The Synthesis and X-Ray Structure Analysis of an Unusual Bent Anthraquinone Based Coronand†

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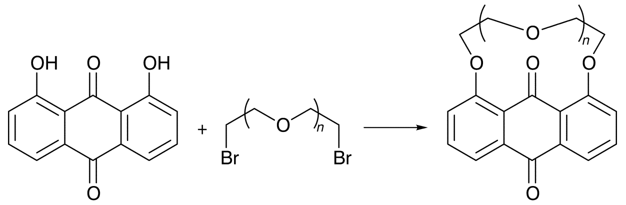
The phase transfer catalyzed cyclisation of 1,8-dihydroxyanthraquinone with bis(2-bromoethyl) ether provides an unusual bent anthraquinone based coronand.

The remarkable stability and reversibility of the anthraquinone radical anion and its unique capability of enhancing cation binding and transport across membranes has generated great interest in anthraquinone based receptors.[1–3] However, lack of convenient and effective synthetic methods for the preparation of required substituted anthraquinones has been a major drawback in these studies. Here, we report that under phase transfer catalytic conditions 1,8-dihydroxyanthraquinone **1** undergoes facile cycloalkylation[4] with oligoethylene glycol dibromides to provide 1:1 macrocycles. In the case of reaction of **1** with bis(2-bromoethyl ether) a unique bent anthraquinone (X-ray) based coronand is obtained.

The solution of **1** and bis(2-bromoethyl) ether in dimethylformamide (DMF) containing a suspension of KF–alumina (base) and tetrabutylammonium hydrogensulfate (catalyst) provides macrocycle **3a** (25%), mp 200 °C, FAM ($M^+ + 1$) *m/z* 311. its ^{1}H NMR spectrum shows ABXY patterns (four doublets each) centered at δ 3.37, 3.66, 3.89, 4.64 each due to OCH_2 protons and the anthraquinone unit shows two doublets at δ 7.37 (2 H, *J* 7.8, ArH), 7.90 (2 H, *J* 7.8, ArH) and a triplet at δ 7.59 (2 H, *J* 7.8, ArH). The appearance of two normal doublets and one triplet due to aromatic signals shows that 1,8-dihydroxyanthraquinone is symmetrically substituted but the diethylene glycol unit shows unusual coupling of protons. Its visible spectrum shows an absorption band at λ_{max} 331.6 nm ($\varepsilon = 9.20 \times 10^3$). 1,8-Dihydroxyanthraquinone and its mono- and di-O-alkylated derivatives[5] show λ_{max} at 427, 410 ± 2 and 378 ± 3 nm, respectively. The 45 nm hypsochromic shift in **3a** in comparison with acyclic 1,8-dialkoxythraquinone derivatives (378 ± 2 nm) points towards the loss of planarity in the anthraquinone unit.



1 **2** **3**

For **2** and **3** **a**: $n = 1$; **b**: $n = 2$; **c**: $n = 3$

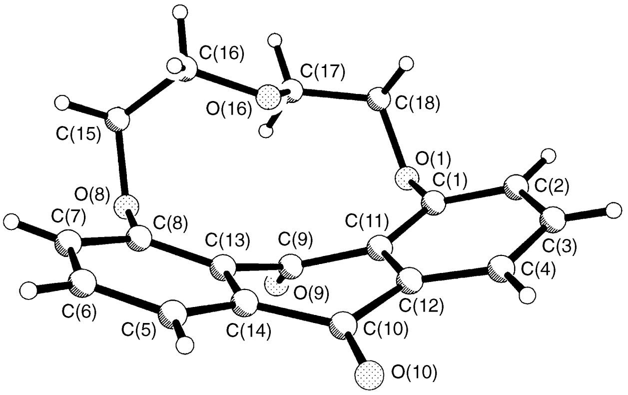


Fig. 1 X-Ray crystal structure of macrocycle **3a**

The X-ray crystal structure of **3a** (Fig. 1) shows that the anthraquinone unit has lost its planarity and two aryl rings form a 'V' intersecting at C9 and C10 forming a dihedral angle of 31.9(2)° in comparison with 3.1(1)° found in **3c** having a larger polyether space.[3] This arrangement also forces the two carbonyl oxygens to move in a direction opposite to the two mean planes. These results are in contrast to the nearly planar arrangement observed in the case of 1,8-dihydroxyanthraquinone and a butterfly arrangement observed in the case of anthraquinones possessing bulky groups at the 1 and 8 positions.[6] So, the presence of the diethylene glycol unit between the 1 and 8 positions of anthraquinone creates a strain on the anthraquinone ring system, thereby causing the loss of planarity.

