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TETRAHEDRON

Synthesis and Electrode Properties of 16-Membered Azo- and Azoxycrown Ethers. Structure of Tribenzo-16-azocrown-6

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Abstract: 16-Membered benzoazo- and benzoazoxycrown ethers have been synthesized by reductive macrocyclization of respective bis(nitrophenoxy)oxaalkanes. The isomers of azocrown ethers were separated and *E* and *Z* structures were ascribed. Behavior of the compounds as ionophores in ion-selective membrane electrodes has been studied. Structure of *Z* isomer of 16-membered tribenzoazocrown ether has been determined. © 1998 Elsevier Science Ltd. All rights reserved.

INTRODUCTION

Azo- as well as azoxycompounds exist in two isomeric forms *Z* and *E*. Their reversible isomerization could be utilized for molecular switching, for construction of sensors and optical memories. Azocompounds were used as photo- or redox active components of films deposited on solid substrates.[1] Molecules combining -N=N- or -N(O)=N- groups and crown ether moieties should lead to materials joining susceptibility to isomerize and to bind cations as a result of specific features of both molecular sites. Competitive reviews on physicochemical behavior of crown ethers with an azo group inside or outside the macrocycle were published.[2] The best cooperative effect of both groups could be expected when the azo or azoxy groups form parts of a macrocycle.

13-, 16-, 19- and 20-membered azocrown ethers of the above mentioned type were prepared and studied by Shiga.[3] The synthesis involved alkylation of hydroxyazobenzene. An alternative synthetic route introduced by us consists in reduction of bis(2-nitrophenoxy)-3-oxapentane or its derivatives with stannites. This procedure leads to 13-membered crown ethers.[4] The respective azoxycrown ethers are simultaneously formed. Both isomers of 13-membered azocrown ether were obtained and *Z*-geometry was ascribed by X-ray for one of them.[5a] *E*-geometry is characteristic for their solid complexes.[6] The same geometry was found for solid azoxycrown ethers[5b] and azocrown compounds derivatives of diazafuranes.[5c]

Stereochemistry of lipophilic derivatives of 13-membered azocrown ethers in monolayers on aqueous subphases[7,8] or accumulated on a solid material[9,10] was analysed by surface pressure and surface potential

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studies or by electrochemical methods.

High sodium selectivities were found for 13-membered azo- and azoxycrown ethers applied as ionophores in ion-selective membrane electrodes.[4] 13-Membered azo- and azoxycrown ethers with attached lipophilic chains form stable monolayers on air-water interface[4,7,9,11] which interact with salts and undergo isomerization upon illumination. It was also shown that optical and electrochemical properties of azo- or azoxycrown ethers deposited on solid electrodes could be useful for molecular design of electrode surfaces for electroanalytical purposes.[10]

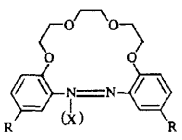
Preliminary studies showed that 16-membered azo- and azoxycrown ethers could be prepared in a similar way to their 13-membered analogues and possess many interesting properties.[3,4b,9] Stereochemistry of the parent 16-membered azo- and azoxycrown ethers and their complexes with potassium ions was elucidated based on ^{1}H NMR, UV-VIS spectra and X-ray studies.[12] Their reversible $Z \rightleftarrows E$ isomerization is slow at high pH. Z and E isomers of some 16-membered azocrown ethers accumulated on electrode surface could be detected and determined by cyclic voltammetry.[9]

The aim of this work was preparation of 16-membered azo- and azoxycrown ethers, separation and identification of their stereoisomers and presentation of their properties in ion-selective membrane electrodes.

RESULTS AND DISCUSSION

Synthesis

The presented synthesis of 16-membered azocrown ethers proceeds by the following route: *o*-nitrophenol or its derivatives were condensed with 1,8-dichloro-3,6-dioxaoctane [or 1,2-bis(2-chloroethoxy)benzene] in dry boiling dimethylformamide in the presence of anhydrous potassium carbonate to form the respective derivatives of 1,8-bis(2-nitrophenoxy)-3,6-dioxaoctane (compounds 17-24).

