

## CHAPTER I

### INTRODUCTION

#### 1.1 Role of cations

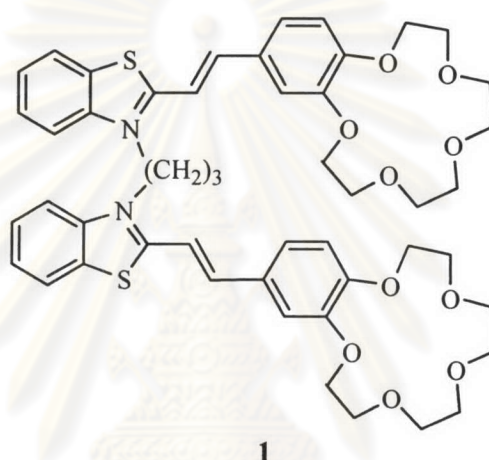
Detecting cations is of great interest to many scientists, including chemists, biologists, clinical biochemists and environmentalists. Sodium, potassium, magnesium, calcium are involved in *biological processes* such as transmission of nerve impulses, muscle contraction, regulation of cell activity, etc. Moreover, various metal ions belong to metalloenzymes. In *medicine*, it is important to control the serum levels of lithium in patients under treatment for manic depression, and potassium in the case of high blood pressure. Regarding aluminum, its toxicity has long been recognized and there is controversy about its possible implication in Alzheimer's disease. In *chemical oceanography*, it has been demonstrated that some nutrients required for the survival of microorganisms in seawater contain zinc, iron, manganese as enzyme cofactors. Finally, it is well known that mercury, lead and cadmium are toxic for organism, and early detection in the environment is desirable.<sup>1</sup>

#### 1.2 Alkali and Alkali earth metal ion sensors based on crown ether

Over the last two decades, the search for new materials as chemical sensors for alkali metal and alkali earth metal ions has been an area of rapid development. Especially, attention has been on crown ether since they have binding ability toward alkali metal and alkali earth metal ions that play various important roles in biochemistry and environmental science.

In the view of this trend, there is a real need to establish a simple and reliable analytical method to study these important ions. The well-known high sensitivity of various absorption and fluorescence spectroscopy led to design and development of crown ether functionalized by UV and fluorescence active groups for analytical use.<sup>1-5</sup>

In 1999, Evgeny N. Ushakov and coworkers synthesized two benzo-15-crown-5 ethers containing styryl, compound **1** shown in Figure 1.1 showed high complexation abilities toward alkali earth metal ions especially  $\text{Sr}^{2+}$  and  $\text{Ba}^{2+}$  because of the formation of intramolecular sandwich complexes. For the complexes **1**. $\text{Ca}^{2+}$ , **1**. $\text{Sr}^{2+}$  and **1**. $\text{Ba}^{2+}$ , the cations induced hypochromic shifts of absorption spectra and long-lived emission in the case of the  $\text{Ba}^{2+}$  complex.<sup>5</sup> These enhanced absorption shifts are likely to be due to the stacking “H-type” of chromophoric units in the sandwich complexes. According to these approaches based on exciton theory, distortion of parallel structure of the aggregates leads to band splitting.<sup>6</sup>



**Figure 1.1** Structure of crown-containing styryl dye

### **1.3 Alkali and Alkali earth-metal ion sensors and molecular switches based on conformation change of linear polyether**

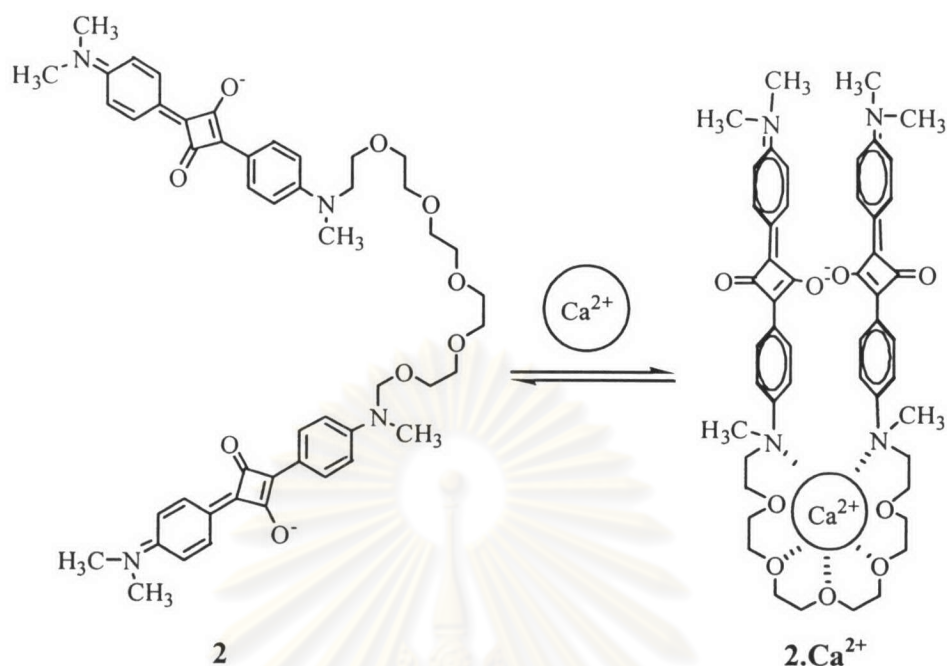
Even through a variety of crown ethers and related macrocycle-based chemosensors are known, the responding acyclic-polyethers (podand) based sensor are relatively rare because these non-cyclic ether derivatives do not show a strong complexation ability compared to that crown ethers. An early study on artificial non cyclic crown ether derivatives was carried out by Vögtle et al., they demonstrated that oligo-oxaethylene compounds appending quinoline units at their terminals bind  $\text{K}^+$  strongly via electrostatic interactions between the ion and oxygen atoms with the aid of  $\pi$ - $\pi$  interactions between end-capped quinolines.<sup>7-9</sup> Their study also showed that quinoline moieties which were strong ligands themselves, provided an increase in rigidity around the oxyethylene part and significantly contributed to stabilization of the complex with  $\text{K}^+$ .

