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Communication

A Redox-switchable Molecular Receptor Based on Anthraquinone

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The reaction of two equivalents each of bisphenol A with 1,5-dichloroanthraquinone in the presence of base leads to a molecular box designed to be electroactive. The compound is fully characterized, it exhibits reversible redox behavior, and its solid state structure has been obtained. Two molecules of toluene are present in the crystal lattice but these are not located within the receptor's cavity. Evidence for an interaction of ferrocene (guest) with a precursor to the molecular box is described.

Unlike cation binders, molecular receptors normally rely for complexing strength upon interactions that lack full charges. Typically [1], receptors are prepared that disolve in water so that complexation of a neutral guest can be enhanced by hydrophobic contacts between it and the host. Weak interactions such as π-stacking or charge transfer may also play a role in molecular complexation by these systems. In a few cases, such feeble forces have been augmented by electrochemical switching [2]. The principle was demonstrated for cation binding by lariat ethers a number of years ago [3] and more recently for viologen-substituted molecular boxes [4]. Despite the interesting results obtained, the redox "switchability" of the latter receptor was not originally designed into the compound. We thus set about designing a simple receptor system that it was hoped would exhibit redox-switched binding ability toward a variety of molecular species.

The anthraquinone residue has proved to be a versatile redox switching element that has been used by a number of groups [5] as well as our own [6]. Its three fused rings make it a module of potential utility in supramolecular chemistry for the construction of rigid, planar systems. The distance between its 2- and 6-positions is

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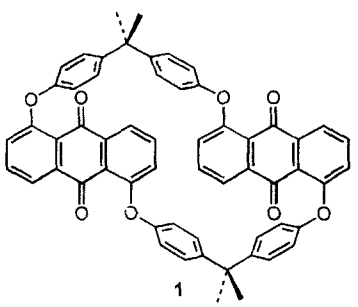
approximately 10 Å. The compound is flat overall and the π-surfaces are electron poor. The presence of two carbonyl groups directly opposite each other, however, makes anthraquinone reducible by one- or two-electron transfer to the radical anion or to the dianion, respectively. The anthraquinone residue has been incorporated into crown ethers [7], podands [8], cryptands [9], cyclodextrins [10], fluorescent sensors [11], and molecular (cyclophane) receptors [12], and even an "organic superstructure" [13]. Some of this work has recently been reviewed [14].

An examination of CPK molecular models suggested that an essentially square molecular receptor would result from a "2 + 2" double cyclization reaction between readily available 1,5-dichloroanthraquinone and bisphenol A. Molecular receptor **1** is essentially square and is bounded by arenes on all sides. It appeared from models that the arenes on opposite sides of the receptor would be approximately parallel. Molecular models further suggested that ferrocene was of an appropriate size to be bound intrapyxially by receptor **1**. It occurred to us that not only might ferrocene be bound by receptor **1** but that ferrocene might template its formation. Ferrocene is an electron donor and anthraquinone is an electron acceptor and we speculated that some π-acid, π-base interaction might also have a salutary effect on synthetic access.



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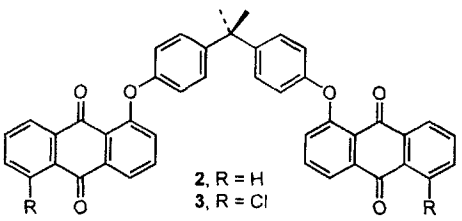
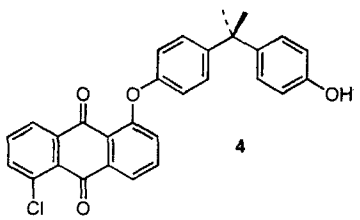
The "half-receptor unit" **4**, was obtained in 40% yield from bisphenol A and 1,5-dichloroanthraquinone by using a variation of the previously published procedure for anthraquinone displacements [15]. Thus, **4** was obtained after chromatography as a glassy, dark yellow solid, mp 109–111°C [16]. Cyclodimerization of **4** was then attempted under similar conditions. The desired anthraquinone receptor was obtained from **4** in 28% yield (mp > 320°C) by cyclization as previously described. After **1** was isolated and characterized, it was discovered that a single step reaction was possible for its preparation. Thus, equimolar 1,5-dichloroanthraquinone and bisphenol A were suspended in a mixture of acetonitrile, toluene, and triethylamine (37.5:2.5:1 v/v) in the presence of 5 equivalents of base and heated under reflux for 5 d. Chromatographic workup gave **1** in 10% yield. When either triethylamine or toluene was omitted from the reaction mixture, the isolated



2, R = H
3, R = Cl



4

yield was lower but not enough experiments have been done to be sure that the differences in yield are statistically significant.

An alternate approach was to prepare the dihalide resulting from the reaction of bisphenol A with two equivalents of 1,5-dichloroanthraquinone. This was done using NaH as base in THF. After workup, **3** was isolated as a yellow solid, mp 160–161°C. Although the yield in this reaction was 26%, this sample of **3** decomposed fairly quickly upon standing and was not used further in the synthetic effort.