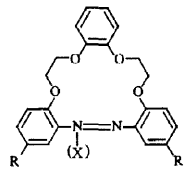


X = none

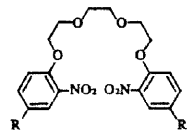
1. R=H
3. R=*t*-Bu
5. R=tetramethylbutyl
7. R=*n*-octyl
9. R=*n*-dodecyl
11. R=phenyl

X = O

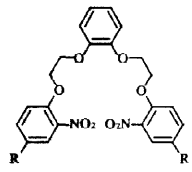
2. R=H
4. R=*t*-Bu
6. R=tetramethylbutyl
8. R=*n*-octyl
10. R=*n*-dodecyl
12. R=phenyl



13. R=H; X=none
14. R=H; X=O
15. R=*t*-butyl; X=none
16. R=*t*-butyl; X=O



17. R=H
18. R=*t*-butyl
19. R=*n*-octyl
20. R=tetramethylbutyl
21. R=*n*-dodecyl
22. R=phenyl



23. R=H
24. R=*t*-butyl

The last compounds were in turn reduced in a two phase system with sodium or potassium stannite to produce low molecular macrocyclic 16-membered azocrown ethers with moderate yields beside various amounts of polymers. Cautious crystallization allowed in many cases separation of both Z and E isomers. Their geometry could be easy ascribed based on significant differences in ^{1}H NMR spectra. $Z \rightleftarrows E$ isomerization is fast especially for compounds 7,9 and 11. The Z isomers show generally higher melting points. Azoxycrown compounds during the synthesis are formed in small yield in the case of the unsubstituted compounds.

Therefore they were synthesized by oxidation of the respective azocrown ethers. Azoxycrown ethers 8,10 and 12 are the main macrocyclic products of the reduction. All isolated azoxycompounds are *Z*(trans) isomers.

Membrane electrodes

The ion-selective membrane electrodes based on 16-membered azo and azoxycompounds are potassium selective. The best selectivity coefficients $\log K^{pot}_{K,Na}$ equal -3.5 and -3.6 for dodecyl- **9** and phenylazocrown ether derivative **11**, respectively (Figure 1).

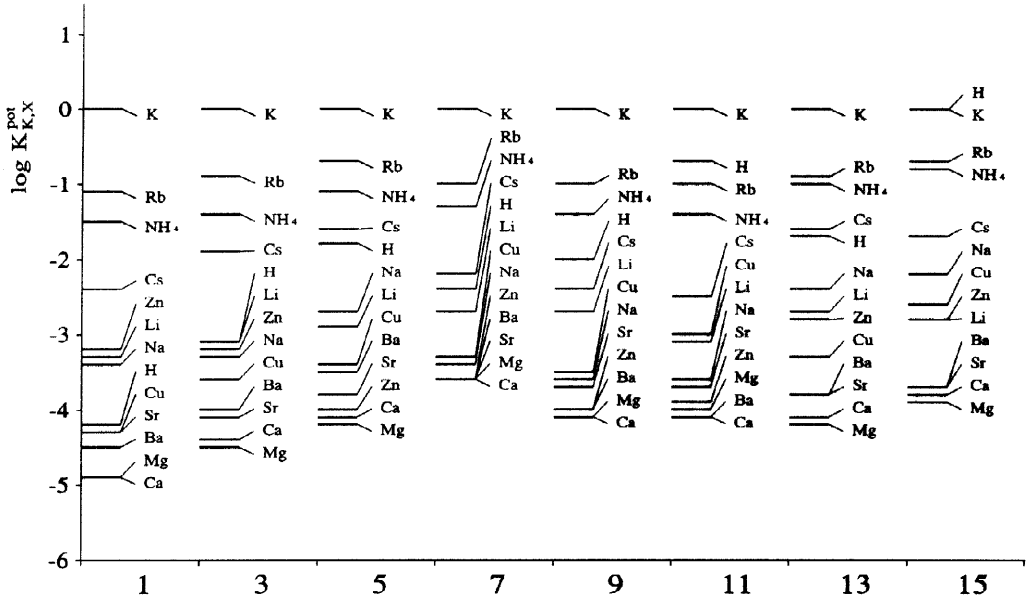


Figure 1. Diagram of $\log K^{pot}_{K,X}$ values of ion-selective membrane electrodes based on respective azocrown ethers.