Some podand derivatives incorporating ionophoric functional groups such as carboxylic acids, hydroxy groups, quinolines and some dyes located at the terminal of molecules exhibit an excellent property as metal carriers.<sup>9</sup> These systems are of considerable interest because of their application as photoswitchable ionic devices, the binding of metal forces the conformation change of non-cyclic crown ether, converted into physical signal by a charge transfer, electron transfer, or energy transfer process. Such changes when translated to optical as well as electronic properties can form the basis of switching devices or sensors. On this basic idea, new alkali and alkali earth metal ion sensors based on linear polyether which has two chromophores or fluorophores at both terminals have been developed.

Ajayaghosh and coworkers, demonstrated a rigid-flexible-rigid bichromophore **2** shown in Figure 1.2, which consisted of two squaraine dyes as the rigid signaling unit, linked by a flexible chain (pentakis ethylene oxide) as the recognition moiety that exhibit high selectivity for  $\text{Ca}^{2+}$  over  $\text{Na}^+$  and  $\text{K}^+$ .<sup>10</sup> In acetonitrile, the bichromophore **2** showed a maximum absorption at 630 nm with a weak shoulder around 570 nm and an emission at 652 nm. Addition of  $\text{Ca}^{2+}$  into the acetonitrile solution of **2** resulted in a color change visible to the naked eye, from light blue ( $\lambda_{\text{max}}$  630 nm) to intense purple-blue ( $\lambda_{\text{max}}$  552 nm) and quenched the fluorescence emission ( $\lambda_{\text{max}}$  652 nm).

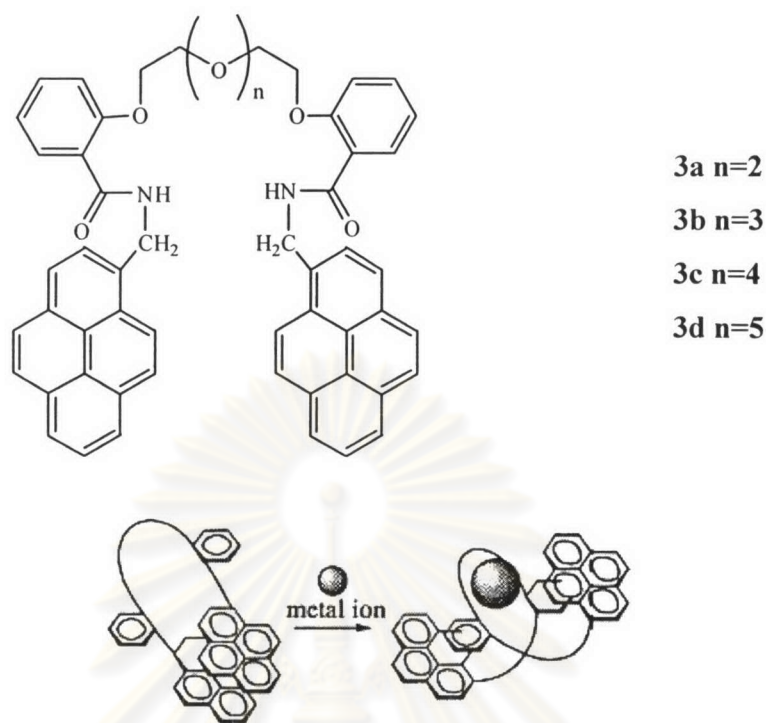
The presence of  $\text{Na}^+$  and  $\text{K}^+$  did not change its absorption or emission properties. Addition of other metal ions, such as  $\text{Mg}^{2+}$ ,  $\text{Sr}^{2+}$  and  $\text{Ba}^{2+}$  showed only marginal changes to absorption and emission of **2** compared to those with  $\text{Ca}^{2+}$ . Thus, **2** exhibits extraordinary selective toward  $\text{Ca}^{2+}$  with the stability constant of  $1.9 \times 10^4 \text{ M}^{-1}$ . The observed changes in absorption and emission behavior of **2** in the presence of  $\text{Ca}^{2+}$  can be rationalized on the basis of metal ions induced folding of the chromophores to form a face-to-face stacked foldamer as showed in Figure 1.2 which is analogous to the “H” aggregates of squaraine dyes.





**Figure 1.2**  $\text{Ca}^{2+}$ -ion induced folding of **2** to the “H” foldmer

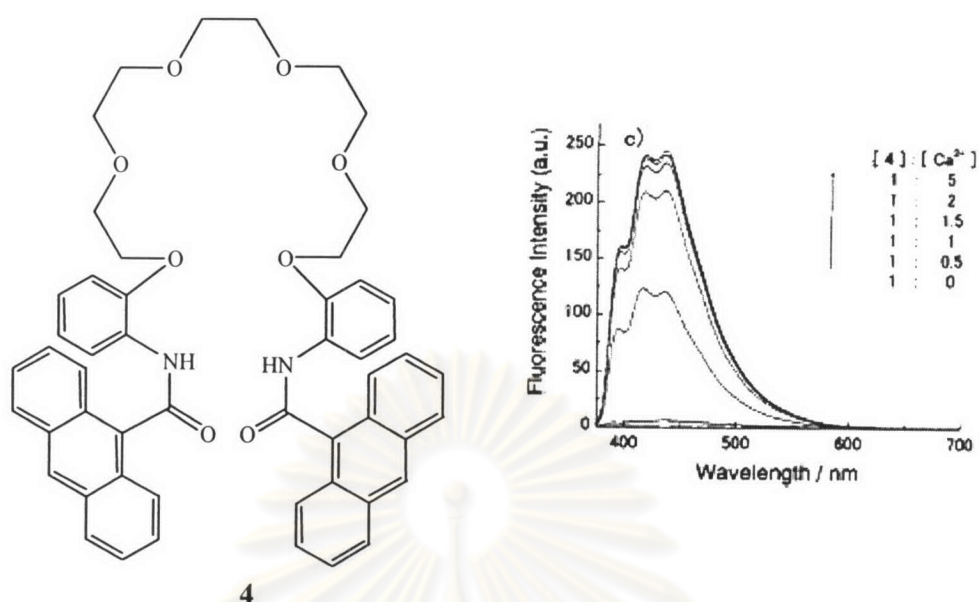
Suzuki et al. have recently synthesized novel emitting compounds that have two pyrenes placed at the terminals of polyethylene compounds **3a-3d**, and their complexation with alkali and alkaline earth ions was investigated by fluorescence spectrophotometry and  $^1\text{H-NMR}$  spectroscopy.<sup>11</sup> These ligands showed strong intramolecular excimer emission around 400 nm accompanied by the disappearance of intramolecular excimer emission of free ligands. These ligands formed 1:1 complexes, and the order of complex formation constants was  $\text{Ca}^{2+} \sim \text{Sr}^{2+} > \text{Ba}^{2+} > \text{Mg}^{2+} > \text{Li}^+$  for all ligands. The stability constants of the complexes with  $\text{Ca}^{2+}$ ,  $\text{Sr}^{2+}$  and  $\text{Ba}^{2+}$  in acetonitrile are quite high (ca.  $10^6$ - $10^7$  for **3d**), but the selectivity is poor because of the flexibility of the oxyethylene chain.