The conformation about the C–C bonds in the two 1,4-dioxa units is close to synclinal [46.6(1)°, 72.4(1)°] for both the units as is required for the minimum energy conformation[7] in 1,4-dioxa units (O–C–C–O ~ 60°, C–C–O–C ~ 180°), but torsion angles about C–O bonds show significant deviations. Out of four C–C–O–C torsion angles, only one is antiperiplanar [C18–C17–O16–C16, 164.5(1)°] whereas the remaining three have been forced to be synclinal. Two of these torsion angles, *i.e.* C1–O1–C18–C17 [91.1(1)°] and C8–O8–C15–C16 [49.3(1)°], involve aryl carbons and their deviations may be attributed to the rigidity of the ring. The fourth torsion angle, C17–O16–C16–C15, is 67.5(1)°. This flipping from the *anti* to *gauche* conformation brings O16 towards the cavity leading to O16 . . . O1 [2.98(1) Å] and O16 . . . O8 [2.90(1) Å] contacts as van der Waals contacts.

The packing of the molecule shows π–π interactions between the two symmetry related rings C1, C2, C3, C4, C11 and C12 parallel to the *ab* plane with the centre-to-centre distance between the two rings being 3.715(1) Å. It also shows a short intermolecular contact C17–H17A . . . O9^i (C17 . . . O9, 3.44(1) Å, H17A . . . O9^i 2.55(1) Å, C17–H17A . . . O9i 152(1)°, where $i = x$, $-y + 1/2 + 1$, $z - 1/2$.

The macrocycles **3b** and **3c**, obtained by reaction of **1** with the respective dibromides, show in their UV spectra λ_{max} at 368 and 378 nm. So, the increase in spacer length between the 1,8-positions of anthraquinone results in release of the bend in the anthraquinone unit. **3b** and **3c** have been obtained previously[1f,1g] in 30–45% yields by reaction of 1,8-dichloroanthraquinone with the respective glycols.

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Table 1 Crystallographic data for **3a**

Empirical formula	$C_{18}H_{14}O_5$	Crystal size/mm	$0.2 \times 0.3 \times 0.2$
M_r	310.29	$\lambda(MoK\alpha)/cm^{-1}$	0.71073
Crystal system	monoclinic	$2\theta_{max}/^\circ$	45
Space group	$P2_1/c$	R_{int}	0.0325
a/Å	7.766(1)	No. observations [$I > 3\sigma(I)$]	1287
b/Å	17.839(2)	No. of variables	209
c/Å	10.787(1)	R	0.0325
$\beta/^\circ$	109.94(1)	D_c,	1.467 Mg m^{-3}
U/Å^3	1404.8(3)	μ	0.108 mm^{-1}
Z	4	wR	0.0825

Therefore, phase transfer catalyzed *O*-alkylation of **1** with dibromides provides a versatile synthetic methodology for the synthesis of cyclic receptors and in one case results in unprecedented strained coronand **3a**.

Experimental

For general experimental see ref. 8.

Synthesis of Macrocycles **3a**–**c***: General Procedure*.—A solution of 1,8-dihydroxyanthraquinone **1** (1 g, 4.1 mmol) and diethylene glycol dibromide (1.58 g, 6.25 mmol) in 30 ml of DMF containing a suspension of KF–Al_2O_3 (3:2) and tetrabutylammonium hydrogensulfate ($TBAHSO_4$) catalyst was stirred at 80 °C. After completion of the reaction (TLC, 72 h), the suspension was filtered and the residue was washed with ethyl acetate. The combined filtrate and washings were distilled under vacuum and the crude reaction product was chromatographed on a silica gel column using hexane–ethyl acetate as eluent to isolate pure compound **3a**. Similarly **1** reacts with oligoethylene glycol dibromides **2b** and **2c** under the above reaction conditions to provide macrocycles **3b** and **3c**, respectively.

Macrocycle **3a**.—(25%), mp 200 °C ($CHCl_3$–MeOH); ^1H NMR ($CDCl_3$): δ 3.37, 3.66, 3.89, 4.64 (ABXY pattern, 2H at each position, $4 \times CH_2$), 7.37 (2H, d, $J = 7.8$ Hz, ArH), 7.59 (2H, t, $J = 7.8$ Hz, ArH), 7.90 (2 H, t, $J = 7.8$ Hz, ArH); ^{13}C NMR (normal/DEPT-135) ($CDCl_3$): δ 69.53 (–ve, OCH_2), 73.32 (–ve, OCH_2), 122.71 (+ve, OCH_2), 122.71 (+ve, ArCH), 128.20 (+ve, ArCH), 132.29 (+ve, ArCH), 132.56 (absent, ArC), 134,29 (absent, ArC), 156.13 (absent, ArC), 182.54 (absent, C=O), 184.22 (absent, C=O); UV (CH_3CN): λ_{max}/nm 331.6 ($\varepsilon = 9.20 \times 10^3$), 253 ($\varepsilon = 6.67 \times 10^4$), 209 ($\varepsilon = 5.77 \times 10^4$); IR: ν_{max}/cm^{-1} (KBr): 1680, 1682, 1582; m/z 310 (M^+) (Found: C, 69.8; H, 4.4%. $C_{18}H_{14}O_5$ requires C, 69.68; H, 4.52%).

