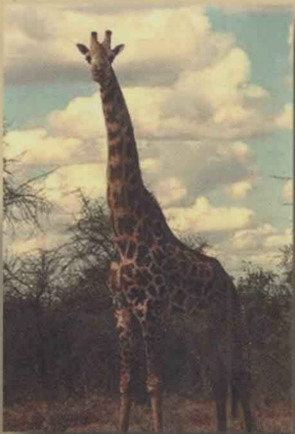
Polymers, Interfaces, and Biomaterials

BIOLOGY *in* PHYSICS

Is Life Matter?



Konstantin Bogdanov

Foreword by **Vitaliy L. Ginzburg**

Biology in Physics

Is Life Matter?

Konstantin Bogdanov
Institute of Developmental Biology
Russian Academy of Sciences
Moscow, Russia

ACADEMIC PRESS
A Harcourt Science and Technology Company
San Diego San Francisco New York Boston
London Sydney Tokyo

This book is printed on acid-free paper. ∞

ACADEMIC PRESS
A Harcourt Science and Technology Company
525 B Street, Suite 1900, San Diego, CA 92101-4495, USA
http://www.apnet.com

Academic Press
24-28 Oval Road, London NW1 7DX, UK
http://www.hbuk.co.uk/ap/

Library of Congress Catalog Card Number: 99-65060
International Standard Book Number: 0-12-109840-0

Printed in the United States of America
99 00 01 02 03 EB 9 8 7 6 5 4 3 2 1

Biology in Physics

Is Life Matter?

Series in *Polymers, Interfaces, and Biomaterials*

Other books in the series:

Alexander Grosberg, *Theoretical and Mathematical Models in Polymer Research: Modern Methods in Polymer Research and Technology* (1998).

Kaoru Tsujii, *Chemistry and Physics of Surfactants: Principles, Phenomena, and Applications* (1998).

Teruo Okano, Editor, *Biorelated Polymers and Gels: Controlled Release and Applications in Biomedical Engineering* (1998).

Also Available:

Alexander Grosberg and Alexei R. Khokhlov, *Giant Molecules: Here, There, and Everywhere* (1997).

Jacob Israelachvili, *Intermoleculer and Surface Forces, Second Edition* (1992).

To my parents

Foreword

"The whole of science is nothing more than a refinement of everyday thinking," A. Einstein. However, along with the development of human society, both the weight and the role of different sciences have varied. In the seventeenth and eighteenth centuries mechanics was focused upon, including heavenly mechanics, but in the nineteenth century it is already difficult to establish whether it was physics (and mechanics) that played the leading part, or whether it was chemistry or biology. But from the end of the nineteenth century and until the middle of the twentieth century, physics domineered; it was the top priority for all scientists. In 1897 the electron was discovered; soon after; radioactivity and x-rays; in 1900 the quantum theory appeared, and the whole physical outlook of the world changed. The development of physics reached its climax point, first with the special and general relativity theories (1905 and 1915), and then with quantum mechanics (in the 1920s). It was then that the atom and atom nuclei structure were clarified, and as a result, modern natural sciences, including chemistry and biology, started their independent development. Unfortunately, nothing but physics was the crucial factor for both the A-bomb and the H-bomb creation. The era of physics was over in the 1950s — exactly at that period of time biology suddenly rushed forward, when DNA structure and the nature of genetic code were described (1953). Thus, the development of molecular biology was triggered.

Now that we are entering the twenty-first century, it is undoubtedly biology that plays the leading role, as far as the interest of the human society and the development of its potential are concerned. Illustrating this idea very well is one of the most famous international scientific journals, *Nature*: its basic weekly issue covers all sciences, biology among them. As for its six monthly satellites, all of them contain articles only on biology or areas related to biology: *Nature: Genetics*, *Nature: Structural Biology*, *Nature: Medicine*, *Nature: Biotechnology*, *Nature: Neuroscience*, *Nature: Cell Biology*.

