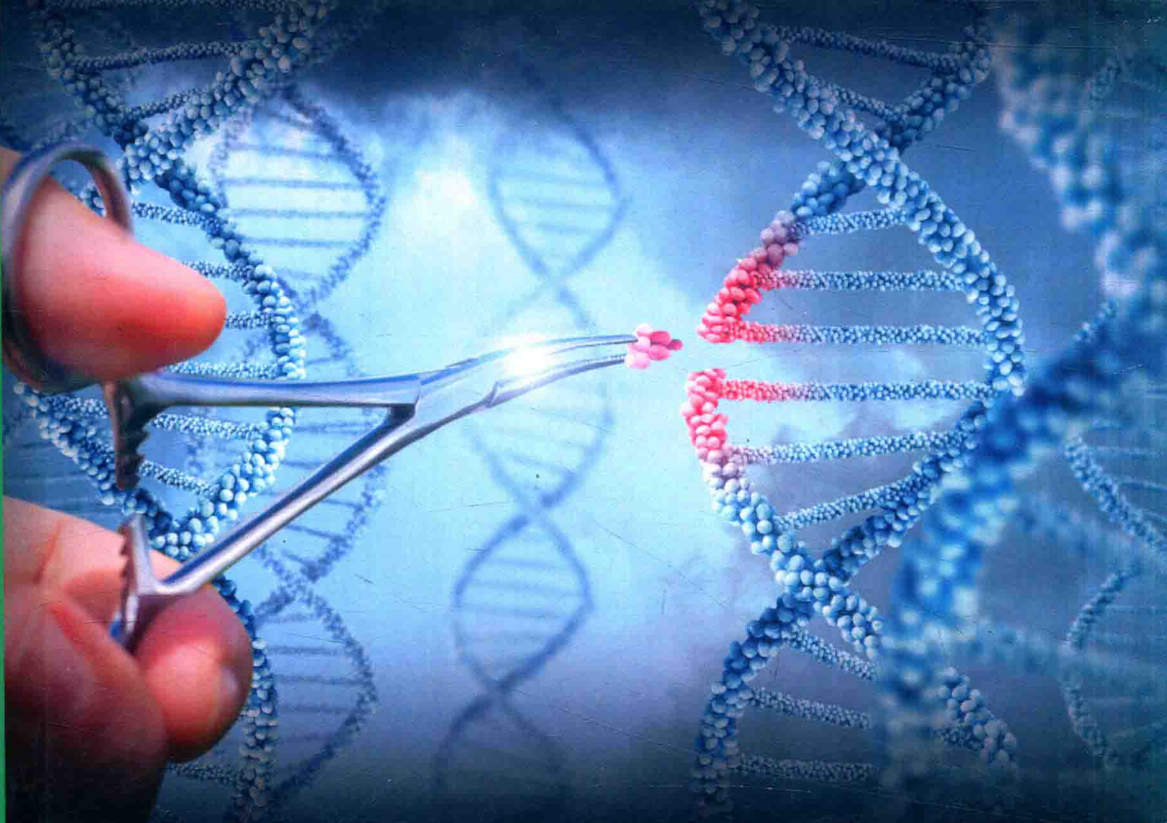

BIONANOTECHNOLOGY

PRINCIPLES AND APPLICATIONS

Anil Kumar Anal

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Bionanotechnology

Principles and Applications

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Bionanotechnology

Preface

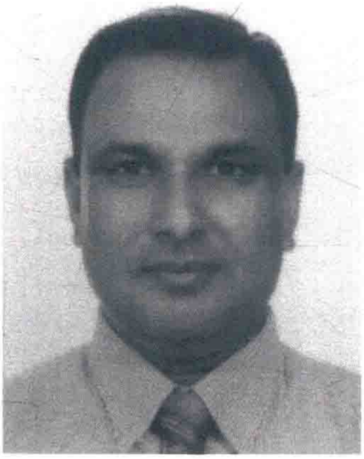
The book *Bionanotechnology: Principles and Applications* deals with a subject area, which is of high interest and importance in all sectors, including biomedical, food, agriculture, and environment. Bionanotechnology combines nanotechnology with biology. Nature has provided us with nanostructures that are extremely efficient and well designed. This book describes the science and technology of controlled building up of new architectures from individual biomolecules and biomacromolecules. Biological systems are essential in nanotechnology and mimicking the natural systems is developing many new applications. This book provides insights into the detail of cellular structures, nanoscale fabrication processes, and their practical applications. The basics of biology and chemistry, with a focus on how to engineer the behavior of molecules at the nanoscale, are also introduced and analyzed. This book is thus designed, so as to (1) focus on the broad accessibility, (2) build design problems of interest that cross the traditional boundaries, (3) accelerate assimilation of new knowledge-spanning multiple domains through individual and construct-centered design problems, and (4) effectively exchange knowledge of state-of-the-art developments and capabilities using collaborative learning projects.