**Figure 1.3** Pseudocyclic structure of an excimer-forming podand

In 2001, Morozumi et al. developed new fluorophores based on linear polyether. Their complexation properties with various alkali metal and alkaline earth metal ions were investigated by fluorescence, UV, and <sup>1</sup>H-NMR spectroscopies.<sup>12</sup> In the absence of metal ions, **4** showed almost no fluorescence emission ( $\Phi = 0.0003$ , fluorescence “off” state) since twisted intramolecular charge transfer (TICT) occurred through the amide bond. Complexation with alkaline-earth metal ions demonstrated a significant increase in fluorescence intensity around 430 nm. In the case of **4**.Ca<sup>2+</sup>, a large enhancement effect on the quantum yield ( $\Phi = 0.014$ , fluorescence “on” state) was observed.

This “off-on” fluorescence characteristic was originated from cooperative strong binding made between the carbonyl group and the ethoxy moiety for alkaline earth metal ions, resulting in effective inhibition of photoinduced TICT relaxation.



**Figure 1.4** Fluorescence spectra of **4** and its Ca<sup>2+</sup> complex in CH<sub>3</sub>CN at 25 °C

#### 1.4 Role of anions

Anions are of key importance across many fields as the following illustrative example indicates, in *biology*, between 70 and 75 percent of enzymes, substrates and cofactors are anions, very often phosphate residues (as in ATP and ADP)<sup>13</sup> or inorganic phosphates. Anions such as sulphate and carboxylate are also found in biochemical systems. In *chemistry*, anions have various roles as nucleophiles, bases, redox mediators and phase-transfer catalysts.<sup>14</sup> In *environments*, anions are a pollution problem. In particular, the nitrate anion that is used in fertilizers on agricultural land often pollutes river water to unacceptable levels.<sup>15</sup> In *medicine*, anions are of great importance in many disease pathways. Chloride anion is the major extracellular anions, and the function of chloride transport channels is thought to be linked intimately to cystic fibrosis.<sup>16</sup> Cancer is caused by the uncontrolled replication of polyanionic DNA. Anion-binding proteins have also been implicated in the mechanism of Alzheimer's disease.<sup>17</sup>



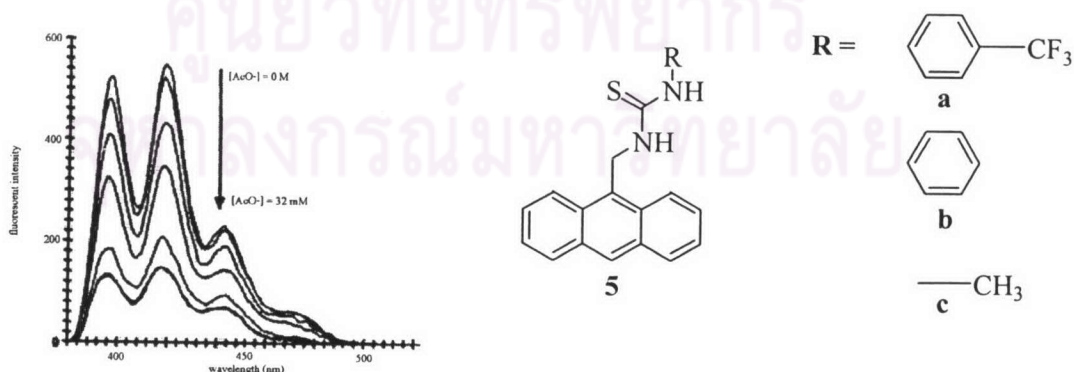
## 1.5 Anion Receptors

In spite of recent advances and the variety of cation receptors developed so far, the problem of achieving strong and selective anion recognition has not yet been solved, in contrast to the far more developed classical cation receptors. The basic strategy for construction of anion receptors is to employ electrostatic interactions and/or hydrogen bond, or Lewis acid metal ligand interactions.<sup>18-19</sup> Among these noncovalent interactions, numerous research groups have been interested in developing hydrogen bond-based neutral anion receptors.<sup>20-23</sup>

## 1.6 Anion sensing based on urea or thiourea groups

A molecular sensor for cations can be built through a modular approach, i.e. by covalently linking an appropriate photoactive fragment to the receptor displaying a satisfactory affinity to a desired substrate. Following the receptor-anion interaction, an intercomponent process must take place, e.g. an electron transfer (eT) or an energy transfer (ET) process, that distinctly modifies chromophores or luminophores, thus signaling the occurrence of the recognition event.<sup>24</sup> It is well known that urea and thiourea group can interact with anionic species effectively by hydrogen bonding. Several sensors containing these functional groups have been reported.<sup>25-27</sup>

