BIONANOTECHNOLOGY: Lessons from Nature, David S. Goodsell, Wiley-Liss, Inc., Hoboken, New Jersey, USA, 2004, 337 pages, ISBN 0-471-41719-X

The subject of this book is a different approach to nanotechnology, which is available today to any researcher with a moderately equipped laboratory – it is bionanotechnology, nanotechnology that looks at Nature for its start. In Chapter 1, bionanotechnology is defined as a subdivision of nanotechnology: atom-level engineering and manufacturing using biological precedents for guidance. It is also closely related to biotechnology, but additionally offers the ability to design and modify the atom-level details of the objects created. Bionanomachines are designed according to atomic specifications, they perform a well-defined three-dimensional molecular task, and, in the best applications, mechanisms for individual control are embedded in their structure.

Chapter 2 explores the bionanomachines made by living cells. Bionanomachines have been developed by the process of evolution and are selected to perform their tasks in a very specific environment and are subject to the unfamiliar forces imposed by this environment. At their small scale, bionanomachines are almost immune to the laws of gravity and inertia which are negligible at the nanoscale, the world of bionanotechnology being an unfamiliar and shifting world, which plays by different rules. In general, biomolecules may be thought of as articulated chains of atoms that interact in a few well-defined ways. Bionanomachines operate in a chaotic environment, being bombarded continually by water molecules. They will scatter randomly if not firmly held in place. Bionanomachines operate by forming interactions with other bionanomachines, fitting together and breaking apart in the course of action. If two molecules fit closely together and have the appropriate matching of chemical groups, they will interact over long periods of time. If the interactions are weaker, they will form only temporary interaction before moving on to the next. The form and function of biomolecules are dominated by two things; the chemistry of their component atoms and unusual properties of the water surrounding them. The energetics of this interaction is quite different from anything we experience in our macroscopic world. In this context, the biological molecules (proteins, nucleic acids, lipids and polysaccharides) as a structural ensemble are discussed. At the same time, some examples of natural bionanomachinery are evidenced.

Chapter 3 presents an overview of the many techniques that are available for the design, synthesis and analysis of biomolecules. The first example refers to the recombinant DNA technology, which is the core capability of bionananotechnology. This technology allows us to construct any protein that we wish, simply by changing the genetic plans that are used to build it. Thus it is possible to modify and/or to create new proteins with specific functions (e.g. monoclonal antibodies). The understanding of the mechanics of the biomolecular function and the ability to engineer them for new functions are possible by applications of techniques, such as X-ray diffraction, NMR spectroscopy and electron microscopy. On the other hand, along with experiments, molecular modeling can be used to study biomolecules and to predict biomolecular structure and functions.

The structural principles of bionanotechnology are presented in Chapter 4. The first goal in nanotechnology is to build a stable nanostructure. To achieve this basic goal, we need to understand the forces that link atoms together inside a nanostructure. The ways used by bionanomachines are based on their optimal function and stability, when they are surrounded by water at temperatures of about 37 °C. Natural bionanomachines are also constructed to be stable over a typical biological time scale. There are four strategies for the construction of a nanostructure: sequential covalent synthesis, covalent polymerization, self-organizing synthesis and self-assembly. These aspects are discussed in the case of proteins. Self-assembly is used throughout biology. It is made necessary by the bottom-up assembly technique used in living cells. They specify the building of three-dimensional bionanomachines with only the one-dimensional information held in DNA. Self-assembly requires specific geometry of interaction and unique interaction between subunits and it is spontaneous. On the other hand, natural bionanomachines are designed for optimal function under crowded conditions. In some cases, a less concrete building material is needed. Self-organization is a perfect method for creating structures that are flexible, resilient and self-repairing. In natural systems, self-organization is used primarily to create lipid membranes and in current bionanotechnology, a number of self-organized forms of lipids and lipid-like molecules are being explored to create novel infrastructure and to create delivery vehicles for nanomedicine. Natural bionanomachines combine a stable, global structure of arbitrary precision and a few local regions specified to high precision. At the same time, flexibility at all levels is used to enhance the function of bionanomachines. This includes harnessing of thermal motion for chemical catalysis, the use of induced fit for recognition, the design of different conformational states for use in regulation, and the incorporation of selective flexibility to link several separate functionalities. Biomolecular flexibility will provide one of the greatest challenges and potential benefits of bionanotechnology.