The cells and their entire structures (e.g., cell membranes, lipids, proteins, and nucleic acids) are extremely good at self-assembling complex (e.g., synthesis of proteins and nucleic acids at cellular levels), multifunctional systems at the nanoscale level. By understanding how these systems work, nanotechnologies are developing new biosensing, biomedical, and tissue engineering applications. The use of biological macromolecules as sensors, biomaterials, information storage devices, biomolecular arrays, and molecular machines is significantly increasing. Currently, accumulated knowledge in this area is scattered in few journals and books. This book seeks to bring information of different fields including nanoscale biomaterials; cells; biological macromolecules such as polypeptides, proteins, nucleic acids, lipids, and glycans; interactions between biomaterials and functional bioengineered materials; bionanoencapsulation; controlled release of dosage forms;nanoscale proteomics, genomics, and nanotechnology in immunoisolation and tissue engineering; and so on under one umbrella.

It is essential to understand the fundamental aspects of nanotechnology. This book provides the broader knowledge, including an understanding of biological methods for signal transduction and molecular-recognition systems and how these can be mimicked in biosensing applications. This book attempts to harness various structures, interactions, and functions of biological macromolecules and integrate them with the value addition in multidimensional approaches, including basic structures and interactions of biomacromolecules in developing the biocompatible and ecofriendly devices to be applicable in medicine, agriculture, and food sectors. It encompasses structural biology, biomacromolecular engineering, material science, and extending the horizon of material science.

The aim of this book is to enhance the knowledge to the students, researchers, academicians, professionals, and other stakeholders in the interface between biology, chemistry, and physics; material science; and technology. This book introduces and conveys an understanding about the vast, exciting, and challenging field of bionanoscience, nanotechnology, and the nature behind the developments of these technologies. This book discusses several important and unaddressed aspects of cells, biomacromolecules, and their structures, and interactions and roles in developing the devices for applications, especially in medicine, agriculture, and food sectors. This book also discusses the uptake and health aspects of engineered nanoscale biomaterials and the nanodevices.

Author



Dr. Anil Kumar Anal is the head of the Department of Food Agriculture and Bioresources and an associate professor in Food Engineering and Bioprocess Technology at the Asian Institute of Technology (AIT), Khlong Nung, Thailand. His background expertise is in the food and nutrition security, food safety; food processing and preservation, valorization, as well as bioprocessing of herbs and natural resources, including traditional and fermented foods, microorganisms, agro-industrial waste to fork, and value addition including its application in various food, feed, neutraceuticals, cosmetics, and pharmaceutics. His research interests also include the formulation and delivery of cells and bioactive for human and veterinary applications; controlled release technologies; particulate systems; application of nanotechnology in food, agriculture, and pharmaceutics; and functional foods and food safety. Dr. Anil has authored 5 patents (U.S., World Patents, EU, Canadian, and Indian); more than 100 referred international journal articles; 20 book chapters; 3 edited books; and several international conference proceedings. He has been invited as keynote speaker and expert in various food, biotechnology, agro-industrial processing, veterinary, and life sciences-based conferences and workshops organized by national, regional, and international agencies. Dr. Anil has been serving as advisory member, associate editor, and members of editorial board of various regional and international peer-reviewed journal publications. Dr. Anil has experience of conducting various innovative research and product developments funded by various donor agencies, including the European Union, the FAO, the Ministry of Environment, Japan, and various food and biotech industries.

Contents

1

Bionanotechnology and Cellular Biomaterials

1.1 Bionanotechnology

Bionanotechnology is a combination of three terms: *bios* meaning *life*, *nano* (origin in Greek) meaning *dwarf*, and *technologia* (origin in Greek—comprises *techne* meaning *craft* and *logia* meaning *saying*), which is a broad term dealing with the use and knowledge of humanity's tools and crafts. *Biomolecular Nanotechnology* or *Bionanotechnology* is a term coined for the area of study in which nanotechnology has applications in the field of biology, chemistry, and medical sciences. One can also say that *bionanotechnology* is derived by the combination of two terms: (1) *nanotechnology* and (2) *biotechnology*. Bionanotechnology, thus as a subset of nanotechnology implies atomic-level engineering and as a subset of biotechnology and implies atomic-level modification adapting biological machines (Goodsell 2004). The terms *bionanotechnology* and *nanobiotechnology* refer to the intersection of biology and nanotechnology. However, bionanotechnology involves applications of biology to nanotechnology, that is, utilization of biological machines in nanomaterials or nanoscale; for instance; genetic engineering or cellular engineering. Conversely, nanobiotechnology refers to the applications of nanotechnology to study biological system such as nanosensor used for diagnostic purposes or nanoparticles for delivery of active biomolecules (Ramsden 2011).