For the parent compound **1** the selectivity is only slightly lower, however its moderate solubility in water causes leakage from the membrane. The detection limit ($\log L_{DK}$) for azocrown ether electrodes was in the range of -5.5 to -6.1. Slightly inferior is the detection limit for compounds **13** and **15** where the values are -5.0 and -5.3. The slopes are in the range of 58-60 mV/decade for the substituted azocrown ethers and 56 mV/decade for the parent compound.

The selectivities ($\log K^{pot}_{K,Na}$) for the electrodes with azoxycrown ethers are poorer (Figure 2). The values are lower by 0.6 to 1.2 unit as compared with the respective azocrown ethers. It could be stated, that drop of the electrode properties is mainly caused by decreased electron density on nitrogen atom neighboring the NO group or to the different mode of cation binding.

The azocrown ether electrodes are also highly potassium selective in the presence of many cations occuring in physiological fluids allowing application of these electrodes in clinical analysis (Figure 1).

The parent 16-membered azocrown ether **1** forms in acetonitrile 1:1 sodium and potassium complexes with the following stability constants: $\log K_{Na} = 3.69$ and $\log K_K = 3.15$. More stable is the 1:1 complex with

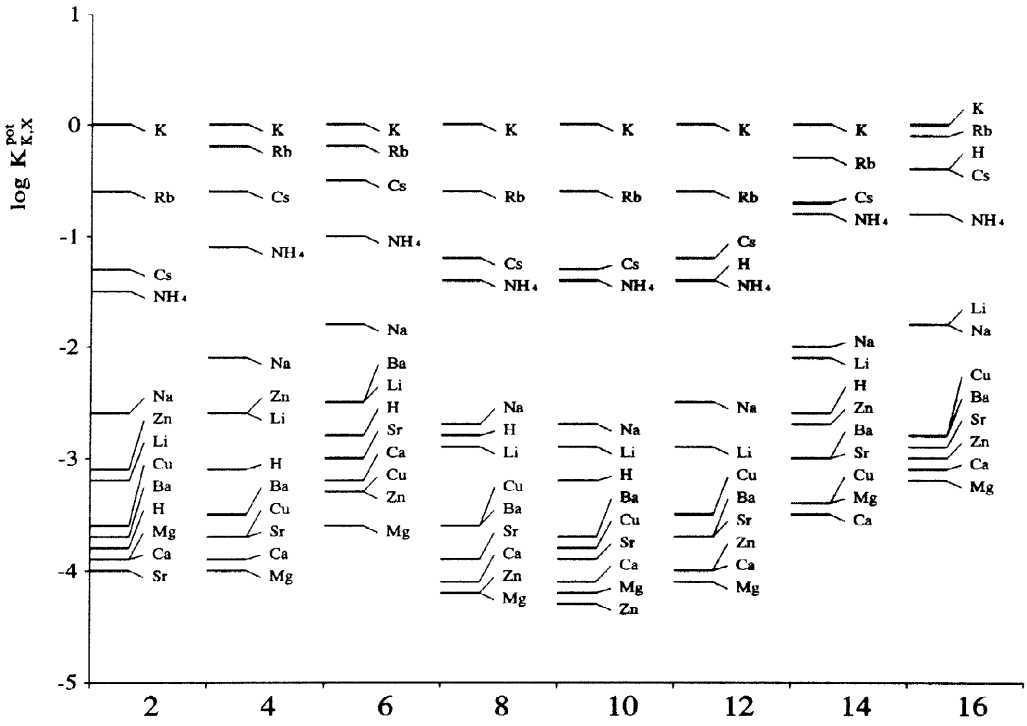


Figure 2. Diagram of $\log K^{pot}_{K,X}$ values of ion-selective membrane electrodes based on azoxycrown ethers.

lithium ($\log K_{Li} = 4.00$).[3] The order of stability constants does not reflect selectivities of the respective ion-selective membrane electrodes. Similar disagreement was noticed earlier for benzo- and naphtho-15-crown-5 ionophores applied in membrane electrodes.[13] A correlation of ion-selective electrode selectivities with structures of the ionophore complexes considering differences in lipophilicity, stoichiometry, the manner of anion binding to the complex cation and to the presence of solvent (water) molecules was discussed.[6b,12,14]

X-Ray structure

Isomers of tribenzo-16-azocrown-6 are relatively easy to obtain in pure form. The crystal quality of the *Z*-tribenzo-16-azocrown-6 enabled determination of its structure by X-ray diffraction.