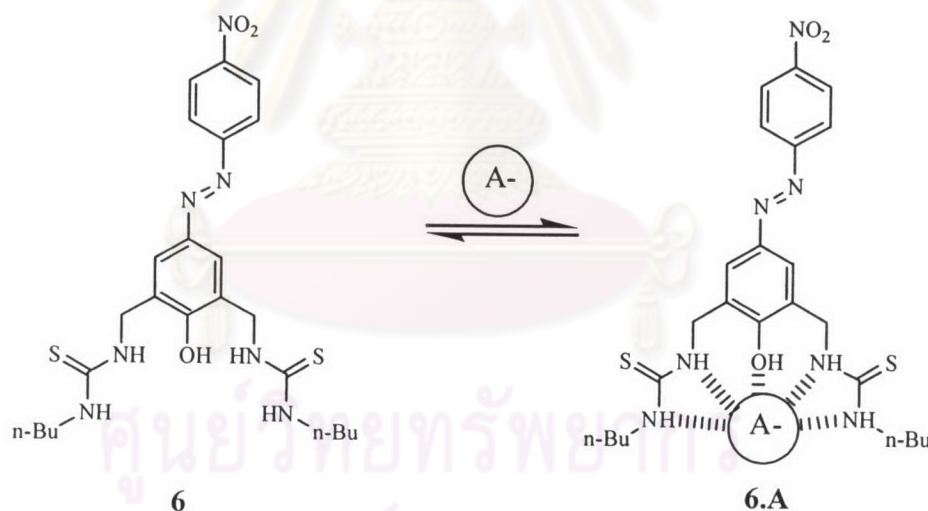
Gunnlaugsson et al. have incorporated the aromatic or aliphatic thiourea moiety, in combination with anthracene to produce the anion fluorescent sensor as shown in Figure 1.5.<sup>28</sup>



**Figure 1.5** The changes in fluorescence spectra of **5** in DMSO upon addition of  $AcO^-$

Different substituents (**5a**, **5b** and **5c**) were chosen with the aim of being able to modulate or tune the acidity of the thiourea receptor moiety, which would lead to a different receptor-analyte complex stability and hence a different binding constant. Studies of anion complexation abilities of **5a** by fluorescence titrations in DMSO, showed the order of binding constant as  $F^-$  ( $\log K = 3.35$ )  $>$   $AcO^-$  ( $\log K = 2.50$ )  $>$   $H_2PO_4^-$  ( $\log K = 2.05$ ) and no recognition to  $Cl^-$  and  $Br^-$ . Compound **5b** and **5c** showed similar results with smaller binding constants due to the reduction of acidity of the thiourea protons.

Later, Lee and coworkers have shown that azophenol-thiourea system (compound **6**, Figure 1.6) can act as a colorimetric sensor. The selectivity trend of binding affinities for anions was  $F^- \sim H_2PO_4^- \sim AcO^- \gg \gg HSO_4^- \sim Cl^- > Br^- \sim I^-$ .  $F^-$ ,  $H_2PO_4^-$  and  $AcO^-$  gave stronger complexes than other anions because of the basicity order of anions. Furthermore, these solutions showed dramatic color change from light yellow to deep red. However, this system is not able to discriminate the color change between  $F^-$ ,  $H_2PO_4^-$  and  $AcO^-$ .<sup>29</sup>

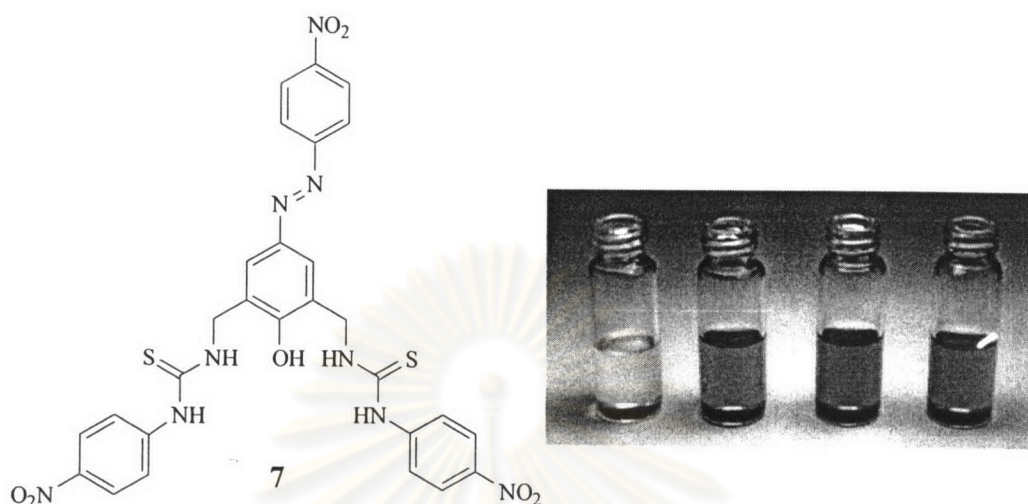


**Figure 1.6** The complexation of chromogenic azophenol thiourea with anion

In 2000, the same group presented a dual-chromophore anion sensor **7** with *p*-nitrophenyl azophenol and *p*-nitrophenyl thiourea moieties as two different chromophores.<sup>30</sup> In the case of **7**, the introduction of a *p*-nitrophenyl group to the thiourea moiety as another chromophore enabled color differentiation of anions in a cooperative manner, along with an azophenol group upon anion binding. This



approach brings together changes in  $\lambda_{\max}$  of two chromophores to render colorimetric detection of anions more effective than only one chromophore.