Molecular receptor **1** proved difficult to characterize because of its high melting point and poor solubility. It was also difficult to obtain a combustion analysis since **1** occluded whatever solvent or combination of solvents that were used for chromatography. The NMR and high resolution mass spectra were unambiguous, however [17]. The identity of **1** was confirmed by obtaining the solid state structure on a sample that was crystallized from toluene [18]. The structure is shown in Figure 1.

The solid state structure shows the receptor along with two molecules of toluene. The solvent apparently fills interstitial sites within the lattice and is not embraced directly by the molecular box. It seemed possible that toluene was trapped inside **1** but that it was disordered and therefore not visible. This is unlikely since in this case, at least, the two anthraquinones are not in an ideal face-to-face and parallel arrangement but rather offset with respect to each other. This spatial arrangement contracts the internal cavity bringing the anthraquinones almost into contact with one another. This suggests that if the receptor is not dynamic, its ability to bind substrates may be hampered by the collapsed cavity.

The ability of compounds **1**, **2**, or **3** (see structures above) to complex xylene, naphthalene, and ferrocene was assessed by dissolving the receptor in DMSO-d_6 and adding 0–100 equivalents each of the guest. The ^{1}H-NMR spectrum for the host was recorded in the absence of and after addition of 2, 4, 8, 16, 32, 64, and 100 equivalents of guest. No significant NMR shift was observed for any of these three guest molecules at any of the concentrations studied.

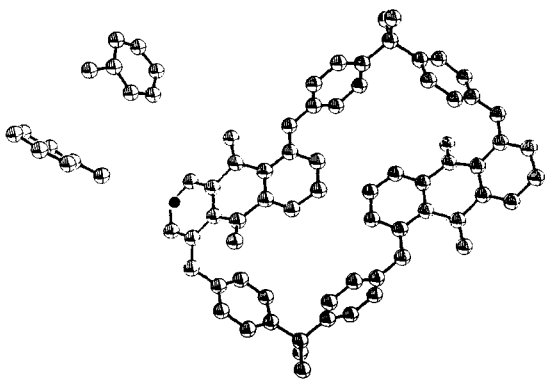


FIGURE 1 Solid state structure of **1**·(toluene)$_2$.

An alternate approach to assessing the complexing ability of this series of receptors was to observe any change in redox potential as a solution of the host was titrated with ferrocene. Cyclic voltammetry was undertaken on **1** by observing it (1 mM in DMF, 0.2 M $Bu_4N^{\oplus}$ $PF_6^{\ominus}$) in the window 0 to −1.3 V (*vs.* SSCE, Pt° counter-electrode) while titrating with 0 to 20. equivalents of ferrocene. Only the first wave was observed; a second wave near 2 V was outside the selected window. Redox potentials ($E_{1/2}$) for **1** and **2** were, respectively −822 and −820 mV. In neither case was a significant difference observed in the presence of guest suggesting a lack of complexation. While it was anticipated that the redox potential of **2** would not be affected by ferrocene, the lack of any apparent complexation by **1** was disappointing. Our initial interpretation of this was that like the situation in the solid state, the cavity is collapsed precluding complexation even of an appropriately-sized substrate.

The inability of either **1** or **2** to complex may not be due entirely to steric factors. Cyclic voltammetry was undertaken for compound **3** as described above for **1** and **2**. Compound **3** which differs from **2** by the presence of a chlorine atom in each anthraquinone. In the absence of any ferrocene, the observed potential was −770 mV. The potential is lower than for **1** or **2** due to the electron withdrawing effect of chlorine compared to oxygen. Ferrocene was added incrementally up to 20 equivalents by which time the redox potential of the host had altered from −770 to −805 mV, a small but significant shift. We therefore believe that complexation of receptor **1** would be enhanced by

the presence of electron withdrawing groups and this may be sufficient to overcome the apparent steric effect resulting from proximity of the intra-annular anthraquinones.

References

[1] Diederich, F. N. (1990). Cyclophanes, Vol. 2 in Stoddard J. F. (Ed.), Monographs in Supramolecular Chemistry, The Royal Society of Chemistry, London, England.

[2] Kaifer, A. E. and Mendoza, S. (1996). "Redox-switched receptors", Chapter 19 in Gokel, G. W. (Ed.), Comprehensive Supramolecular Chemistry, Vol. 1, Pergamon, Oxford, p. 701.

[3] Kaifer, A., Echegoyen, L., Gustowski, D., Goli, D. M. and Gokel, G. W. (1983). *J. Am. Chem. Soc.*, **105**, 7168–7169.

[4] (a) Bissell, R. A., Córdova, E., Kaifer, A. E. and Stoddart, J. F. (1994). *Nature*, **369**, 133–137; (b) Córdova, E., Bissell, R. A. and Kaifer, A. E. (1995). *J. Org. Chem.*, **60**, 1033–1038.

[5] Nakatsuji, S., Ohmori, Y., Iyoda, M., Nakashima, K. and Akiyama, S. (1983). *Bull. Chem. Soc. Jpn.*, **56**, 3185–3186.

[6] Zhang, L., Lu, T., Gokel, G. W. and Kaifer, A. E. (1993). *Langmuir*, **9**, 786–791.

