

## Synthesis and uses of macrobicyclic cryptands: From complexation of transition metal ions to molecular devices

DILLIP K CHAND, PRADYUT GHOSH, RAMESH SHUKLA,  
SAYAM SENGUPTA, GOPAL DAS, PRASUN BANDYOPADHYAY  
and PARIMAL K BHARADWAJ\*

Department of Chemistry, Indian Institute of Technology, Kanpur 208 016, India

**Abstract.** Syntheses of a number of cryptands having heteroditopic as well as heterotritopic receptor sites have been achieved using alkali metal ions as templates. Some of the cryptands can be synthesized on a multi-gram scale without using any templating metal ions at low temperature (278 K). Each of these cryptands readily forms inclusion complexes with transition metal ions. These cryptands exhibit interesting properties and can further accommodate small anions inside the cavity. Further, upon suitable derivatization, some of the cryptands can behave as amphiphiles and form Langmuir–Blodgett films very readily. When derivatized with 9-methylanthracene, some of the cryptands show interesting fluorescence properties and can be of use as molecular photonic devices.

**Keywords.** Macrobicyclic cryptands; cascade complexes, molecular recognition; molecular devices.

### 1. Introduction

Cryptands soon after their introduction (Dietrich *et al* 1969) proved useful in many fascinating areas viz. molecular recognition, catalysis, transport (Lehn 1983), molecular electronics (de Silva *et al* 1993). These molecules were shown to act as receptors for selective binding of substrates, as catalysts by assisting chemical transformation among bound substrates and as carriers for the transport through the membrane (Lehn 1986). The disposition and rigidity of the donor atoms in the cryptands might lead to the stabilization of unusual oxidation states of coordinated metal ions (Sargeson 1986). Moreover, encapsulation may help in stabilizing the labile substrates inside the cavity. A combination of coordination and encapsulation may lead to oxygen/moisture sensitive chemistry being effected inside the protected cage (Meade and Busch 1985). The topology of the donor atoms in cryptands can be regulated by clever designing which can enforce unusual coordination geometries on to the metal ions, thereby offering an opportunity of modelling the active sites of the metalloproteins (Bharadwaj 1993). The macrobicyclic molecules possessing polytopic receptor sites can also lead to desirable metal–metal and metal–substrate interactions. Hence, a suitably designed cryptand molecule holds rich promise for unusual or novel transition metal chemistry being carried out with it and can offer insight into the diverse phenomena associated with such reactions.

---

\*For correspondence

## 2. Synthesis

Synthesis of cryptands has remained a challenging task for chemists over the years. As the synthesis involves many steps and high dilution techniques are often necessary, yields are generally low. Lehn (1985) described the major strategies adopted in the synthesis of cryptands starting from acyclic components. These strategies form the basis of the synthesis of cryptands and have been accepted by workers in the field.

Stepwise synthesis is the most commonly used method and this involves the generation of an intermediate macrocycle followed by bridging of another chain to yield the macrobicyclic. A number of cryptands have been synthesized by [2 + 3] Schiff base condensation method using prefabricated amines and aldehydes (Jazwinski *et al* 1987; McDowell and Nelson 1988; Hunter *et al* 1990; Chen and Martell 1991; Ragunathan *et al* 1993). By adopting [1 + 1] Schiff base condensation, a number of heteroditopic cryptands have been synthesized in very good yields (Ragunathan and Bharadwaj 1992; Ghosh *et al* 1995, 1996). Adopting low temperature (278 K), some of the cryptands can be synthesized on multi-gram scale (Smith *et al* 1993; Chand *et al* 1996; Ghosh *et al* 1995, 1996) making these cryptands readily available for use as ligands for transition metal ions or for derivatizing them with suitable groups to have supramolecular systems. Some of the cryptands reported by us (Ragunathan and Bharadwaj 1992; Ragunathan *et al* 1993; Ghosh *et al* 1995, 1996) are shown in figure 1.

## 3. Complexation by transition metal ions including secondary recognition

Cryptands with N atoms as donor groups have been extensively used as complexands for various transition metal ions. Both mono- as well as dinuclear cryptates have been synthesized while only one trinuclear species has been reported (Mendoza *et al* 1991). Polyaza cryptands incorporating  $sp^3$  donors have been extensively investigated (Lehn 1985). They show great coordinating power towards transition metal ions. In cases