**Figure 1.7** UV-vis changes of 7 in CHCl<sub>3</sub> after the addition of 40 equiv. of anions, (left to right) 7, 7+F<sup>-</sup>, 7+H<sub>2</sub>PO<sub>4</sub><sup>-</sup> and 7+AcO<sup>-</sup>

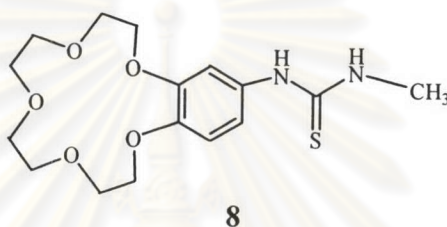
The color discrimination between F<sup>-</sup>, H<sub>2</sub>PO<sub>4</sub><sup>-</sup> and AcO<sup>-</sup> come from different  $\lambda_{\max}$  values in each complex and the relative contribution of two chromophores as shown in Figure 1.7. The degree of red shift for 7 was determined to be H<sub>2</sub>PO<sub>4</sub><sup>-</sup> >>> AcO<sup>-</sup> ~ F<sup>-</sup>. The dramatic color change was observed from light yellow to violet through addition of H<sub>2</sub>PO<sub>4</sub><sup>-</sup> and no detectable color change are observed upon excess addition of HSO<sub>4</sub><sup>-</sup>, Cl<sup>-</sup>, Br<sup>-</sup> and I<sup>-</sup>.

### 1.7 Bifunctional cation-anion receptors

The design of new multisite ion pair receptors that contain covalently linked binding site for both cations and anions is a new area of coordination chemistry. In addition to being a potential selective extraction/membrane transportation reagent for metal salts, these ditopic ligand systems can be tailored to exhibit novel cooperative and allosteric behaviour whereby the complexation of one charged guest can influence, through electrostatic and conformation effect, the subsequent coordination of the pairing ion. In a bifunctional receptor, the binding site for anions and cations are covalently link so as to exhibit allosteric or cooperative complexation where the

binding affinity for anions is modified as a result of the cations complexation, or *vice versa*.<sup>31-34</sup>

In 1999, a new bifunctional receptor **8** in Figure 1.8 for cooperative complexation of cations and anions was synthesized on the basis of benzo-15-crown-5, functionalized with the thiourea moiety as binding sites. Binding properties of the receptor **8** and their complexes were studied using <sup>1</sup>H NMR titration in CD<sub>3</sub>CN. The addition of anions as N(C<sub>4</sub>H<sub>9</sub>)<sub>4</sub><sup>+</sup> salts resulted in significant downfield shifts for both thiourea protons of **8**, suggesting that hydrogen bond mediated complexation of **8** with anions take place in the thiourea moiety of the receptor.



**Figure 1.8** Structure of a bifunctional receptor

The order of the association constants followed the trend: H<sub>2</sub>PO<sub>4</sub><sup>-</sup> > Cl<sup>-</sup> > Br<sup>-</sup> > NO<sub>3</sub><sup>-</sup> > I<sup>-</sup>. <sup>1</sup>H-NMR titration experiments were carried out repeatedly in the presence of 2 equivalents of NaBPh<sub>4</sub>, under which over 95% of **8** complexed with Na<sup>+</sup> (K = 8.2 X 10<sup>3</sup> M<sup>-1</sup>) and showed a substantial increase in the anion binding ability as compared to free **8**.<sup>35</sup>

Association constants of I<sup>-</sup>, Br<sup>-</sup> and NO<sub>3</sub><sup>-</sup> complexes are increased approximately by a factor of 5, 10 and 11, respectively in the presence of Na<sup>+</sup>. Thermodynamic studies indicate the difference in binding ability of **8** in the absence and the presence of Na<sup>+</sup> can be attributed primarily to the enthalpic effect. The greater enthalpic gain of **8**-Na<sup>+</sup> over free **8** is probably rationalized by the enhanced hydrogen bond donation ability of the thiourea NH protons and by the favorable attraction caused by the closely located Na<sup>+</sup>.

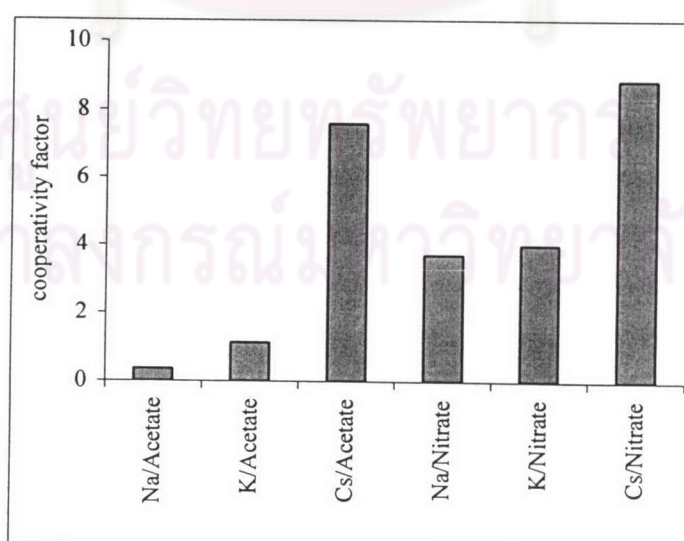
Previous designs of bifunctional systems have used allosteric effects (induced fit) and/or through-bond electrostatic effect to enhance anion association constants. In these cases, the binding of the receptor was either enhanced or suppressed depending upon the nature of the ion-pairing ability of the cationic guest. Smith and co-workers have reported the effect of compete alkali metal cations on binding ability of receptor

8.  $^1\text{H-NMR}$  titration experiments in  $\text{CD}_3\text{CN}$  determined the association constants that summarized in Table 1.

