Review Article

Entrapment of toxic anions using calixarenes framework

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Abstract

Calixarenes are excellent macro cyclic platforms that can be functionalized with numerous organic moieties to show cooperative binding towards anions. Their characteristic structural features with the ease of functionalization offers the way to tune the size of receptor cavity. This has led to finely tune the binding site and central hydrophobic cavity for the specified anions. Calixarene based systems provide prospective commercial applicability's in anion sensing and helps in understanding complex binding interaction. Intending to decipher the detailed insight of anion-calixarene binding, the present review discusses the reports of calixarene compounds tested for their toxic anionic recognition ability.

Keywords: calixarene, calixpyrrole, anion recognition, binding interactions, toxic anionic

Introduction

Anion binding is a key process in many biological and chemical processes and the design of synthetic molecular receptors which bind specifically to anions is an area of current importance.[1–4] There are numerous reasons to heighten up this interest. One of the open challenge for modern chemist in anion recognition chemistry is selective recognition of anions. In this course, many synthetic receptors have been developed owing to the coordination ability of the appended substituents. However, the development of anionic receptor is comparatively slow than cationic receptor due to the exceptional properties of anions.[5] These include, delocalised nature of negative charge over atoms, larger size, diverse geometry of anions (spherical, linear, tetrahedral or octahedral), pH dependence and salvation.[6] Release of anion through various commercial applications viz. nucleophiles, bases, catalysts, redox reagents can pose unwanted environmental toxicities.[6] Hence, entrapment of anions through receptors is pivotal that enables the separation using the coordination mechanism. Intriguingly, anions are also essential for the biological relevant metabolic functions therefore molecules that mimicks the anion binding are therapeutically pertinent for treating cystic fibrosis, cancer and Alzheimer's diseases.[7] There is, therefore, intense effort being devoted to the problem of anion complexation and recognition using macro cyclic receptors based on calixarenes, cyclophane, steroid, pyrroles, and other charged and non-charged macro cyclic receptors are reported so far.[8–10]

Calixarenes are the macro cyclic architectures with upper/lower rim and a characteristic central cavity.[11–14] Calix[n]arenes was found as easy to make anion binding agents due to adoption of range of conformations and capability of being functionalized at both upper and lower rim.[15] The main feature of this new macro cycle is its ability to bind selectively with various anions, cation and neutral analytes (Figure 1). Among calix architectures, there have been many theoretical and experimental studies on calixpyrrole.[16–18] The binding to anions can be achieved through protonated N-containing macro cycles. Owing to partially filled with NH protons, Hexacyclen (Nitrogen analogy of crown ether) or azacorand type macro cycle cavity selectively able to bind with the anions.[19] Moreover, the appended amide and urea substituent's have engendered significant anion binding properties to the calixarenes. For instance, montecarlo simulations on 1,3-difunctionalised bis (urea)calix[4] arenes with long flexible butyl spacers displayed that fluoride binds with the greatest affinity in the centroid of the cleft formed by NH bonds.[20] Subsequently, Liu, synthesized neutral anion receptors optimizing the suitable distance between the binding site, which demonstrate selectivity against dicarboxylate anions.[21] It was further articulated that increased acidity of NH protons in urea (pKa=26.9) and thioarea (pKa=21.0) was responsible for the enhanced complexation ability of such receptors.[22]

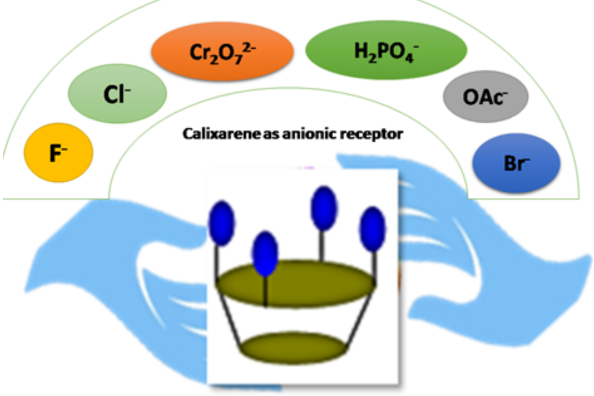

Figure 1 Anion binding diversity of calixarenes.

