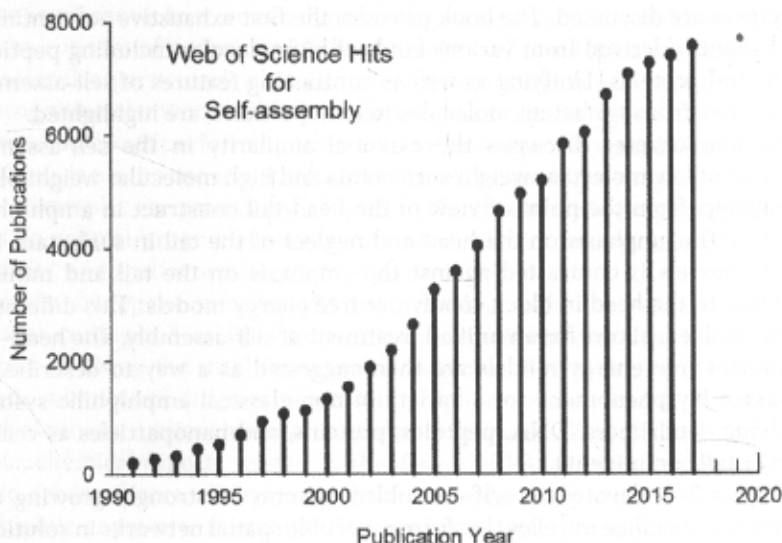


## Preface

Self-assembly was first recognized by James McBain in classical colloid science almost 100 years ago, with the discovery of spontaneous formation of multimolecular aggregates of soap molecules. For almost 80 years after the initial discovery, self-assembly studies were dominated by classical soap and surfactant molecules, and for the latter part of this period, studies on high-molecular-weight block copolymer systems were also prevalent. However, the term “self-assembly” did not appear in the literature until 1966, as revealed by a Web of Science search. In the following decade, the term began to appear in publications, but less than 10 times each year, and only to describe the self-assembly of protein or viral subunits. To the best of my knowledge, the first use of the term to describe amphiphilic systems was in the classic paper of Israelachvili, Mitchell, and Ninham “Theory of self-assembly of hydrocarbon amphiphiles into micelles and bilayers.” Since then, there has been an explosion of studies in the literature, invoking the terminology of self-assembly.



Over the last 20 years, the study of self-assembly has emerged as a distinct field, encompassing much larger and more complex molecular and nanoparticle systems. The study of self-assembly has extended far beyond surfactants and block copolymers and has been applied to peptide amphiphiles, DNA amphiphiles, protein-polymer conjugates, and nanoparticles. Self-assembly of molecules to create nanoparticles, self-assembly of nanoparticles to create new materials or devices, self-assembly in biological cell and its components contributing to essential life functions, self-assembly of proteins leading to neurodegenerative diseases, self-assembly of molecules/particles for nanomedicine applications of drug delivery, imaging, molecular diagnostics and theranostics, and self-assembly as the processing method to design materials to specification such as smart responsive materials and self-healing materials, have all made self-assembly a topic of great importance and have assured its continuing growth.

This book provides an effective entry for new researchers into this exciting field while also assessing state-of-the-art understanding of these diverse self-assembling systems. The book introduces the fundamentals and applications of self-assembled systems to academic and industrial scientists and engineers. Within its 10 chapters, the fundamental physical chemical principles that govern the formation and properties of self-assembled systems are considered. Important experimental techniques that can be used to characterize the properties of self-assembled systems, particularly the nature of molecular organization and structure at the nano-, meso-, or micro-scales, are reviewed. The synthesis and functionalization of self-assembled nanoparticles and the further self-assembly of the nanoparticles into one-, two-, or three-dimensional materials are discussed. Numerous potential applications of self-assembled structures are discussed. The book provides the first exhaustive accounting of self-assembly derived from various kinds of biomolecules including peptides, DNA, and proteins. Unifying as well as contrasting features of self-assembly, as we move from surfactant molecules to nanoparticles, are highlighted.

The first chapter discusses the essential similarity in the self-assembly behavior of low molecular weight surfactants and high molecular weight block copolymers from the point of view of the head-tail construct in amphiphilic systems. The emphasis on the head and neglect of the tail in surfactant free energy models is contrasted against the emphasis on the tail and minimal attention to the head in block copolymer free energy models. This difference, when resolved, allows for an unified treatment of self-assembly. The head-tail dependent free energy models are then suggested as a way to describe the self-assembly phenomena for a variety of non-classical amphiphilic systems involving dendrimers, DNA, peptides, proteins, and nanoparticles as critical head or tail components.

Chapter 2 is devoted to self-assembled systems of strongly growing and branching wormlike micelles that form reversible spatial networks in solutions.

Network reversibility and controllable viscosity make such systems very useful in numerous applications such as for drag reduction, paints, self-healing, and coatings. Relation of the observed viscoelasticity of a micellar solution to its structure is explained within the framework of the kinetic theories of breaking and recombining chainlike aggregates. The growth of non-ionic and ionic micelles, electrostatic rigidity, effects of branching, and scaling of the viscosity with the concentration of surfactant are all discussed in this chapter.

