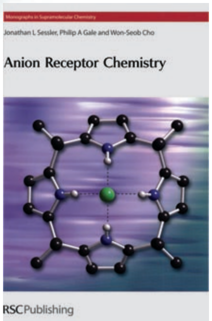
Anion Receptor Chemistry



Edited by *Jonathan L. Sessler, Philip A. Gale* and *Won-Seob Cho*. Royal Society of Chemistry, Cambridge 2006. 414 pp., hardcover £ 119.95.—ISBN 078-0-85404-974-6

Supramolecular chemistry is concerned with the noncovalent interactions between objects that drive them to assemble in a selective fashion. The driving forces are electrostatic interactions—including hydrogen bonds, which play a special role because of their directionality (as opposed to charge–charge interactions, which are stronger but not directional)—and hydrophobic effects (or solvophobic effects in general), which involve the release of bound water (or solvent) molecules. Supramolecular entities can be either polymeric (which involves solid-state chemistry) or discrete, in which case solution studies may lead to a detailed understanding of host–guest or receptor–ligand interactions. Whereas the receptor–ligand terminology relates to large objects such as those encountered in biology (enzymes, proteins, DNA, etc.), solution host–guest chemistry can be divided into four different subfields based on the nature of the (small) guest, which can be cationic, neutral, or anionic. Cation recognition was the first of these to be explored (in seminal work by Cram, Lehn, and Pedersen, which led to a Nobel Prize) and has now become a mature field. In contrast, anion recognition, in spite of its biological and environmental importance, has been developed only recently. That is mainly because the interactions are less directional, and therefore one has to design more sophisticated receptors that are efficient (strongly binding) and selective.

In this context, the monograph *Anion Receptor Chemistry*, by Sessler, Gale, and Cho, presents the state of the art of anion recognition in the molecular field. The book is divided into nine main chapters. All are very pleasant to read, clear, and well organized, with a large number of references (including reviews) and nice color illustrations.

Chapter 1 begins by emphasizing the importance of anion production in modern life, with the related environmental and health problems. The implication of anions in biology is then illustrated by several examples of the binding of chloride, sulfate, and phosphate derivatives to proteins or to natural polyamines such as prodigiosin. That is followed by a short description of the major challenges that a chemist has to face in designing an anion receptor, and the relative difficulty of the task compared to that for cation receptors, because of the larger size and reduced directionality in the anion case. This introductory chapter ends with an interesting historical overview of synthetic anion receptors. It starts in 1968 with the work of Simmons and Park of DuPont, who studied the interaction of a protonated tricyclic diamine with Cl^-, and continues with Lewis acid based receptors, Lehn's protonated cryptands, and Schmidtchen's quaternary ammonium ions, to finally arrive at neutral receptors based on amides (first described by Pascal, then developed by Reinhoudt), urea, thiourea (Wilcox), and Sessler's pyrroles. This short description of the evolution of the field ends with a special warning about the interpretation of the data, as the medium plays a key role in both electrostatic and hydrophobic interactions.

Chapter 2 is the longest in the book (about 100 pages). It describes in detail the classical charged nonmetallic systems, and distinguishes five major receptor types within this class. Thus, the chapter is organized according to the geometry of the binding motif: quaternary ammonium (cyclophanes), guanidinium and amidinium (with biological examples that emphasize the highly directional nature of the interactions with carboxylates and phosphates), imidazolium, and thiouronium. These are further divided according to their structure (acyclic or linear, monocyclic, bicyclic, and polycyclic). This chapter also introduces the major basic structural elements that have been used to link various binding motifs.

All in all, this chapter is very descriptive and somewhat encyclopedic, but it is an excellent resource to answer questions such as: which tools should one use for construction of an anion receptor, what is best for a specific anion, what kind of structural elements are needed for the linking of several binding motifs, etc. However, some fundamental and difficult questions are not specifically addressed: it remains difficult to compare the ligand properties, or to know which ligand to choose for a particular medium, and there are very few discussions about the enthalpy/entropy counterbalance issues.

There then follow five shorter chapters that are devoted to more specific families of receptors. The pyrrole-based receptors are discussed either in Chapter 3 (if protonated) or in Chapter 5 (if neutral). Other neutral nonmetallic systems are described in Chapter 4, whereas the metallic ones (including Lewis acids) are the subject of Chapter 7. Chapter 6 deals specifically with receptors for ion pairs.

Chapter 3 starts with porphyrins, and then deals in turn with ring systems of increasing size up to 8, followed by one example of a decamer, and lastly a short overview of the corresponding acyclic oligomers. A new dimension of anion recognition is introduced in this chapter, based on the fact that when the positive charges of the receptor neutralize the negative charges of the anion the resulting complex is hydrophobic, which allows it to pass through a membrane. Accordingly, the chapter includes a historical discussion about the transport properties of a phosphorylated species. All in all, this chapter provides a very interesting, detailed, and comprehensive description of the intrinsic properties of the protonated pyrrole unit, followed by more sophisticated systems with additional binding sites.