Anion binding receptor requirement

In contrast to cations, anions are relatively larger in size therefore require receptors of considerably greater size than cations (Table 1). This size match between anion and host cavity for complementarity and topology selectivity is crucial. Prevailing interactions which takes place in anion binding are: hydrogen bonding, ion-dipole, ion-ion and van der Waals interactions. Moreover, anions have high free energies of solvation and hence they can compete more effectively with the medium. The anion binding specificity arises from the preorganized placement of complementary binding sites. As such, the various anionic acceptors have been exercised.

Table 1 Size of the anion that corresponds to the size of the calix binding site

Anion	Diameter (Å)
Na^-	4.4
F^-	2.66
Cl^-	3.62
Br^-	3.9
I^-	4.32

Binding interaction types

In particular, many anions have diverse geometries that offer a possible route to the development of shape-selective anion receptors. Although, the non-covalent interactions involved in anion coordination are hydrogen bonds, electrostatic interactions, metal coordination, Anion- pi interactions and Lewis acid interactions, hydrophobicity and combination of these forces.[8] Organic based receptors have been developed which rely solely on hydrogen bond donors such as amides.[23] Typically, the indispensable binding interactions can be classical non-covalent ranging from H-bonding to cation-π,[24] π- π stacking[25] or anion- π.[26] However, its definition is also extended to interactions involving aromatic moieties,[27] weak C-H hydrogen bonds[28,29] or interactions between halogen atoms and lewis bases.[30–33] The lewis acid-base type of interaction also termed as σ-hole bonds represent an important and emerging class of non-covalent bonding. Loss of electronic charge at the covalent bonds results the generation of positive electrostatic potential which thereby act as lewis acid centre.[34,35] However, halogen,[36] pnictogen[37] or chalcogen[38] are the most widely used lewis base centres forming the σ- hole bonds. More recently, σ-hole bonds have been recognized and described as pivotal to generate new family of anion receptors that can be selective especially for spherical and linear anions.[39,40]

Calixarenes derivatives as anionic host

Unmodified calixarene frameworks show no affinity for anionic guests, functionalized calixarenes have been shown to be capable of binding anions.[41–43] Calixarenes and their derivatives interact via these non-covalent interactions with certain anions like phosphate, cyanide, chloride, fluoride, etc. and find applications in material chemistry.[44–48] Some instances of previous works are, Gale reported the synthesis of fluorescent anthracene- calyx[4] pyrrole conjugates which can detect the presence of anions like (e.g. F^-, Cl^-, $H_2PO_4^-$) through quenching of their fluorescence.[49] Anion-binding properties of a new calix[4]pyrrole with flexiblecatechol-derived diether strap on one side was reported by Samanta. which showed different preferences of binding towards dihydrogenphosphate, acetate ions and fluoride ions.[50] The extraction of dichromate anions were reported by Yilmaz. using new calixarene based extractantsynthesizedfrom from 5,11,17,23-tetra-tert-butyl-25,27-bis(chlorocarbonyl-methoxy)-26,28-dihydroxycalix[4]arene by treatmentwith isoniazid in the presence of pyridine.[51] Another synthetic receptors for monocharged anions using new p-tert-butylthiacalix[4] arenes linked with phenylurea fragments was reported by Stoikov et al.[52] The compound, phenylurea-equipped p-tert-butylthiacalix [4]arenes was found to show interactions with for fluoride, acetate or dihydrogenphosphate anions depending on the conformation of the macro cycle (cone, 1,3-alternate) and the number of substituents. Chromogenic anion recognition abilities in case of fluoride, acetate and dihydrogenphosphate ions was reported by Kumar et al.[53] by anion complexation induced σ-extended conjugation in iminoazophenol appended calix[4]arene/thiacalix[4] arene derivatives.

Conclusion

To sum up, the use of various calixarenes framework have opened a broader gateway for researchers working in the field of anion sensing applications. Non-covalent coordination of calix based compounds has received immense attention realizing its inherent properties exemplified by the hydrophobic nature of the cavity. A better understanding of calix-anion complexation using theoretical repositories based on computational work offers a rationalized perceptiveness to the current subject. Thus, the promises that calixarenes heralds in the field of anion binding is a destined area with respect to contemporary chemistry.

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Conflict of interest

The author declares no conflict of interest.

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