Book Review

The Machinery of Life by David S. Goodsell

Springer-Verlag, New York, 1993. 140 pages. $29.00

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This book is billed as an introduction to biochemistry for the nonspecialist, but it is much more than that. In its slim 140 pages, counting the index, it contains a wealth of illumination about biochemistry and cell biology. The 93 illustrations, 16 in color, carry a large share of the information to an extent unusual even in these days of sophisticated scientific illustration. The relative sizes of molecules and functional supramolecular assemblies, and the high degree of crowding of cellular environments, are dramatically conveyed. The black-and-white drawings are distinctive and will undoubtedly become classics. They are models of economy, thought, and style. The jacket picture, of a jam-packed *E. coli* cell, is worth the price of the book by itself.

In his preface, David Goodsell says "I have written the text with the nonscientist reader in mind; I have drawn the illustrations at a level of scientific rigor to satisfy the biochemist. For the lay reader this book is an introduction to biochemistry. . .for the biochemist, it is my hope that this book will act as a touchstone to intuition." I think that nearly every biologist's intuition of what actually goes on in cells will be changed by these pictures.

Goodsell draws all illustrations at a few consistent sizes, to help us understand relative scales. Regions of cellular interiors are drawn at 1 million magnification, macromolecules at 10 million, and small molecules at 30 million. All representations are consistently space-filling. The color figures, in familiar computer graphic style, conform to the same scales as the distinctive black-and-white drawings. Cellular interiors are drawn, to the extent current knowledge allows, with "the proper number of molecules, in the proper place, and having the proper size and shape."

The book begins with a brief introduction to molecules, cells, and the representation of molecules by illustrations. It then describes the important "Molecular Machines"—nucleic acids, proteins, lipids, and polysaccharides—emphasizing their functions as well as structures. Hydrophobicity is introduced as a key structure-determining feature, and in molecular drawings consistent shading is used: black is strongly hydrophilic, white is hydrophobic, and gray is intermediate. The molecular aspects of crucial processes of life are described: making use of available energy, reproduction, protection, and perception. The ten main steps in glycolysis are illustrated in successive pages, with the enzyme at 10,000,000 × above and the chemical reaction at 30,000,000 × below. (Aldolase is the only one of these ten enzymes whose coordinates have not been deposited in the Brookhaven Protein Data Bank; its blank outline makes a ghostly contrast to the others.)

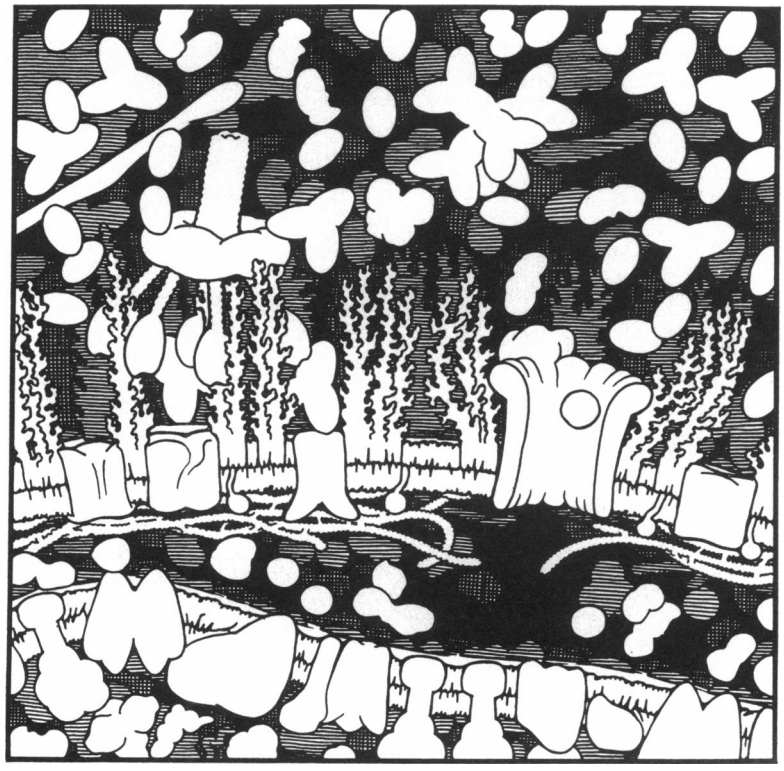

FIGURE 1 The immune system piercing a bacterial cell wall. (1,000,000 × magnification). Reprinted with permission of David Goodsell and Springer-Verlag.

Part II describes how molecules are organized in cells: first the fundamental features of cytoplasm, cell wall, and nuclear region in prokaryotic *E. coli*; then some of the compartments in eukaryotic yeast—cytoplasm, mitochondria, nucleus—and transport of proteins from endoplasmic reticulum to Golgi apparatus to vacuoles. Greater specializations are described in man taken as a typical multicellular organism: cytoskeleton and cell filaments, intercellular junctions, blood, and nerves. This part ends with the specialized cell walls and photosynthetic apparatus of plants. Part III deals incisively with some health-related topics: vitamins, viruses, poisons, and drugs.

In addition to his artistic flair, Goodsell has a knack for the startling but instructive numerical comparison: "Typical cells in our bodies are about ten micrometers in length—roughly one thousand times smaller than the last joint in your finger. . . .[A] grain of rice is about one thousand times smaller in length than the room you are sitting in. Imagine your room filled with rice grains, and this will give you an idea of the billion or so cells that make up your fingertip." The book promotes a sort of cellular numeracy. One illustration shows the cross-section of a volume in an *E. coli* cell, 100 nm on a side. We are told that it "contains roughly 450 proteins, 30 ribosomes, 340 tRNA molecules, and several long mRNA molecules. Between these large molecular machines, thousands of small molecules circulate: 30,000 small organic molecules. . .and 50,000 ions. The space that remains, about 70% of the volume, is filled with water."

I am not sure how this book will work as a guide to biochemistry for the nonspecialist. It would be effective as a text for a beginning molecular/cellular biology course for nonmajors, if it were supplemented with more details by the lecturer. The text, while gracefully written and accurate within the limits of an admirable avoidance of jargon, may not be sufficiently vivid for a general audience, and the elegance of the illustrations may need some sophistication to be fully appreciated.

However, I think that the book should have wide success and influence among biologists as an aid to imagining "biological molecules in their proper context: packed into living cells." The elegantly simple style of illustration developed by Goodsell may have the same impact on the way we visualize molecular structures and processes in cells as the three-dimensional paintings of Irving Geis and the ribbon diagrams of Jane Richardson have had on the way we think about macromolecules.