In the assymetric part of the unit cell of the molecular crystal there are two crystallographicaly independent molecules **a** and **b** with similar conformational and geometrical parameters. One of the molecules is presented on Figure 3.

Selected bond lengths, valence and torsion angles are shown in Table 1 and 2. They are similar to those described for similar macrocyclic molecules.[5,6,12]

The macrocyclic fragment of the molecule has pseudo symmetry mirror plane intersecting the C(5)-C(6) and N(13)=N(14) bonds. The oxygen atoms are bent out of the mean plane of oxygen atoms in the macrocycle by ±0.06 and ±0.09 Å for molecule **a** and **b**, respectively, whereas the nitrogen atoms are displaced by 1.35 or 1.12 Å (for molecule **a**), and 1.23 or 1.10 Å (for molecule **b**). Both benzene rings bonded to nitrogen atoms are located on one side of the mean plane of oxygen atoms and the respective angles

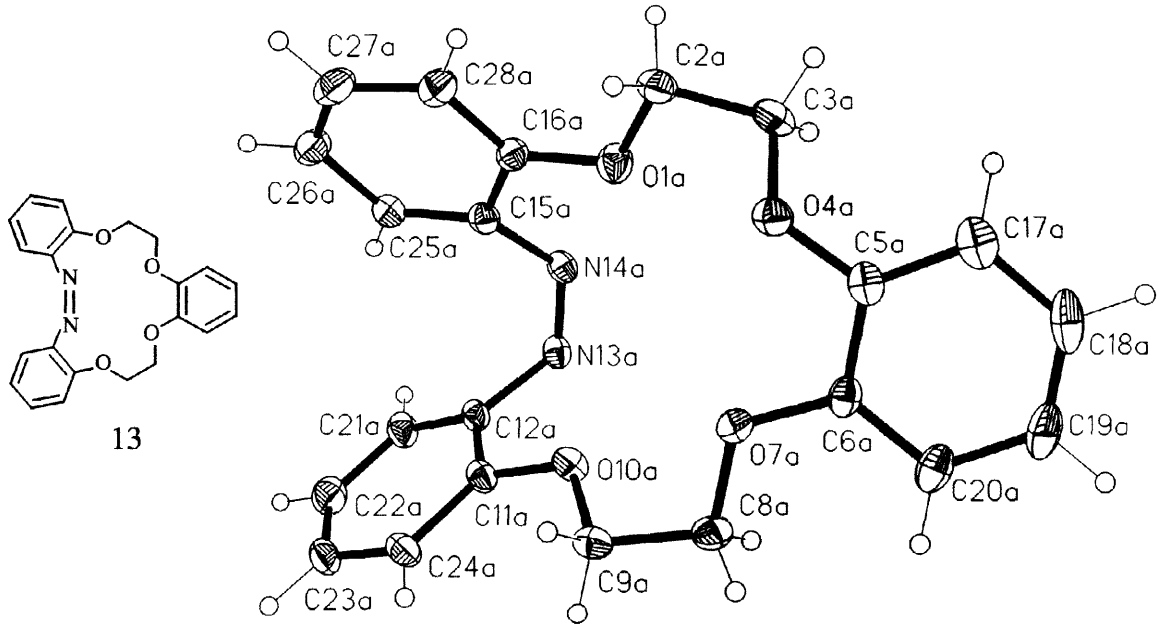


Figure 3. Structure of *Z*-tribenzo-16-azocrown-6 (molecule **a**).

are 44 and 55° for molecule **a** and 48 and 54° for molecule **b**. The plane of the third benzene ring forms with the mean plane an angle of 41 and 38° for molecule **a** and **b**, respectively.

