

Intramolecular C–H···O hydrogen bonding reduces cation complexation strength in a fluorescent crown ether

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Received (in Columbia, MO, USA) 6th April 1999, Accepted 20th May 1999

Complexes of the fluorescent crown ether, *N,N*-bis(9-anthrylmethyl)-4,13-diaza-18-crown-6, with NaI₃ and KSCN reveal the presence of intramolecular C–H···O hydrogen bonds that appear to control conformation and lead to reduced cation binding affinity.

For more than a decade, the fluorescent properties of macrocycles have proved fascinating.¹ A hope has been that fluorescent residues appended to macrocycles would afford lariat ethers² that could function as cation sensors.³ Indeed, de Silva and de Silva demonstrated ‘fluorescent signaling’ in *N*-(9-anthrylmethyl)aza-15-crown-5 and -18-crown-6 nearly 15 years ago.⁴ Anthracene has proved particularly popular as the fluorescent element. It has, for example, been incorporated into crowns and cryptands used as probes of phospholipid membrane fluidity.⁵ It has been attached to one crown, to two crowns, and *via* the 9- and 10-positions of a single molecule to a macrocycle to afford proton sensors.⁶ Two anthracenes incorporated into a macrocycle⁷ and two anthracenes attached to a crown afforded a crown–cryptand photoswitch.⁸ Anthracene has also been incorporated as the fluorescent element for sensing Cu²⁺ ions⁹ and D-glucosamine.¹⁰ Very recently, Kubo, Ishige and Sakurai have prepared and studied *N,N'*-bis(9-anthrylmethyl)-4,13-diaza-18-crown-6 **1** for use as a fluorescent cation sensor. In the latter case, some cation binding selectivity and cation-induced fluorescence change were observed, but the results were generally modest. This is surprising for such a widely used and strongly fluorescent residue. We now report the first solid state structures of **1** bound by either Na⁺ or K⁺. Intimate C–H···O hydrogen bonding between the sidearm and macrorings clearly decrease the ability of **1** to form stable cation complexes and, in turn, diminish their utility as sensors.

Compound **1** was prepared by heating commercial 9-chloromethylantracene, 4,13-diaza-18-crown-6,¹¹ and Na₂CO₃ in MeCN for 72 h. Crystallization from toluene afforded **1** as yellow needles (68%, mp 195–196 °C).¹² Kubo and co-workers report **1** in 90% yield as yellow needles (from CHCl₃) having mp 189–190 °C. The NaI₃ complex of **1** was isolated from a mixture of **1** and NaI (1 : 1) in THF that was not protected from

the air. The rhombohedral crystals obtained (dark yellow to brown) had the stoichiometry **1**·NaI₃·(THF)₂ and decomposed on melting, presumably with loss of THF, at *ca.* 215 °C. A projection of the complex is shown in Fig. 1.

There are several notable features about this complex. First, the macroring is in the *D*_{3d} conformation, as expected. The average Na⁺–O distance is 2.46 Å and the Na⁺–N distances are 3.03 and 2.92 Å. These values are typical for diaza-18-crown-6 Na⁺ complexes. The sidearms are in the *anti* conformation, one being above, and the other below, the mean plane of the macroring heteroatoms. The *anti* orientation of the anthryl sidearms effectively excludes the anion from the cation's solvation sphere. It is especially interesting that the two (disordered) THF molecules (normally excellent donors) found in the crystal lattice do not coordinate the cation. Since the macroring is essentially planar, it is reasonable to expect the apical position(s) to be occupied by donor groups. Either I₃[−] or THF or a combination of the two could fill the void above and below the macrocycle but neither does. Instead, the space is filled by anthracene.

There are two especially close contacts between C–H bonds and electronegative elements. The first involves the hydrogen atoms on anthracene's 1-position (α -position). The C···O distances are 3.54 ($\theta = 152.7^\circ$) and 3.58 Å ($\theta = 156.7^\circ$). If the aromatic C–H bonds are 0.95 Å long, this makes the average H-bond distance ~ 2.7 Å from the nearest macroring oxygen atom. The second type of close contact is a C···I interaction observed between one (but not the other) of the anthracene 2-positions (β -positions) and the proximal terminus of I₃[−] (3.79 Å) and has a C–H–I bond angle of *ca.* 140°. In contrast, the shortest distance between Na⁺ and any iodine atom or either THF oxygen is ≥ 6 Å. There are also anthracene–crown C···N contacts apparent in both structures (3.17–3.39 Å range) but the contact angles (113–117°) make their overall importance unclear.