The word *biotechnology* was first used in early nineteenth century by a Hungarian engineer, Karl Ereky, to refer utilization of the living cells to produce valuable metabolites. The term biotechnology is the combination of Greek words: *bios—life*; *techno—technical*; and *logos—study*. Biotechnology includes a biological process for novel product development and nanotechnology involves engineering and manufacturing at nanometer scales along with atomic precision. Biotechnology can also be termed as, "the application of scientific and engineering principles to the processing of materials by biological agents." Biotechnology is the integration of biochemistry, microbiology, and engineering disciplines to promote industrial applications of microorganisms, engineered cells, tissues, and so on (Amarakoon et al. 2017).

Biotechnology implies the controlled use of biological agents such as cells or cellular components for beneficial use. In general, biotechnology is defined as the utilization of cells, cellular organelles, and living organisms, to produce compounds of interest or the controlled genetic improvement for the benefit of man (Nair 2008).

Along with new discoveries in life-sciences principles and evolution in technologies, biotechnology has undergone various stages of development that can be categorized as ancient, classical, and modern biotechnology. Since ancient period, humans learnt to cultivate and propagated plants, domesticated and interbreed animals to improve their attributes, and got familiar with fermentation and brewing processes. People started using microorganisms to produce wine, beer, cheese, and bread. During the classical biotechnology era, from 1800 to middle of the twentieth century, scientific discoveries and evidence began to outpour. Discoveries made during classical period, form the base for the development of modern biotechnology period. In 1953, Watson and Crick's *Double Helix model of DNA* helped to explain deoxyribonucleic acid (DNA) replication and its role in inheritance. In 1975, Kohler and Milstein postulated the concept of cytoplasmic hybridization and produced the first monoclonal antibodies. Irish scientist Ian Wilmut was successful to clone an adult sheep and developed the first ever cloned animal name *Dolly*. Similarly, there was possibility to sequence the human genome in 2000 AD (Verma et al. 2011). Ancient biotechnology and classical biotechnology also known as first- and second-generation biotechnology were based on technological applications, whereas modern biotechnology, the third generation of biotechnology, is based on the underlying scientific progress (Amarakoon et al. 2017).

Unlike a single discipline, biotechnology is highly multidisciplinary and interdisciplinary related to different scientific disciplines such as pharmaceuticals, immunology, microbiology, genetics, food science and technology, and different aspects of engineering such as mechanical, electronic, food, chemical, and biochemical engineering. Biotechnology has wide applications in the fields of agriculture, livestock, medicine, food, pharmaceutical, aquatic in development of vaccines, drugs, transgenic plants, animals, fish, and so on, and other valuable products and for improving the environment (Bhatia 2005).

Nanotechnology or technology at nanoscale, that is, in the range of 1–100 nm, implies *engineering with atomic precision*. The term *nanotechnology* has been defined in numerous ways, focusing on its design and functionalities. Nanotechnology is the study of material with the size of matter maintained at the nanometer scale to develop innovative devices with distinct properties and various functions. Nanotechnology has also been defined as "the design, synthesis, characterization, and application of materials, devices, and systems that have a functional organization in at least one dimension on the nanometer scale." Figure 1.1 illustrates some of the examples of nanosized biological materials. The benefits associated with nanotechnology