Chapter 3 reviews ways in which the self-assembly of redox-active and light-responsive surfactants have been used to achieve spatial and temporal control over interfacial and bulk properties of aqueous systems, including the interactions of surfactants with biomolecules. The switching of stimuli-responsive functional groups on the surfactants is shown to permit tuning of the surface tensions of aqueous systems, to induce surface tension gradient-driven flows, to change the state of aggregation of the surfactants in bulk solution, to permit temporal control over the transport of DNA across cell membranes and to achieve spatial control of surfactant-based microfluidic systems.

Chapter 4 highlights the importance of self-assembly to life processes. The knowledge about self-assembly of amphiphiles in aqueous environments is translated to the understanding of how lipids are uniquely connected to the formation of the cell, with cellular identity, with cellular functions, and also with cell death. The chapter discusses the idea that the spontaneous self-assembly of membranes may also be fundamental in the emergence of the first living cells in the context of an early Earth devoid of life. It describes how single-hydrocarbon-chain amphiphiles have been used to construct protocellular compartments in origin of life studies.

Chapter 5 shows how we can dynamically manipulate self-assembly. It develops the concept of programming the formation of synthetic assemblies using biomolecules, particularly peptides and nucleic acids. Biomolecules are utilized as recognition elements enabling the building of analytical probes or functional systems capable of performing sense-and-response processes in living systems. The focus is on the use of peptides and nucleic acids as the programming element. Examples are presented to highlight the ability of the programming element to control properties such as micelle formation, morphology, binding, reactivity, and spatial organization.

Protein analogous micelles (PAMs) resulting from the self-assembly of peptides conjugated to lipid tails or peptide amphiphiles are discussed in Chapter 6. Using the machinery of self-assembly, PAMs can be designed to include mixtures of different peptide amphiphiles leading to multifunctional, multivalent assemblies that can be stimuli responsive. This chapter discusses physicochemical aspects related to the design of PAMs including thermodynamic driving forces, the role of peptide secondary structure, micelle shape, amphiphile geometry, mixed micelles, and stimuli responsiveness. Based on

these properties of PAMs, their applications for tissue engineering, diagnostics, and therapeutics are discussed, focusing on how the PAM structure dictates function.

Chapter 7 explores the approach to controlling the self-assembly of proteins into materials by incorporating them as one block in a block copolymer, creating the protein conjugate block copolymer. The folded conformation of the protein significantly impacts the nanostructure formation in the materials. This chapter focuses on the physics of self-assembly of the protein-conjugate block copolymers based on a categorization of the bioconjugates by the shape of the protein block: rod-like proteins, crystallizable proteins, cyclic proteins, coil-like proteins, and globular proteins. The thermodynamics of self-assembly for each shape is summarized, with an emphasis on general principles that guide the development of new materials.

Chapter 8 discusses the design and creation of novel materials with unique properties where DNA-nanoparticles self-assembly plays a critical role. The ability to independently alter individual components of the system, such as nanoparticle shape, size, and composition, as well as DNA length, sequence, and coating density results in a highly customizable system. The inherent self-assembly capability of the DNA-coated nanoparticles provides a unique platform for constructing complex crystalline structures. These nanoscale building blocks hold great potential for applications in medical diagnostics, plasmonics, catalysis, and photonics. This chapter emphasizes the recent progress in the field using multiscale modeling and simulation directed towards designing and predicting novel DNA-nanoparticle assemblies.

Chapter 9 addresses the intriguing phenomenon of using self-assembled lipid vesicles to controllably transport nanoparticles. It uses dissipative particle dynamics to model the interaction between fluid-driven lipid vesicles and Janus nanoparticles in order to establish design rules for the vesicle-mediated particle transport. The transport is enabled by adaptive behavior of the vesicle, shedding lipids to cover the Janus particle and undergoing a self-healing process after the particle deposition, so that the vesicle can be used in successive particle pick-up and delivery events.

Chapter 10 describes "giant surfactants," which are analogs of classical surfactants but with one or more molecular nanoparticles as headgroups. The combination of the molecular nanoparticle heads having diverse symmetries and surface functionalities with the tails possessing variable compositions and architectures is shown to generate a large family of giant surfactants. These novel giant amphiphiles self-assemble into a great variety of ordered supramolecular structures in solution. The universal principles that govern their self-assemblies are explored in this chapter in order to provide guidance to the rational design and manipulation of new functional materials for technologically relevant applications.

It is my hope that this book will most efficiently introduce the reader to the field of self-assembly, providing from basic to advanced information, on each of the multiple topics covered. There are no textbooks or courses (or even professional short courses) covering all of these topics in any one place. The contributors are pioneers in their respective topical areas of research. I hope the book stimulates both entrant and experienced researchers to become active participants in this field of research.

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