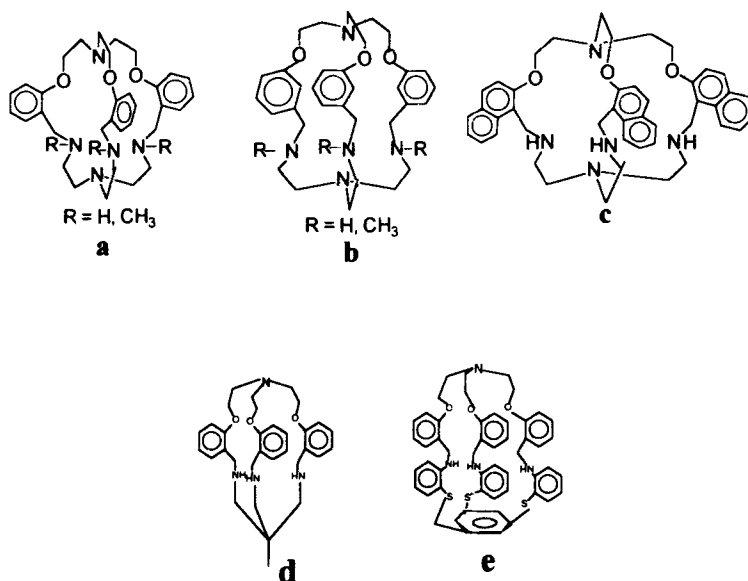


Figure 1. Some of the cryptands described in the paper.

where the cryptands provide a pair of  $N_4$  donor sites, binuclear cryptates can be formed (Hunter *et al* 1990; Ragunathan and Bharadwaj 1992; Bazzicalupi *et al* 1995). The donor atoms in such cryptands, being somewhat rigid, can impose a coordination geometry which may not be possible to achieve with a simple ligand. With suitably designed heteroditopic cryptands, metal cryptates can be formed which might add on to inorganic/organic fragments forming cascade complexes (Ragunathan and Bharadwaj 1995; Chand and Bharadwaj 1996). Cascade complexes are of potential importance in the area of homogeneous catalysis (Lehn 1985).

#### 4. Molecular recognition of water by cryptands

Complexation of water by crown ethers and by oxa-aza macrocycles is well documented (Izzat *et al* 1992). There are not many examples of water cryptates in the literature. The first one is a diprotonated cryptand which accepts a molecule of water in its cavity as shown by NMR study (Lehn 1978). One partial crystal structure is given for a neutral water cryptate (Takemura *et al* 1991). The recent one is a penta-coordinated water cryptate published with its full crystal structure (Bazzicalupi *et al* 1994). Heteroditopic cryptands have been found to be excellent hosts for water molecules (Chand *et al* 1996). In these cryptands, only two out of three N atoms (non-bridgehead) get protonated even in presence of excess acids and bind a water molecule inside the cavity where the O atom of the water molecule is tetrahedrally bonded by four H atoms. The abnormal protonation behaviour is the result of a cooperative effect mediated by the water molecule.

#### 5. Cryptands with long alkyl chains attached for supramolecular assembly

The lipophilic nature of a cryptand can be greatly enhanced by attaching long alkyl chain(s) to it (Behm *et al* 1993). Sarcophagine complexes of Co(III) (figure 2) were found to be quite effective in breaking the cell walls of rat tapeworm (*Hymenolepis diminuta*) when tied with long aliphatic tail at one end due to higher lipophilicity as well

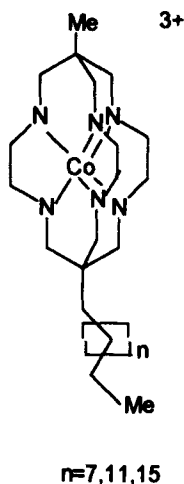


Figure 2. Sarcophagine molecules with long alkyl chains attached.

as high charge. Such experiments can lead to many possible applications of these cages in biological membranes. Besides, the possibility exists of having the cryptands/cryptates in the form of Langmuir–Blodgett films due to their amphiphilic nature when long alkyl chains are attached to them (Ghosh *et al* 1995, 1996).

## 6. Cryptands as molecular photonic devices

A molecular photonic device is defined as an assembly of molecular components that are able to perform light-induced logic operations. Such molecules are prerequisites for molecular information processing and computation. A number of crown ether-based systems have been reported which are capable of acting as (AND)/(OR)/(YES) logic gates (Lehn 1990; Bissell *et al* 1992; de Silva *et al* 1993). A cryptand having an anthracenyl moiety attached, capable of functioning as an (OR) logic gate has been reported (de Silva *et al* 1990) which binds  $K^+$  and  $Rb^+$  separately in methanol to enhance the fluorescence signal by a factor of only 9.4 and 10.6 respectively. The heteroditopic cryptands shown in figure 1(a and b) can be derivatized by anthracenyl moieties to have ideal orientations of the fluorophore (anthracene) and receptor units. These systems are capable of acting as (OR) logic gates (Ghosh *et al* 1995, 1996) in presence of proton as well as transition metal ions.