In Chapter 4, neutral nonmetallic systems are organized according to the chemical nature of the binding group. The amide-based receptors are presented first, from acyclic through cyclic to macrocyclic scaffolds (calixarenes and steroids), and finally up to peptides. Then the urea motif is discussed, with the same form of organization. The description of alcohol-based receptors includes the important cyclodextrin family. Finally, hybrid-based receptors, as well as phosphine oxides and sulfoxides, are briefly discussed.

Chapter 5 deals with the last family of neutral receptors, namely those based on pyrrole moieties. The chapter starts with the so-called calix[*n*]pyrroles, where *n* is the number of pyrrole units that are connected in a cyclic fashion by methylene bridges. The discussion of the most intensively studied one, calix[4]-pyrrole, is especially detailed. Indeed, it was the first neutral pyrrole-based anion binding system to be described (first by Baeyer in 1886, then exploited by Sessler starting in the 1990s, more than a century later!). Applications based on a second recognition site and extended cavity systems stem essentially from Sessler's work. The rest of the chapter, in analogy with Chapter 3, is organized according to increasing values of *n*, ending with linear and mixed amidic and pyrrolic systems.

Chapter 6 describes the still relatively rare receptors for ion pairs, which are classified into ditopic, cascade, and zwitterion receptors. The first category is exemplified by the association of a crown ether (a prototype cation binding site) with either a Lewis acid center or a polyamide for anion capture. The so-called cascade complexes present several transition-metal coordination sites. The corresponding metal complexes are stabilized by the binding of one or several anion ligands that are often bridging. Although questionable, because clearly not obtained for the purpose of anion binding, these systems are quite interesting, as they open doors for the "synergistic binding of an anion and another entity" (here a transition metal). Finally, the rare examples of zwitterion binding are reported at the end of this chapter.

Chapter 7, which deals with metal and Lewis acid based receptors, is restricted to systems in which the metal ion is an organizational element in addition to a Lewis acid center. It starts with the description of complexes based on strong Lewis acids such as boron chelates, subvalent mercury clusters, mercury carborands, and tin-containing macrocycles. It then describes complexes where the transition-metal ions are organized in space for anion recognition, either through direct binding or by defining a polycationic cavity (usually aromatic), or by forming micropockets with amide-, urea-, or pyrrole-based hydrogen-bond binding sites. Poly(hydroxo)-bridged multinuclear complexes that give rise to highly polar structures are also described. Thus, the scope of this chapter is wide, and it presents a selection based on systems that bind anions in ways other than through a simple coordinative link. However, from these selected examples, it may appear difficult to extract novel modes of anion binding that could lead to applications.

Chapter 8 has a different focus, as it describes practical systems that behave as sensors. Three strategies are reported: ion-selective membrane sensors in which systems are incorporated into membranes to form ion-selective electrodes or optodes, discrete redox-active, fluorescent, or calorimetric molecular sensors, and finally displacement assays, the description of which completes the chapter.

Chapter 9 ends this book by describing the anion-controlled formation of assemblies of metal–ligand coordination compounds and anion-templated syntheses of macrocyclic systems through the selective formation of covalent links (CN or CC bonds). It also describes oxyanion-directed assemblies of inorganic clusters, some cage compounds synthesized by Fujita, anion-templated condensations of pyrroles, the interaction of PhOH within aza macrocycles, that of amidinium with carboxylate, phosphates (Hosseini's solid-state assemblies), and finally assemblies of coordination compounds assisted by perfluoro anions (PF_6, BF_4). As a result, this last chapter appears as a mixture of examples, some of which, although of interest, may be considered as being off the subject.

In conclusion, this book is mainly devoted to a description of the different strategies that synthetic chemists have used to bind anions, and to a lesser extent ion pairs. Through this approach, it deals with the main facets of solution anion-recognition systems. Although, from time to time, the discussions highlight relatively unexplored fields such as zwitterion receptors, the book does not go into detail about the problems to be overcome for important applications (specific issues and the requirements that must be fulfilled). In particular, different strategies are needed for the design of receptors in solid phases, in organic media, or in aqueous (biological) media. The book fails to give a clear account of such needs. What are the major obstacles, difficulties, goals, new directions for either fundamental or applied advances? The book only skims over these issues, and the chapter conclusions or "summary remarks" are generally short, and do not discuss these points as the reader might have hoped for. However, as the authors point out, "much more work is needed to transition from accomplishments of academic interest into working devices…".

All in all, with this book, Sessler, Gale, and Cho have succeeded in presenting an excellent up-to-date overview of the recently developed field of anion recognition. It constitutes an excellent base for starting a project in this field. The many nice illustrations (often in color), with well-chosen examples that are representative of the major advances in this field, are also very appealing for a teacher who wishes to prepare a lecture on anion recognition, as well as for the students, PhD candidates, and young researchers who would like to broaden their knowledge. Therefore, I strongly recommend the reading of this book for all who like molecular chemistry!

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