Of course, the current progress in biology would be impossible without modern physical devices and methods. In this respect, particularly in technology and computer science, physics has not shifted to the background. On the other hand, biology provides new food to physics, particularly when it offers examples of information control and transfer. Examples of this kind show how biology is valid for physicists, and how physics is important for biologists. This book by Konstantin Bogdanov spans the two sciences, and should be equally interesting for both physicists and biologists.

In conclusion, I would like to touch upon a problem of primary importance, that of reduction: Is it possible to explain biology through physics? Since we know the laws of the electron and atom nuclei interaction that form the matter of living organisms, we should be able to explain all the living organisms' processes from the point of view of physics. A lot has been achieved by scientists working in this direction, and yet there is one thing that remains unclear: the origin of life, the step between life and nonlife. Perhaps the molecular approach will help to clarify the transformation from complex molecules to simplest organisms that can self-regenerate. But can physics explain the emergence of conscience? I personally don't understand it at all. Those who believe in God solve this problem very easily: nonliving matter becomes live when God "inhales" life into it; and it is also God who supplies a human being with a conscience. Unfortunately, this explanation does not convince atheists, me among them; it only substitutes one unknown for another, and is definitely beyond the scientific approach and scientific outlook. Nevertheless, if we remain within this approach, we cannot consider the reduction of biology to modern physics fully proven. What if there are other fields and particles that have not been yet discovered by physicists as well as processes valid for living organisms only, and not for nonliving ones? Of course, this assumption does not reject reductionism in principle, only the reductionism based on what modern physics knows at present. To be honest, I am saying it only to be careful. Most likely, at the fundamental level (fields and particles) no new discoveries in physics are necessary to explain what happens in biology. On the other hand, the physics of complex systems, to say nothing of living organisms, is still quite vague. To solve the problem of reductionism, that is, what connects basic biology with physics, is, to my mind, the central problem of twenty-first century science.

Of course, Konstantin Bogdanov's book is rather far from problems of this kind; yet it is indirectly connected with them and can facilitate the interaction of physicists and biologists, which will enable more rapid progress in biology.

The objective of the book is to make biology more attractive to physicists. Still it cannot be called popular, as the reader has to have a certain academic background in physics. Every chapter triggers further research and contains comprehensive reference to recent publications.

This is not a textbook; rather, it is a collection of separate stories about how physics can be used when biology is studied. The author does not try to categorize the results of biophysical research. This is why what you feel after you have read this book is similar to what you feel in an art gallery. It is quite likely that this method of research in biology can become more attractive, particularly for the physicists who find it difficult to approach complicated physiological processes.

This book is very useful for university students and physicists as well as for anyone who is still fascinated by the perplexing script according to which biological processes are carried out in both ourselves and nature around us.

Vitaliy L. Ginzburg
Member of Russian Academy of Sciences
Lebedev's Physical Institute
Moscow, Russia November, 1998

Acknowledgments

Production of this book would not have been possible without the help of many people. However, the first and most honorable position in this list of acknowledgments must be given to my first teacher in biophysics, Dr. Vladimir Golovchinsky, who introduced me to biophysics three decades ago when I was still an undergraduate at the University of Physics and Technics at Moscow. Special thanks to Dr. Yuliy Brook who gave me the idea to write the book many years ago, and Dr. Alexander Grosberg, who helped me choose the most appropriate style of presentation. I am particularly grateful to Dr. Alexei Chernoutsan who found and recovered the manuscript of my book considered as lost forever. It has been a pleasure working with Mrs. Maria Ovchinnikova, whose skillful work as an artist created a handsome volume from an author's dream. I gratefully acknowledge the various authors and publishers who gave their permission to reproduce several figures and tables. Many thanks to Dr. Zvi Ruder for help and support in preparation of the manuscript for publishing. Finally, I am sincerely grateful to academician Vitaliy Ginzburg for writing the foreword for my book.

I promised my wife, Nadejda Kosheleva, that I would not give her the stereotypical public thanks for her support, and I am not doing so! Also, I feel sorry that in the very beginning I forgot to thank Dr. Edward G. Lakatta who taught me to run wishbone, helping me to stay healthy and wealthy while writing this book.