The torsion angles in the macrocycle are to a great extent restricted due to presence of tree condensed to it benzene rings. The orientation of benzene residues around -N=N- bond is *cis*; in the chain C-N=N-C the order of torsional angles is *ac-sp-ac*. For $C_{(sp^3)}$ - $C_{(sp^3)}$ bonds the conformation is *sc*, for O - $C_{(sp^3)}$ it is *ap*, while for O - $C_{(sp^2)}$ the torsion angles varied from *ac* to *ap*.

In the structure of *Z*-tribenzo-16-azocrown-6 the nonvalence interactions are absent and the individual molecules in the crystal lattice are on the van der Waals distances.

Table 1. Selected bond distances (Å)

Bond	molecule **a**	molecule **b**	Bond	molecule **a**	molecule **b**
O(1)-C(2)	1.447(7)	1.451(6)	C(9)-O(10)	1.439(6)	1.443(6)
C(2)-C(3)	1.493(8)	1.505(8)	O(10)-C(11)	1.374(6)	1.359(6)
C(3)-O(4)	1.425(7)	1.424(6)	C(11)-C(12)	1.383(8)	1.398(7)
O(4)-C(5)	1.377(6)	1.375(6)	C(12)-N(13)	1.454(7)	1.448(6)
C(5)-C(6)	1.404(8)	1.382(7)	N(13)-N(14)	1.245(7)	1.272(6)
C(6)-O(7)	1.363(6)	1.364(6)	N(14)-C(15)	1.438(7)	1.451(6)
O(7)-C(8)	1.429(6)	1.425(6)	C(15)-C(16)	1.403(7)	1.413(7)
C(8)-C(9)	1.502(8)	1.501(7)	O(1)-C(16)	1.365(6)	1.374(6)

Table 2. Selected valence and torsion angles (°)

Angle	molecule a	molecule b	Angle	molecule a	molecule b
C(16)-O(1)-C(2)	117.7(4)	116.1(4)	C(5)-C(6)-O(7)	115.1(4)	114.8(4)
C(5)-O(4)-C(3)	116.6(4)	115.5(4)	C(20)-C(6)-O(7)	125.4(5)	124.2(4)
C(8)-O(7)-C(6)	116.5(4)	117.6(4)	C(9)-C(8)-O(7)	109.3(4)	109.4(4)
C(11)-O(10)-C(9)	117.7(4)	116.4(3)	C(8)-C(9)-O(10)	107.7(4)	107.8(4)
C(12)-N(13)-N(14)	122.4(4)	121.6(4)	C(12)-C(11)-O(10)	115.9(4)	115.8(4)
C(15)-N(14)-N(13)	122.6(4)	121.4(4)	C(11)-C(12)-N(13)	118.0(5)	118.9(4)
C(3)-C(2)-O(1)	108.1(5)	106.5(4)	C(21)-C(12)-N(13)	120.8(5)	120.3(4)
C(2)-C(3)-O(4)	107.3(5)	108.1(4)	C(16)-C(15)-N(14)	116.8(4)	118.0(4)
C(6)-C(5)-O(4)	116.8(4)	118.6(4)	C(25)-C(15)-N(14)	122.5(5)	122.0(4)
C(17)-C(5)-O(4)	122.4(5)	121.6(4)	C(15)-C(16)-O(1)	115.9(4)	115.3(4)
C(17)-C(5)-C(6)	120.8(5)	119.8(5)	C(28)-C(16)-O(1)	123.9(5)	124.8(4)
O(1)-C(2)-C(3)-O(4)	-72.2(6)	-81.1(5)	C(9)-O(10)-C(11)-C(12)	-170.3(5)	-171.9(4)
C(2)-C(3)-O(4)-C(5)	155.7(5)	157.4(4)	O(10)-C(11)-C(12)-N(13)	3.0(7)	2.7(6)
C(3)-O(4)-C(5)-C(6)	-134.0(5)	-121.3(5)	C(11)-C(12)-N(13)-N(14)	-91.2(6)	-91.5(6)
O(4)-C(5)-C(6)-O(7)	0.3(7)	2.6(6)	C(12)-N(13)-N(14)-C(15)	-4.2(8)	-7.1(7)
C(5)-C(6)-O(7)-C(8)	171.2(4)	172.9(4)	N(13)-N(14)-C(15)-C(16)	134.2(5)	129.2(5)
C(6)-O(7)-C(8)-C(9)	-171.1(4)	-178.8(4)	N(14)-C(15)-C(16)-O(1)	-10.9(7)	-10.0(6)
O(7)-C(8)-C(9)-O(10)	63.3(6)	65.2(5)	C(15)-C(16)-O(1)-C(2)	173.8(5)	169.4(4)
C(8)-C(9)-O(10)-C(11)	163.6(5)	169.3(4)	C(16)-O(1)-C(2)-C(3)	174.9(4)	177.3(4)