A cooperativity factor was generated from Table 1 (in Figure 1.9) implies the effect of binding host/anion in the presence of competing alkali metal ions. A value  $< 1$  indicates that host/anion binding is inhibited by the ion pairing, whereas a cooperativity value  $> 1$  reflects host/anion binding enhancement due to ion-pairing recognition. It was found that the ion-sequestering ability of the Group 1 metal cations was in the order  $\text{Cs}^+ < \text{K}^+ < \text{Na}^+$  matching their ion-pairing ability.<sup>36</sup>

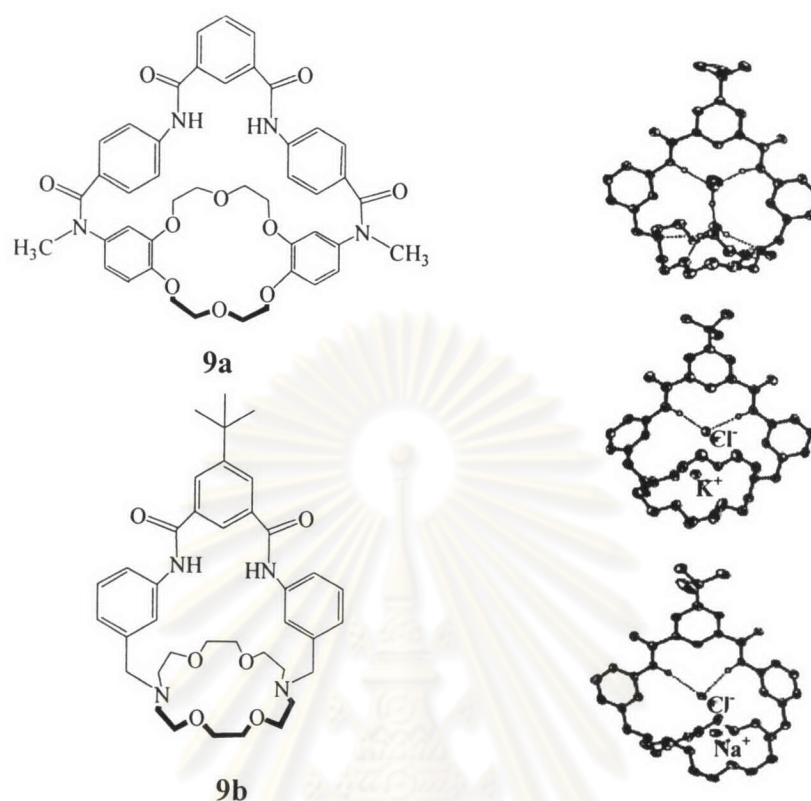
**Table1.** Anion association constants in  $\text{CD}_3\text{CN}$  at 295 K

metal ion	anion	$K_{\text{ass}} (\text{M}^{-1})$	$\text{NH } \Delta\delta_{\text{max}} (\text{ppm})$
None	acetate	220	3.12
$\text{Na}^+$	acetate	80	3.20
$\text{K}^+$	acetate	250	3.08
$\text{Cs}^+$	acetate	1670	2.92
None	nitrate	35	1.33
$\text{Na}^+$	nitrate	130	1.32
$\text{K}^+$	nitrate	140	1.08
$\text{Cs}^+$	nitrate	310	0.92



**Figure 1.9** Cooperativity factor for host 8



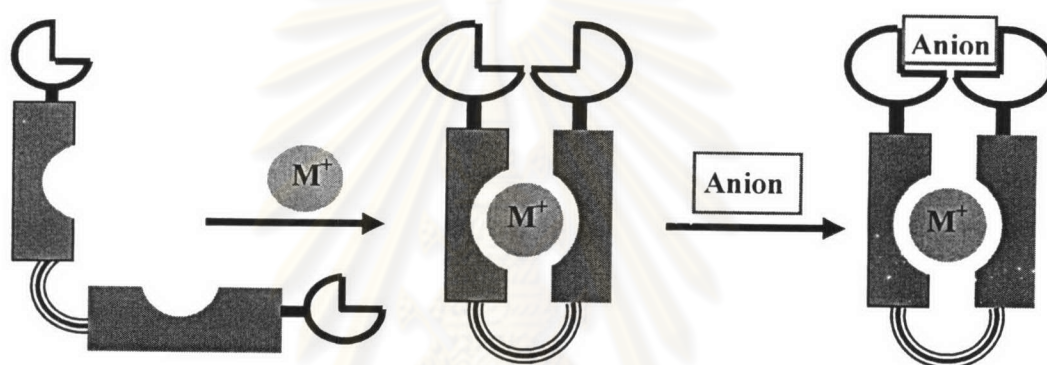


**Figure 1.10** X-ray crystal structures of **9** with water and methanol (top), **9** complex of KCl (middle) and the complex **9** with NaCl (bottom)

In order to form an ion-pair successfully, Smith and coworkers have synthesized a variety of compounds including the strapped crown ether diamide clef receptors **9a** (Figure 1.10) that is capable of binding a solvent separated ion-pair ( $\text{Na}^+/\text{CHCl}_3/\text{Cl}^-$ ) and **9b** (Figure 1.10) that is capable of recognizing KCl contact ion-pair. The association constant of receptor **9b** with chloride is enhanced from  $35 \text{ M}^{-1}$  in  $\text{DMSO-d}_6$  at 295 K to  $460 \text{ M}^{-1}$  in the presence of 1 equivalent of potassium tetraphenylborate. Addition of sodium to the receptor only increases its affinity for chloride to a  $K_a$  of  $50 \text{ M}^{-1}$  under the same condition. X-ray crystal structures of the NaCl and KCl complexes reveal that the sodium cation is bound more closely to the crown ether than the potassium ion so increasing ion-dipole repulsion between chloride and crown ether oxygens (Figure 1.10).<sup>37</sup>

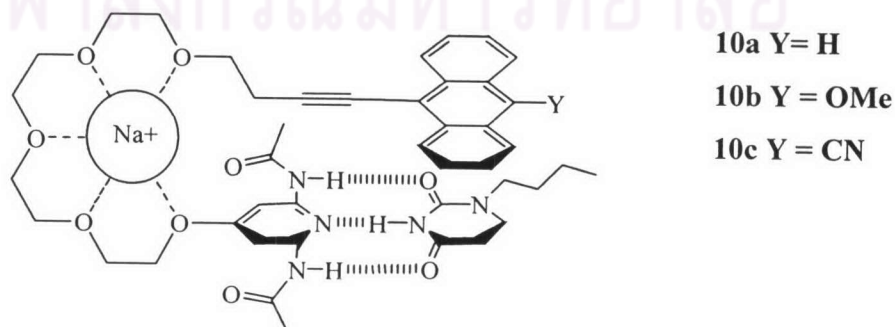
### 1.8 Allosteric switches

Allosteric interactions between subunits are known as one of the elegant strategies for precisely regulating and controlling the function in biological systems. An allosteric system is one that involves conformation coupling between two or more binding sites. Thus, binding at one site produces a conformational change that influences (turn on or off) the binding ability of the second site. This concept is exemplified in Figure 1.11, where coordination of one part of molecule to metal center results in the allosteric organization of a second distant binding site.<sup>38-40</sup>