Introduction

Life is much too important
a thing ever to talk seriously about it.
Oscar Wilde, *Vera, or The Nihilists*, 1883

We are entering the third millenium. Of course this statement is relative: we merely have to deal with decimal notation. If we were using a hexadecimal system to count how many years have passed since Jesus Christ was born, we would have another 2096 years to wait for the third millenium. However, is it the only convention produced by the human mind? The answer is no.

"Living" and "nonliving" nature is another example. Can we really distinguish between living and lifeless objects? Since conventions generate one another, for many years different people studied living and nonliving nature separately. Physicists, biologists, and chemists were looking for laws common for nonliving objects, and managed to accomplish a great deal. Meanwhile, biologists were producing piles of data concerning "live" nature that can hardly be systematized.

Biological laws are so numerous and complicated that physicists used to feel scared: What would happen to them if the law governing the motion of a stone thrown at a certain angle to the horizon depended on the shape and size of the stone? Or, can you imagine different laws for the motion of bodies thrown up and down? Yet, unfortunately, that is what is going on in biology. For example, however thoroughly we may have studied the law of the rat's heart systole, we find it next to impossible (or impossible) to apply it to a human heart. Likewise, it is necessary to use different equations to describe the process of contraction and relaxation of a muscle, whereas for a steel spring one is enough. Probably that is why the number of publications in biology is a dozen times greater than that in physics as you can see by looking through *Science*, *Nature*, or *Proceedings of the National Academy of Sciences*.

However not all the physicists have been scared off by the complexities of biology. Some, who call themselves "biophysicists," decided to help biologists and crossed the border between the alive and the lifeless. As they stepped over to the other side, the first thing they saw was that biologists speak a language they don't understand. The most interesting thing was that this language was familiar to physicists—a kind of broken English—but there were plenty of absolutely unintelligible terms (see the index at the end of the book). Like all aliens, biophysicists have rather mixed feelings as they invade the unknown country of biology. Though scientific curiosity incites them, they realize that it is impossible to learn much without good command of the language.

For a long time I had been among such aliens, until I compiled a phrase-book intended to help me communicate with biologists in their language. It is this phrase-guidebook that is offered here. The book is divided into a number of chapters concerning different, rather unrelated, fields of biology. In each chapter you can find the description of some physical law applied to the explanation of specific biological phenomena, which is done to remind you of the native language of physics that you spoke before crossing the boundary.

Every tourist usually tries to decide where to go. A big city or wilderness? Of course, in a city you find good service and a lot of sophisticated entertainment, but the impressions to share with friends will hardly come as a surprise to listeners. Besides, it is unlikely that urban tourists could make any real discoveries. Now, unexplored paths is an entirely different matter—they make you a pioneer. But how can you get there? And is it really worth the effort? It may very well turn out that you find nothing interesting as you reach the place.

Anticipating such questions, Table 0.1 lists large biological "cities" frequently visited by physicists who work in Mechanical and Electrical Engineering departments. The table was created as a result of the analysis of scientific articles found in the database MEDLINE (U.S. National Library of Medicine), published in 1997. Only the articles where the first author worked in Mechanical or Electrical Engineering departments are included. This table provides the answer to another question: In what area of biology can a physicist apply his or her knowledge and still remain a research team leader?

Table 0.1 Biological issues considered in papers performed in Electrical and Mechanical Engineering departments and published in 1997.

Issues considered	Number of papers published	% of total
Departments of Electrical Engineering, 1997		
Tomography, Magnetic Resonance Imaging—Methods-analysis	36	20
Electric stimulation—methods	28	15
Ultrasonography—methods-analysis	19	10
Cardiography—methods-analysis	19	10
Neural Networks Computer-diagnosis	17	9
Neurology—methods-analysis	17	9
Physiology of heart and circulation—models	13	7
Others	35	20
Department of Mechanical Engineering, 1997		
Mechanics of Bones, Joints, Limbs and Human Body, Prothesis	79	48
Mechanics of Blood Circulation	40	24
Cryosurgery & Cryopreservation	12	7
Minimally Invasive Surgical Procedures, Robotics	8	5
Others	25	15

If you really are fond of travelling and don't like conventions, welcome to a mysterious country — Biology.

Biology in Physics:

Is Life Matter?

Contents