacteria glide over surfaces by extending and retracting thin filaments (called pili) that stick to the substratum at their distal ends, a kind of fly casting. Others move particles linked to the substratum along their outer membranes, by a mechanism as yet unknown. Bacteria of all kinds respond to changes in their environment, for example, to changes in temperature, light intensity, or chemical composition. In short, they move in a purposeful manner.

I have been interested in this world for more than 30 years. When I began, more was known about the genetics and biochemistry of the bacterium *Escherichia coli* than of any other free-living thing. So that has been the organism of choice. The emphasis has been on the responses of this organism to chemical stimuli: chemotaxis. Early work on the motile behavior of bacteria had been done with larger species, more easily seen in the light microscope, so these also are of interest.

How, exactly, does *E. coli* behave? What is the machinery that makes this behavior possible? How is the construction of this machinery programmed? How does this machinery work? And finally, what remains to be discovered?

Since *E. coli* is microscopic and lives in an aqueous environment, the physical constraints that it has had to master are very different from those that we encounter. For example, *E. coli* knows nothing about inertia, only about viscous drag: it cannot coast. It knows nothing about transport by bulk flow, only about diffusion;

as we will see, it can go where the grass is greener, but it has to wait for its dinner. So the methods that its cells use to move and sample their environment are strange to us. This is part of *E. coli*'s charm.

This book is designed for the scientist or engineer, not trained in microbiology, who would like to learn more about living machines. However, it also should be accessible to the educated layman and of interest to the expert. I try to build on first principles. However, if you are overwhelmed by the facts that appear in a given chapter, please read on: the figures might suffice. References are given as entrée to the literature and a tribute to those who have done the work.

My own research has been supported by the Research Corporation, the U.S. National Science Foundation, the U.S. National Institutes of Health, and the Rowland Institute for Science. Much of the writing was done while a Fellow of the John Simon Guggenheim Foundation. Space for thought was provided by the Lorentz Institute, Leiden.

A large number of capable people have contributed to the body of knowledge to be described here: molecular geneticists, biochemists, microbial physiologists, physicists. Some, no doubt, will disagree with my emphasis. I can claim only a small part of this work as my own, built on the labor of students, postdocs, and other colleagues. The real hero is *E. coli*. If nothing else, I hope that this book will convince you that *E. coli* demands our admiration and respect.

Cambridge, Massachusetts
August 2003

HOWARD C. BERG

Contents

Chapter 1. Why <i>E. coli</i>?	1
Heritage	1
Size and Shape	1
Habitat	2
Pathogenicity	2
Preeminence	3
Motile Behavior	3
Simplicity	4
Genes and Behavior	6
Chapter 2. Larger Organisms	7
Seventeenth Century	7
Nineteenth Century	9
The Golden Age of Microbiology	11
Early Twentieth Century	14
Late Twentieth Century	16
Chapter 3. Cell Populations	19
Chemotactic Rings	19
Capillary Assay	23
Chemicals Sensed	24
Other Stimuli	26
More Exotic Patterns	26
Chapter 4. Individual Cells	31
Tracking Bacteria	31
Response to Spatial Gradients	35
Response to Temporal Gradients	36

Chapter 5. Flagellar Motion	39	Chapter 11. Gain Paradox	97
Rotation	39	Receptor Sensitivity	97
Filament Shape	41	Receptor Clustering	98
Tumbling	42	Motor Response	100
Chapter 6. Physical Constraints	49	Precise Adaptation	101
Viscosity	50	A Modelers' Era	102
Reynolds Number	51	Chapter 12. Rotary Motor	105
Diffusion	53	Power Source	105
Diffusion of Attractants or Repellents	56	Torque-Generating Units	107
Recapitulation	59	Stepping	107
Chapter 7. Optimal Control	61	Torque-Speed Dependence	109
Time Resolution	61	Angular Dependence of Torque	113
Impulse Responses	62	Duty Ratio	114
Simulation of the Biased Random Walk	65	Switching	115
Intracellular Signaling	66	Models	115
Chapter 8. Cellular Hardware	69	Reviews	118
Body Plan	69	Chapter 13. Epilogue	121
Why Cells?	71	What We Have Learned	121
More on Proteins	72	Levels of Amazement	121
Growth	72	Where We Go from Here	122
External Organelles	74	Motivations	123
Chapter 9. Behavioral Hardware	77	Appendix. Parts Lists	125
Components	77	Index	131
Signaling Pathway	78		
Receptor Complex	79		
CheY	84		
Flagellar Motor	85		
Flagellar Filament	87		
Chapter 10. Gene Regulation	91		
Genetic Map	91		
Flagellar Assembly	93		