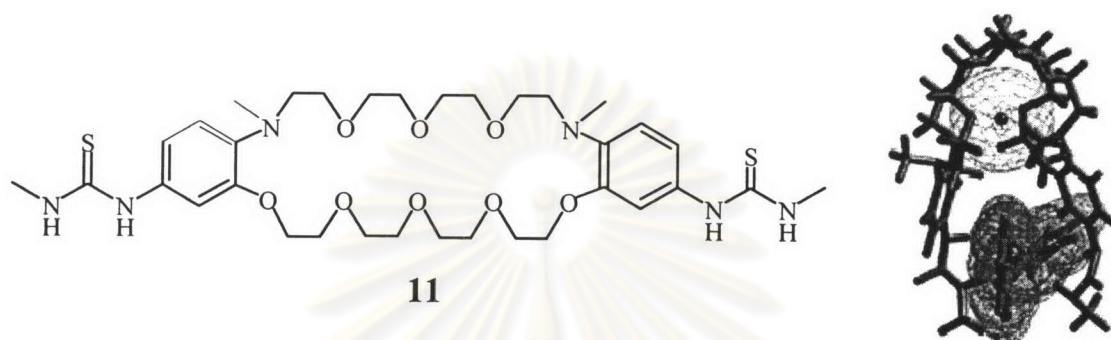
**Figure 1.11** Schematic diagrams for binding organization by metal templated effects

Shinkai has employed oligoether-complexing-alkali metal ions to organize multiple bonding interactions for nucleotide substrates (compound **10**). Anthracene and (diacyamido) pyridine units were positioned at the opposite end of an oligo(ethyleneoxy) cooperatively binding with an alkyl thymine derivatives by simultaneous hydrogen bonding and  $\pi$ -stacking interactions, as shown in Figure 1.12.



**Figure 1.12** The complex of **10** with  $\text{Na}^+$  induced binding for a nucleotide.

A significant increase in the association constant was seen between the salt free ( $1000 \text{ M}^{-1}$ ) and sodium containing ( $7000 \text{ M}^{-1}$ ) solutions. The metal ion was not a mere spectator in this system as molecules containing only the (diacyamido) pyridine unit. Receptor **10** showed significant increase in association to thymine upon addition of  $\text{Na}^+$ , suggesting a possible ionic strength effect.<sup>41</sup>



**Figure 1.13** The energy minimized complex structure [**11**-( $\text{PhO}$ ) $_2\text{P}(\text{O})\text{O}^-$ ]

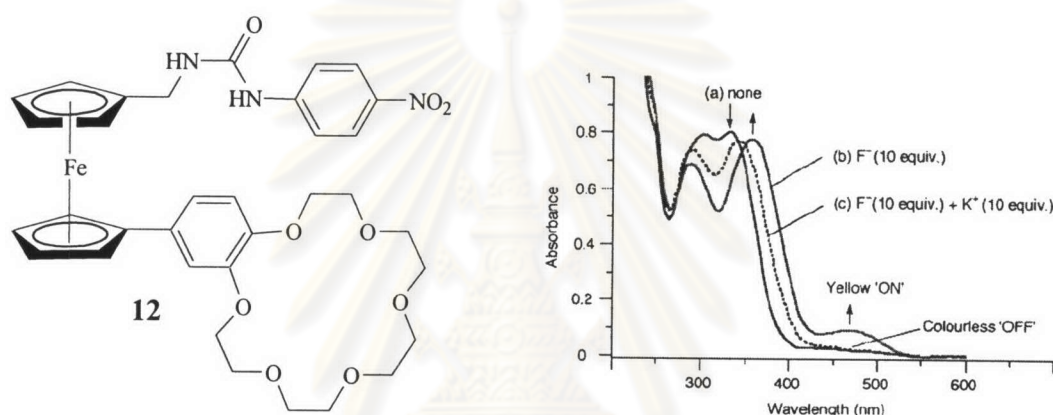
By attaching two thiourea groups to dibenzo-diaza-30-crown-10, Kubo and coworkers have synthesized an ion-pair receptor **11**.<sup>42</sup> The addition of potassium ion causes the crown ether to wrap around the metal so bringing the thiourea groups into close proximity forming a binding site for anion such as  $(\text{PhO})_2\text{P}(\text{O})\text{O}^-$  (Figure 1.13). In fact the affinity of the receptor for  $(\text{PhO})_2\text{P}(\text{O})\text{O}^-$  increases by a factor of 19 in the presence of potassium ion in acetonitrile- $d_3$  at 297 K ( $K_a$  increases from 490 to 9200  $\text{M}^{-1}$ )

Miyaji reported a chromoionophore, **12**, that contained a binding site for both anions and cations. Compound **12** functioned as a molecular switch by using appropriate combinations of anions and cations in solution to control its color. A nitrobenzene-linked urea moiety was chosen as an anion-binding site. The crown ether was chosen as a second binding site of the receptor. Ferrocene was chosen as a spacer unit because it was relatively easy to introduce different functional groups onto its two cyclopentadienyl (Cp) arms and in addition, its Cp unit was able to rotate like a ball-bearing to encourage the formation of a stable ditopic complex.<sup>43</sup>

Fig 1.14 shows the effect of the addition of  $\text{F}^-$  and then  $\text{K}^+$  on the spectrum of **12** in acetonitrile. The absorption maximum associated with a nitrobenzene moiety of the receptor ( $\lambda = 304, 332 \text{ nm}$ ) clearly separates (288, 356 nm) after addition of 10