The K⁺ complex of **1** was isolated from a mixture of **1** and KSCN (1 : 1), dissolved in CHCl₃–EtOH (1 : 1 v/v). The colorless, rhombohedral crystals had the stoichiometry **1**·KSCN·(EtOH)₂. Interactions analogous to those observed in the Na⁺ complex of **1** are apparent here. The average K–O distance for the macroring contacts is 2.73 Å and the average K–

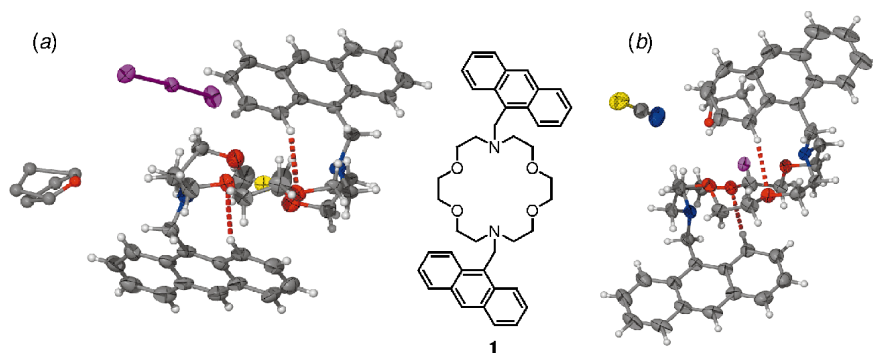


Fig. 1 Solid state structures of **1** complexed by (a) NaI₃ and (b) KSCN. In each case, one of two disordered solvent molecules has been deleted for clarity. Dotted lines indicate C–H···O contacts. Thermal ellipsoids are shown at 50% probability.

N distance is 3.20 Å. We also note a contact between the oxygen of one EtOH molecule and K⁺ (K–O) that is 2.71 Å, essentially identical to the macroring K–O interactions. The anthracene C–H to macroring oxygen contacts (C···O, similar to those observed for **1**·Na⁺) are 3.58 (θ = 177.5°) and 3.63 Å (155.5°). Carbon-3 of one anthracene is 4.12 Å from the sulfur atoms of SCN[−] and the C–H···S angle is 151.3°.

Other data are worthy of note. The transannular N↔N separation in **1**·NaI₃ is 5.93 Å and in **1**·KSCN is 6.11 Å. The latter value is similar to those reported for other K⁺ complexes of diaza-18-crown-6 derivatives.¹³ In contrast, the transannular span for the Na⁺ complex is considerably larger than the value of 5.10 Å reported for *N,N'*-bis(2-hydroxyethyl)-4,13-diaza-18-crown-6.¹³

Kubo *et al.*¹⁴ have titrated **1** with either Na⁺ or K⁺ and used fluorescence changes to determine complexation constants. They have found that in MeOH–CHCl₃ (9:1 v/v), log K_s (Na⁺) for **1** is 2.70 and log K_s (K⁺) is 3.29. They do not report values in the more commonly used solvent: anhydrous MeOH. The poor solubility of **1** in MeOH prevented us from measuring log K_s in this solvent.

Several observations clearly indicate that unusual interactions occur in the Na⁺ and K⁺ complexes of **1**. One of the most obvious is the low cation binding constant. In anhydrous MeOH solution, *N,N'*-dibenzyl-4,13-diaza-18-crown-6 (**2**) was found to have the following cation complexation constants: log K_s (Na⁺) = 2.72 and log K_s (K⁺) = 3.38. It is well known that cation complexation constants diminish with increasing polarity of the solvent.¹⁵ It is expected, therefore, that complexation constants determined in a CHCl₃–MeOH mixture would be greater than in more polar MeOH. In fact, the binding constants are lower by a small factor (1.2- to 1.4-fold). This suggests that in MeOH, log K_s would be significantly lower for **1** than for **2**.

In previous studies, we found a clear correlation between the complexed cation's coordination number and the metal–heteroatom donor group distances.¹³ As the coordination number increased, the M⁺–O distance increased. Indeed, our data correlated well with the values published by Shannon.¹⁶ Thus, metal-ion-to-oxygen distances for six-coordinated Na⁺ and K⁺ should be, respectively, 2.42 and 2.78 Å. (Considering the EtOH interaction in **1**·KSCN, the latter value could be 2.86 Å). In fact, the average distances observed are, respectively, 2.47 and 2.73 Å. The predicted M⁺–N distances are 2.52 and 2.62 Å for Na⁺ and K⁺. The observed average distances are 2.97 and 3.20 Å. The M⁺–O distances are approximately as expected for six-coordinated Na⁺ and K⁺, but the M⁺–N lengths are remarkably long. This suggests that the cation's interaction with macroring nitrogen is weaker than expected and may be compensated by other, less obvious interactions.

The most remarkable feature of these two structures is the short C–H···O contacts observed between the anthracene α-hydrogen and a proximate macroring oxygen. Desiraju has recently discussed the occurrence of such interactions.¹⁷ The four close contacts observed for the interaction noted above are

in the range (designated *D*) of 3.54–3.62 Å and exhibit C–H···O angles from 152.7–177.5°. Desiraju has noted that '*D* values span the range 3.00–4.00 Å' and has further stated that 'linear bonds (150 < θ < 180°) are structurally significant.' Clearly, all of these putative contacts fall within the 'significant' range by both criteria. Moreover, the molecules that possess these remarkable contacts are unusually poor cation binders. The excellent fluorescent potential of the anthryl residue should thus be weighed against its potential to interfere with complexation when considered as the sensor element in fluorescent signaling cation complexers.

We thank the NIH (GM-36262) and the NSF (CHE-9805840) for grants that supported this work. We are also grateful for an American Chemical Society fellowship, funded by Procter and Gamble, to E. S. M. We appreciate helpful discussions with Professors Nigam Rath and Jonathan Steed.

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Communication 9/02676B