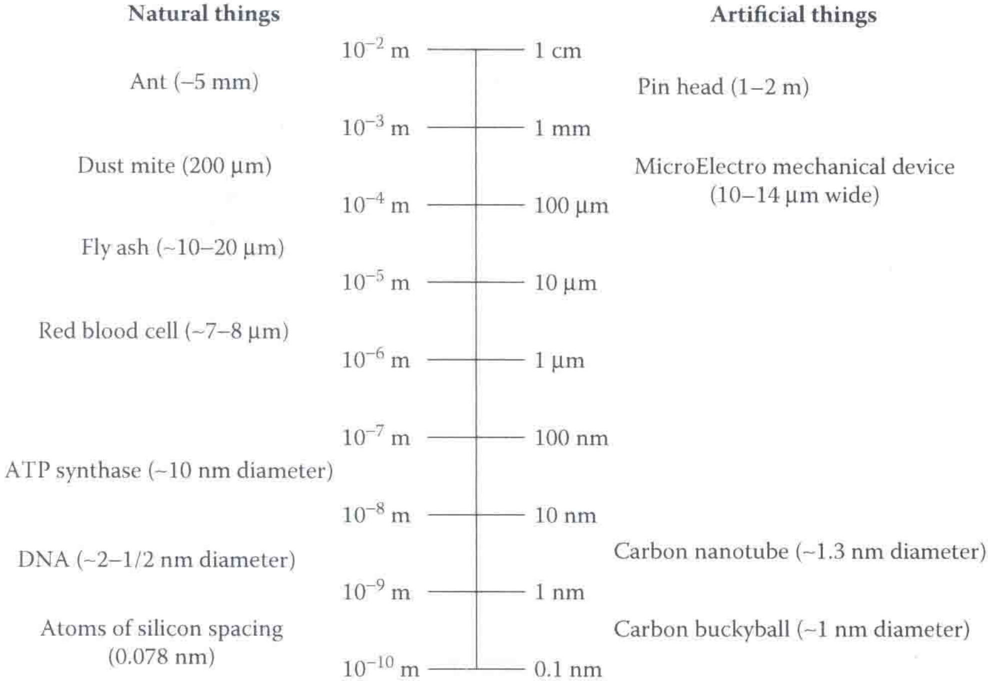


FIGURE 1.1
Examples of size range of natural and artificial things. (From Picraux, S.T., Nanotechnology, Encyclopaedia Britannica. https://www.britannica.com/technology/nanotechnology, accessed June 30, 2017.)

include formulation of novel product, reduction of energy consumption, and improvement of the functionality (Ramsden 2011).

Nanotechnology has the potential for applications in different sectors such as agriculture, medicine, genetics, food, cosmetics, electronics, and so on. It provides novel techniques, which enhance organoleptic qualities of food, development of new devices as biosensor, packaging materials, and formulation of new encapsulation system for delivery of bioactive compounds (Augustin and Oliver 2012). Various chemicals in the form of nanocapsules, nanocomposites, nanomatrix, and nanoclays are expected to influence the sustainable agriculture development leading to the improvement of the crop yield, reduce chemicals use, and minimize nutrient, water, and soil loss (Iavicoli et al. 2017). Bioactive food ingredients such as essential fatty acids, amino acids, antioxidants, vitamins, and minerals with high biological and functional activities are essential but difficult to be supplied to the body. The problem of poor stability and bioavailability associated with these bioactive food ingredients can be solved by the application of nanotechnology (Jana et al. 2017). Similarly, drugs loaded in nanoparticles have the benefits of delivery and release at the target site, maximum drug action, and minimum side effects, which indicate the role of nanotechnology in pharmaceutical industries (Anal and Stevens 2005; Anal et al. 2006).

Various polymer-based nanoparticles and their conjugates such as carbohydrates, proteins, lipids, and nutraceuticals can be utilized as carrier in nanotechnology (Kumar and Smita 2017). Use of antimicrobial components in nanoform along with nanosensor and nanomaterial-based assays in food systems shows the possibilities of future applications of nanotechnology in microbial food safety (Ranadheera et al. 2017).

1.2 Cellular Structures in Bionanotechnology

Cell is the structural unit of all living organisms. The term cell (*Greek, kytos, cell; Latin, cella, hollow space*) was coined in 1665 AD by Robert Hooke, first person to observe the cells in a cork under the primitive microscope. Two German scientists, Schleiden and Schwann, later in 1839 AD outlined the basic features of the cell theory, which describes cell as the basic unit of life. Cell theory has two main components, that is, living things are composed of cells and all cells arise from preexisting cells. Cells vary greatly with respect to shape, for instance, amoebae are irregular in shape, whereas bacteria may exist in rod, spiral, or comma shape; in multicellular organisms, cell shape varies with functions as shown in Figure 1.2. Cell size differs with species; smallest cell (0.2–0.5 μm) found as virus, whereas the largest cell is ostrich egg (6 in. with