Functional principles of bionanotechnology are developed in Chapter 5. The natural tools available in living cells – ribosomes, enzymes, DNA – are involved in building nanomachines. Within cells, there are working assemblers, sensors, motors, factories, rigid and elastic materials, adhesives and the list goes on. All biological processes are based on the information stored in DNA. The information stored in DNA is not used directly by ribosomes to build proteins. Instead, an intermediary molecule is used. For use, the information is copied, or transcripted, into a strand of RNA. This RNA strand is then used directly by the ribosome to direct the construction of proteins. The flow of information from DNA to RNA to protein demonstrates that information may be densely stored at the nanoscale. But, many desirably nanoscale processes do not occur spontaneously. In these cases, energy is added to force the process to occur in the wanted way. There are involved three sources of energy – chemical, light and electrical energies – to drive difficult chemical reactions and to power directed motion. ATP (adenosine triphosphate) is the most common biological fuel molecule. Several methods are used to construct ATP with energy from the breakdown of food or capture of light. The cleavage of ATP is then used to power most unfavorable biomolecular processes. The light capturing event is performed by a class of proteins termed photosynthetic reaction centers. These proteins capture a photon of light and use it to create a high-energy electron, which is then used for power. Biological systems move electrons one at a time from one carrier to the next in well-defined bionanocircuits. The process is termed charge transfer. The transfer of single electrons along complex paths is widespread in biological systems. Thus, the cells create specific molecules by an ordered set of small chemical transformations using bionanomachines – enzymes – that perform each step efficiently and accurately. Enzymes are a priceless gift from nature, providing the starting point for all of bionanotechnology. Based on the activity of enzymes, all components of the cell are synthesized. Further, the cells are assembled by filaments, fibrils, biominerals and bioadhesives to create strong, resilient composite materials. In biological systems, the power strokes are correlated with the binding of ATP and/or the release of ADP and phosphate. At the same time, cells have developed machines that capture thermal energy and use it to do work. Thus different kinds of motions at cell level are explained.

Another aspect refers to the containment in natural biological systems, assured by lipid membranes, which are flexible, self-healing and impermeable to the molecules that must be transported. This creates problems in transporting objects across the barrier. The cells build a wide variety of active and passive transport systems to traffic molecules across membranes. These are based on channels, selective channels, specific transporters, proton pumps and, in some cases, pumps powered by electron flow or light are included. In biological systems, sensing, performed by the receptor protein, is very important. Depending on the nature of the compounds and receptor, there are different ways to transmit the stimuli (chemicals or physical light, mechanical). All cells on Earth are built according to a similar molecular plan, using a similar mechanism to self-replicate. Self-replicating cells contain five basic functionalities: an information-driven assembler, an information storage medium, an information duplicator, a set of synthetic machinery for creating construction materials, and a general infrastructure. Thus bionanomachines are created at the nanoscale and then combined through random diffusion inside cells to perform the more orchestrated tasks of life.

Bionanotechnology is a reality today (Chapter 6). The first glimmerings of nanomedicine allow researchers to make tailored changes to the mechanisms of human body, correcting defects and curing disease. Familiar biomaterials, such as wood, bone and shells are providing the principles needed to create materials tailored at the nanoscale to fit our needs. Biological methods of nanoscale information storage and retrieval are being harnessed to solve computational problems and convict criminals. In this chapter, different examples are presented: synthesis of proteins, computer-aided drug design, immunotoxins, delivery of drugs with liposomes, artificial blood, gene therapy and transformation of general medicine into personalized medicine. Also, the following practical aspects are discussed: self-assembly at many scales, harnessing molecular motors, DNA computers, molecular design using biological selection, artificial life, hybrid materials and biosensors.

The future of bionanotechnology is analyzed in Chapter 7. Three case studies are presented. They refer to nanotube synthase, nanoscale assembler and nanosurveillance. The author underlines that the potential of bionanotechnology for feeding the world, for improving our health, for providing rapid and cheap manufacturing with environmental mindfulness, is immense. But we have to take into account two issues: respect for life and possible dangers.

To conclude, *Bionanotechnology: Lessons from Nature* shows both students and practitioners how the lessons that may be learned from biology can be applied to nanotechnology today.

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