Macrocycle **3b**.—(40%), mp 210 °C ($CHCl_3$–MeOH); ^1H NMR ($CDCl_3$): δ 3.76 (4H, s, $2 \times CH_2$), 3.91 (4H, t, $J = 4.0$ Hz, $2 \times CH_2$), 4.23 (4H, t, $J = 4.0$ Hz, $2 \times CH_2$), 7.20 (2H, d, $J = 8.0$ Hz, ArH) 7.56 (2H, t, $J = 8.0$ Hz, ArH), 7.75 (2H, d, $J = 8.0$ Hz, ArH); ^{13}C NMR (normal/DEPT-135) ($CDCl_3$): δ 69.21 (–ve, OCH_2), 70.24 (–ve, OCH_2), 71.03 (–ve, OCH_2), 119.42 (+ve, ArCH), 120.27 (+ve, ArCH), 127.51 (absent, ArC), 133.19 (+ve, ArCH), 135.06 (absent, ArC), 157.82 (absent, ArC), 183.55 (absent, C=O); UV (CH_3CN); λ_{max}/nm 368 ($\varepsilon = 3.27 \times 10^3$), 253 ($\varepsilon = 1.58 \times 10^5$), 218.4 ($\varepsilon = 2.03 \times 10^5$); IR: ν_{max}/cm^{-1} (KBr): 1680, 1670, 1587; MS m/z 354 (M^+). (Found: C, 67.5; H, 5.4%. $C_{20}H_{18}O_6$ requires C, 67.80; H, 5.08%).

Macrocycle **3c**.—(40%), mp 156 °C ($CHCl_3$–MeOH) (lit.,[1f] mp 155 °C); ^1H NMR ($CDCl_3$): δ 3.78 (4H, t $J = 5.2$ Hz, $2 \times CH_2$), 3.89 (4H, t, $J = 5.2$ Hz, $2 \times CH_2$), 4.04 (4H, t, $J = 5.2$ Hz, $2 \times CH_2$), 4.25 (4H, t, $J = 5.2$ Hz, $2 \times CH_2$), 7.24 (2H, d, $J = 8.0$ Hz, ArH), 7.59 (2H, t, $J = 8.0$ Hz, ArH), 7.83 (2H, d, $J = 8.0$ Hz, ArH); ^{13}C NMR (normal/DEPT-135) ($CDCl_3$): δ 68.87 (–ve, OCH_2), 69.73 (–ve, OCH_2), 70.20 (–ve, OCH_2), 70.98 (–ve, OCH_2), 118.50 (+ve, ArCH), 119.03 (+ve, ArCH), 124.94 (absent, ArC), 133.36 (absent, ArC), 134.88 (+ve, ArCH), 158.24 (absent, ArC), 181.33 (absent, C=O), 183.65 (absent, C=O); UV (CH_3CN): λ_{max}/nm 378 ($\varepsilon = 3.97 \times 10^3$), 253.6 ($\varepsilon = 1.44 \times 10^5$), 220 ($\varepsilon = 2.17 \times 10^5$) nm; IR: ν_{max}/cm^{-1} (KBr): 1685, 1680, 1587; MS m/z 398 (M^+). (Found: C, 66.1; H, 5.8%. $C_{22}H_{22}O_7$ requires C, 66.33; H, 5.53%).

X-Ray Structure Analysis of Macrocycle **3a**.—All intensity data measurements were carried out on a Siemens P4 four-circle diffractometer with graphite monochromated Mo-Kα radiation ($\lambda = 0.71069$ Å). The structure was solved and refined using the SHELXTL software[9] package on a Siemens Nixdorf computer. The unit cell parameters were determined from a least squares fit of setting angles of 25 reflections in the θ range 8–20°. Three standard reflections were measured every 100 reflections and showed no significant intensity variation during the data collection.[10] The data were corrected for Lorentz and polarisation effects. No absorption corrections were applied. The structures were solved by direct methods and refined by a full matrix least squares method on F^2. The hydrogen atoms placed at calculated positions were refined isotropically with fixed thermal parameters and included in structure factor calculations. Scattering patterns used were from the International Tables for X-ray Crystallography. Data reduction, structure solution, refinement and molecular graphics were performed using SHELXTL-C. A summary of the crystal data experimental details and refinement results is given in Table 1. Full crystallographic details, excluding structure factors, have been deposited at the Cambridge Crystallographic Data Centre (CDDC). See Instructions for Authors, *J. Chem. Research* (*S*), 1998, Issue 1. Any request to the CCDC for this material should quote the full literature citation and the reference number 423/11.

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