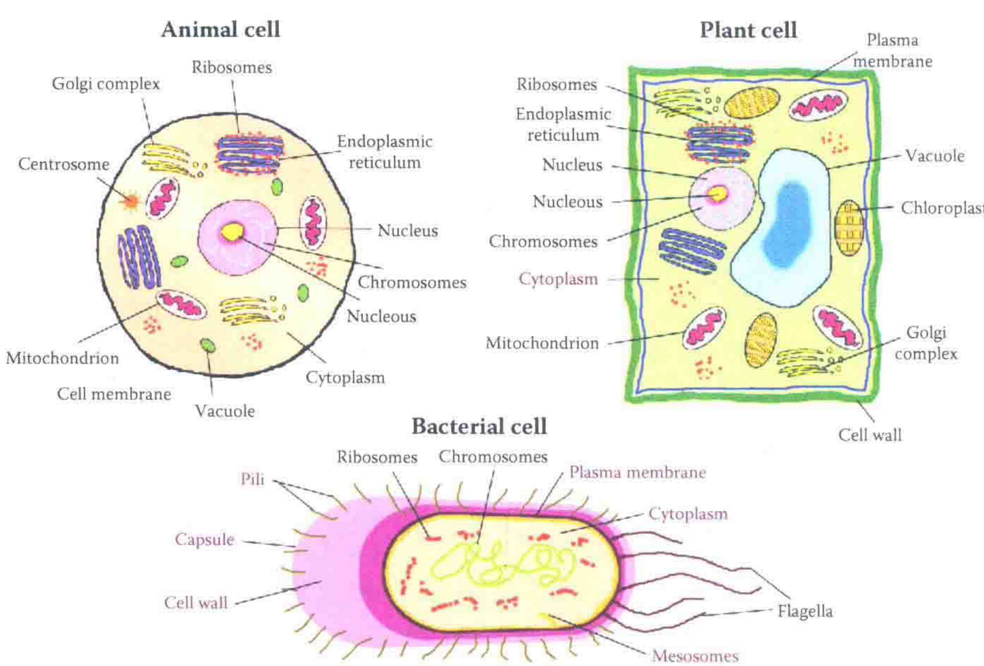


FIGURE 1.2
Structure of bacteria, plant, and animal cells. (From Rogers and Kadner 2017.)

shell and 3 in. without shell). Cell number varies from single cell in unicellular organism to 60,000 billion cells in adult human (Gupta 2008).

Despite differences in external appearance, all living organisms are similar at molecular level, for example, all living organisms store genetic information in nucleic acid, transfer genetic information from DNA and ribonucleic acid (RNA) protein, utilize protein as catalyst, derive energy from adenosine triphosphate (ATP), and possess cell organelles for different functionalities. Living organisms are divided into three divisions: (1) *Bacteria,* (2) *Archaea,* and (3) *Eukarya.*

Bacteria are prokaryotic in nature as they lack membrane bound nucleus, which make them different from eukaryotic plant and animal cells with membrane-bound organelles and genetic materials enclosed by the nuclear membrane. Bacterial cells size vary with species, mostly in the range of 0.5–1 μm in diameter or width; for example, cylindrical typhoid bacteria size ranges from 0.75 to 1.25 μm in width and 2–3 μm in length, or some may be 0.5–2 μm in diameter and more than 100 μm in length. Cell shape of bacteria may be spherical in *cocci,* cylindrical in *bacilli,* or spiral in *spirilla.* Bacterial cells may exist alone or attached to each other in a characteristic arrangement. Bacterial cell size, shape, and arrangement together form the morphology of the cell. Bacteria have external structures such as flagella, which helps to propel them and pili that help bacteria to attach to cell lining the respiratory, intestinal, and genitourinary tracts and also in exchange of genetic materials. Some bacterial cells are surrounded by glycocalyx, which is viscous in nature and helps in capsule formation. On the basis of bacterial cell wall, they are further classified as gram-positive and gram-negative bacteria. Gram-positive bacteria have thicker cell wall (20–25 nm) with large amount of peptidoglycan and teichoic acid as compared to gram-negative bacteria (10–15 nm). Below the cell wall, there is cytoplasmic membrane, which extends in cytoplasm forming tubular structure known as mesosomes that plays role in DNA replication and cell metabolism. However, bacterial cells lack membrane-bound organelles such as mitochondria and chloroplast that are present in eukaryotic cells. Bacterial genetic material, called nucleoid, consisting of a single, circular chromosome is located near center of cells without distinct nuclear membrane but seems to be attached to mesosomes (Pelczar et al. 1986). The structural difference of bacterial cell in comparison to plant and animal cell is illustrated in Figure 1.2.

Animal cells are structurally small with the size in the range of 10–20 μm diameters. They are usually composed of inner cytoplasm and outer double lipid bilayer plasma membrane. Organic and inorganic ions, macromolecules, and cell organelles remain suspended in the cytoplasm, whereas the plasma membrane bounds the cells and internal membrane system divides the cells into compartments. Internal membrane system is formed and supported by filaments and microtubules arranged in network. Cytoskeleton, a microtubule made of protein molecules, functions to support the cell shape and assists in the motility of the cell. The basic form of animal cell constitutes of the cell organelles such as cell membrane, cytoplasm, mitochondria,