## 7. Conclusion

Suitably designed cryptands can be useful ligands for transition metal ions to obtain complexes of the desired coordination geometry. This is of relevance in bioinorganic research. When the cryptand contains one or more derivatizable groups, new types of supramolecular systems can be designed which can be of enormous importance in a number of research areas like molecular recognition, molecular LB-films, molecular devices etc.

## Acknowledgements

Financial support from the Department of Science and Technology, New Delhi and the Department of Atomic Energy, Bombay are gratefully acknowledged. X-ray crystallographic studies were carried out at the National Facility on Single Crystal X-ray Diffraction in our Department. PKB wishes to thank the Department of Science and Technology which funded the X-ray project at the Department of Chemistry.

## References

- Bazzicalupi C, Bencini A, Bianchi A, Fusi V, Paoletti P and Valtancoli B 1994 *J. Chem. Soc., Perkin Trans.* 2 815
- Bazzicalupi C, Bencini A, Bianchi A, Fusi V, Mazzanti L, Paoletti P and Valtancoli B 1995 *Inorg. Chem.* **34** 3003
- Behm C A, Creaser I I, Daszkiewicz B K, Geue R J, Sargeson A M and Walker G W 1993 *J. Chem. Soc., Chem. Commun.* 1844
- Bharadwaj P K 1993 *J. Sci. Ind. Res. (India)* **52** 533
- Bissell R A, de Silva A P, Gunaratne H Q N, Lynch P L N, Maguire G E M and Sandanayake K R A S 1992 *Chem. Soc. Rev.* **21** 187
- Chand D K and Bharadwaj P K 1996 *Inorg. Chem.* (in press)
- Chand D K, Ragunathan K G, Mak T C W and Bharadwaj P K 1996 *J. Org. Chem.* **61** 1169

- Chen D and Martell A E 1991 *Tetrahedron* **47** 6895
- de Silva A P, Gunaratne H Q N and Sandanayake K R A S 1990 *Tetrahedron Lett.* **31** 5193
- de Silva A P, Gunaratne H Q N and McCoy C P 1993 *Nature (London)* **364** 42
- Dietrich B, Lehn J M and Sauvage J P 1969 *Tetrahedron Lett.* **10** 2885
- Ghosh P, Shukla R, Chand D K and Bharadwaj P K 1995 *Tetrahedron* **51** 3265
- Ghosh P, Bharadwaj P K, Mandal S and Ghosh S 1996 *J. Am. Chem. Soc.* **118** 1553
- Hunter J, Nelson J, Harding C, McCann M and McKee V 1990 *J. Chem. Soc., Chem. Commun.* 1148
- Izzat R M, Pawlak K, Bradshaw J S, Bruening R L and Tarbet B J 1992 *Chem. Rev.* **92** 1261
- Jazwinski J, Lehn J M, Lilenbaum D, Ziessel D R, Guilhelm J and Pascard C 1987 *J. Chem. Soc., Chem. Commun.* 1691
- Lehn J M 1978 *Acc. Chem. Res.* **11** 49
- Lehn J M 1983 In *Biomimetic chemistry* (eds) Z Yoshida and N Ise (Amsterdam: Elsevier) pp 163
- Lehn J M 1985 *Science* **227** 849
- Lehn J M 1986 *Proceedings of the XIth International Symposium on Macrocyclic Chemistry* Florence, Italy
- Lehn J M 1990 *Angew. Chem., Int. Ed. Engl.* **29** 1304
- McDowell D and Nelson J 1988 *Tetrahedron Lett.* **29** 385
- Meade T J and Busch D H 1985 *Prog. Inorg. Chem.* **33** 59
- Mendoza J, Mesa E, Rodriguez-Ubis J C, Vasquez P, Vogtle F, Windscheif P M, Rissanen K, Lehn J M, Lilenbaum D and Ziessel R 1991 *Angew. Chem., Int. Ed. Engl.* **30** 1331
- Ragunathan K G and Bharadwaj P K 1992a *J. Chem. Soc., Dalton Trans.* 2417
- Ragunathan K G and Bharadwaj P K 1992b *Tetrahedron Lett.* **33** 7581
- Ragunathan K G and Bharadwaj P K 1995 *Proc. Indian Acad. Sci. (Chem. Sci.)* **107** 519
- Ragunathan K G, Shukla R, Mishra S and Bharadwaj P K 1993 *Tetrahedron Lett.* **34** 5631
- Sargeson A M 1986 *Pure Appl. Chem.* **58** 1511
- Smith P H, Barr M E, Brainard J R, Ford D K, Freiser H, Muralidharan S, Riley S D, Ryan R R, Silks L A III and Yu W 1993 *J. Org. Chem.* **58** 7939
- Takemura H, Shinmyozu T and Inazu T 1991 *J. Am. Chem. Soc.* **113** 1323