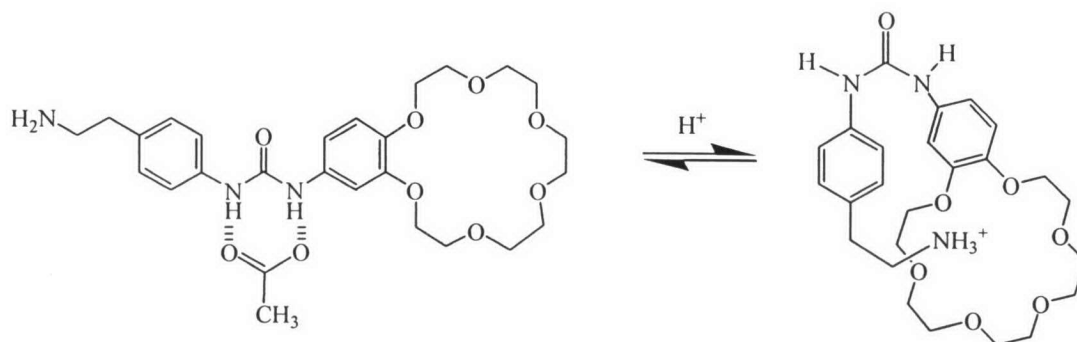


molar equivalents of  $F^-$  and at the same time, a new absorbance appears at 472 nm, resulting in a change of the solution from colourless to yellow. The binding constant for a 1:1 complex between **12** and  $F^-$  in acetonitrile was determined from the increase in absorption intensity at 472 nm, providing  $K_a = 9340 M^{-1}$ . Interestingly, addition of  $K^+$  reversed the chromogenic process. Upon addition of 10 molar equivalents of  $KPF_6$  to the solution, the yellow color induced by the presence of  $F^-$  was now no longer observable and the absorption maximum at 472 nm disappeared. The observed binding constant between  $K^+$  and **12** in the presence of 10 molar equivalents of  $F^-$  was  $1460 M^{-1}$ .



**Figure 1.14** UV-vis spectra of **12** in  $CH_3CN$ , a) in its free form, b) in the presence of 10 mol. equiv. of  $F^-$ , c) in the presence of 10 mol. equiv. of  $F^-$  and 10 mol. equiv. of  $K^+$

As a comparison, the order of guest addition was then reversed. As expected, the addition of  $K^+$  to a solution brought about no color change, although a small change in absorption intensity was observed. When 10 molar equivalents of  $F^-$  were added, the solution remained colorless and only small changes were observed in the spectrum. Therefore  $K^+$  appears to inhibit the chromogenic response of the spectrum of  $F^-$ . A convenient way of representing these changes is through a molecular gate, which gives the logic response of **12** as either 'ON = 1' or 'OFF = 0' in the various combination of anions and cations at either 0 mol equivalent ('INPUT' = 0) or 10 mol equivalents ('INPUT' = 1). The output is only 1 if (anion,cation) = (1,0).



**Figure 1.15** The  $H^+$  as a switch controls the binding properties of receptor **13**

Branda and co-workers reported a novel artificial hydrogen-bonding receptor **13**.<sup>44</sup> They used a single proton as a switch and a negative allosteric cofactor to exhibit substrate recognition.  $^1H$ -NMR titration experiments carried out in  $DMSO-d_6$  revealed that receptor **13** bound acetate in a 1:1 fashion with the association constant ( $K_a$ ) of  $4400 M^{-1}$ . Repeating the titration experiments but replacing the active receptor with the preformed complex  $13.H^+$  generated data that could not be fit to any of binding models due to the intramolecular association between the ammonium group and crown ether in  $13.H^+$ . These interactions resulted in a conformation change of the receptor **13** that is a self-complementary species that fold in on itself with the concomitance distortion of the hydrogen bond site as shown in Figure 1.15.

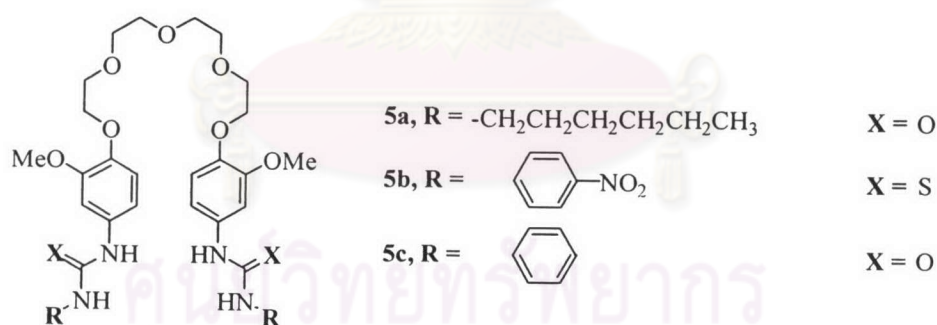
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### 1.9 Objective and the scope of this research

The objective of this research is to synthesize acyclic crown ether containing urea and thiourea moieties **5a**, **5b** and **5c** (Figure 1.16) for binding both cations and anions. Complexation studies of compound **5a** with alkali metal ions ( $\text{Na}^+$  and  $\text{K}^+$ ) and various anions such as  $\text{Cl}^-$ ,  $\text{Br}^-$ ,  $\text{I}^-$ ,  $\text{NO}_3^-$ ,  $\text{H}_2\text{PO}_4^-$ ,  $\text{CH}_3\text{COO}^-$ , and  $\text{BzO}^-$  are investigated by means of  $^1\text{H-NMR}$  titration. Furthermore, we also studied the effect of  $\text{Na}^+$  toward anion binding abilities and inversely the effect of various anions toward cation binding abilities.

Complexations of ligand **5b** are studied by using UV-vis titration technique. The results of this research should give information about the relationship between cavity size of hosts and binding abilities of guests and, moreover, to deduce the effect and function of cations, that influence binding abilities of anion binding sites, and *vice versa*.

Another aim of this thesis is to investigate the redox properties of ligand **5b** in non-aqueous solution by cyclic voltammetry and square wave voltammetry. At last, we expect to explore the possibility to use our synthesized compounds as a molecular device, such as a molecular switch or a molecular gate.



**Figure 1.16** Structures of acyclic crown ether derivatives containing urea or thiourea moieties