[7] (a) Maruyama, K., Sohmiya, H. and Tsukube, H. (1985). *Tetrahedron Lett.*, 3583; (b) Maruyama, K., Sohmiya, H. and Tsukube, H. (1986). *J. Chem. Soc. Perkin Trans.*, **1** 2069; (c) Echegoyen, L., Gustowski, D. A., Gatto, V. J. and Gokel, G. W. (1986). *J. Chem. Soc. Chem. Commun.*, pp. 220–223; (d) Ozeki, E., Kimura, S. and Imanishi, Y. (1988). *J. Chem. Soc. Chem. Commun.*, p. 1353; (e) Echegoyen, L. E., Yoo, H. K., Gatto, V. J., Gokel, G. W. and Echegoyen, L. (1989). *J. Am. Chem. Soc.*, **111**, 2440–2443; (f) Ossowski, T. and Schneider, H. (1990). *Chem. Ber.*, **123**, 1673.

[8] (a) Gustowski, D. A., Delgado, M., Gatto, M., Echegoyen, L. and Gokel, G. W. (1986). *Tetrahedron Letters*, pp. 3487–3490; (b) Echeverria, L., Delgado, M., Gatto, V. J., Gokel, G. W. and Echegoyen, L. (1986). *J. Am. Chem. Soc.*, **108**, 6825–6826; (c) Delgado, M., Gustowski, D. A., Yoo, H. K., Gatto, V. J., Gokel, G. W. and Echegoyen, L. (1988). *J. Am. Chem. Soc.*, **110**, 119–123; (d) Kim, H., Schall, O. F., Fang, J., Trafton, J. E., Lu, T., Atwood, J. L. and Gokel, G. W. (1992). *J. Phys. Org. Chem.*, **5**, 482; (e) Silva, D. J., Kahne, D. and Kraml, C. M. (1994). *J. Am. Chem. Soc.*, **116**, 2641.

[9] Chen, Z., Schall, O. F., Alcalá, M., Li, Y., Gokel, G. W. and Echegoyen, L. (1992). *J. Am. Chem. Soc.*, **114**, 444–451.

[10] Aquino, A. M., Abelt, C. J., Berger, K. L., Darragh, C. M., Kelley, S. E. and Cossette, M. V. (1990). *J. Am. Chem. Soc.*, **112**, 5819.

[11] DeSilva, A. P. and Sandanayake, K. R. A. S. (1991). *Tetrahedron Lett.*, p. 421.

[12] Haeg, M. E., Whitlock, B. J. and Whitlock, H. W.Jr. (1989). *J. Am. Chem. Soc.*, **111**, 692.

[13] Otsuki, J., Oya, T., Lee, S.-H. and Araki, K. (1995). *J. Chem. Soc. Chem. Commun.*, p. 2193.

[14] Bouas-Laurent, H., Desvergne, J.-P., Fages, F. and Marsau, P. (1991). "Anthracenocrown ether and cryptands, cation-directed photophysics and photochemistry", in Frontiers in Supramolecular organic chemistry and photochemistry, Schnieder, H.-J. and Dürr, H. (Eds.); VCH, Weinheim, p. 265.

[15] Fang, J., Lu, T., Kim, H., Delgado, I., Geoffroy, P., Atwood, J. L. and Gokel, G. W. (1991). *J. Org. Chem.*, **56**, 7059–7065.

[16] Analysis, calculated for $C_{29}H_{21}O_4Cl$, C, 74.28%; H, 4.51%; O, 13.51%; Cl, 7.56%. Found: C, 74.07%; H, 4.61%; Cl, 7.46%.

[17] Characterization 1: ^{1}H-NMR (300 MHz, $CDCl_3$): d 1.56 (s, $\underline{H}_2O$, 2H), 1.67 (s, $C\underline{H}_3$, 12H), 6.78 (d, phenol, 8H), 7.11 (m, phenol/anthraquinone, 12H), 7.50 (t, anthraquinone, 4H), 7.80 (d, anthraquinone, 4H). IR (KBr): 1673, 1584, 1453, 1250, 870 cm^{-1}. High resolution FAB mass spectrum, calculated for $C_{58}H_{40}O_8$: 865.2723 g/mol. Found: 865.2764 g/mol.

[18] Crystals suitable for X-ray crystallographic analysis were obtained by slow evaporation of a solution containing 1 in toluene. Crystal structure data $C_{58}H_{40}O_8 \bullet 2C_7H_8$, FW 1049.25 g mol^{-1}, monoclinic crystal system, space group P 21/c, $Z = 2$, $a = 10.5485(9)$ Å, $b = 22.2809(11)$ Å, $c = 14.3415(14)$ Å, $\alpha = 90°$, $\beta = 91.720(4)°$, $\gamma = 90°$, $V = 3369.2(5)$ Å^3, $dc = 1.202$ g cm^{-3}, Mo Kα radiation, $R = 0.0826$ for 5007 unique reflections observed with $F > 4(F)$ measured on an Enraf-Nonius CAD4 X-ray spectrometer using $\omega/2\theta$ scans, $3.66° < 2\theta < 59.97°$.