EXPERIMENTAL

General

All materials and solvents used for synthesis were of analytical reagent grade. Silica gel 60 (FLUKA) was used for column separations. Potassium chloride impregnated Silica gel (5/40 μm) containing 13% gypsum (CHEMAPOL, Czechoslovakia), cf.,[5b] was prepared in a following way: A 50 g portion of silica gel was suspended in 100 mL water containing 2 g of potassium chloride. The solvent was removed under reduced pressure and the residue dried for several hours at 105°, sieved and used for separation. TLC preparative glass plates covered with Silica gel 60 F_{254} (Merck) were used in some cases for separation of crown ethers.

^1H NMR spectra, all in $CDCl_3$, were carried out with a Varian instruments at 200 MHz (mainly) and 500 MHz. In the case of *Z* and *E* isomers of azocrown ethers the spectra were taken immediatelly after dissolution. The purity and identity of macrocyclic compounds was established by mass spectra taken on a

AMD-604 apparatus. The m.p. are uncorrected.

Membrane electrodes and potentiometric measurements

The preparation of membrane for ion-selective electrodes was described earlier in details.[4a] Typical composition of membranes are: ionophore 10 mg, potassium tetrakis(*p*-chlorophenyl)borate 0.5 mg, poly(winyl chloride) 50 mg and *o*-nitrophenyl octyl ether 0.1 mL.

X-Ray Crystal Structure Determination

A single crystal of azocrown **13** was obtained by crystallization from ethyl acetate. The data were collected at 293 K.

Crystal Data: $C_{22}H_{20}N_2O_4$, M 376.44, Monoclinic, a = 20.954(5), b = 13.286(3), c = 14.619(5) Å, β = 111.60(2)°, V 3784 Å^3 (by least-squares refinement on diffractometer angles of 24 reflections, 15° ≤ 2θ ≤ 35°, λ = 0.71069 Å), space group $P2_1/c$, Z 8, D_x 1.321 g/cm^3. Orange plates, crystal dimensions 0.30 x 0.35 x 0.45 mm; μ(Mo-$K\alpha$) 0.10 mm^{-1}.

Data Collection and Processing. RED-4 diffractometer, ω-method, constant scanning speed 3° per minute, graphite monochromated Mo-$K\alpha$ radiation; 3049 reflections [$I > 3\sigma(I)$, θ range 2.26 to 24.76°; h 0 to 23, k 0 to 15, l -16 to 14], 2364 independent reflections [$I(hkl) > 2\sigma(I)$].

Structure Analysis and Processing. The structure was solved by direct method using MULTAN-80 program[15] and refined in the anisotropic approximation yielding all nonhydrogen atom positions. The hydrogen atoms were localized from the differential Fourier synthesis with refining only the isotropic thermal factor. Calculations were performed in the SHELXSM programm package.[16] Final R indices R = 0.0584; wR = 0.0624 $\{w=1/[\sigma(F)^2+0.007F^2]\}$.

Syntheses

4-*n*-Octyl-2-nitrophenol

To a solution of 4-*n*-octylphenol (Aldrich) (6.16g; 25 mmol) in a mixture of chloroform (80 mL) and acetic acid (40 mL) conc. nitric acid (2.9 mL) in acetic acid (40 mL) was added dropwise with stirring at room temperature. Stirring was continued for 1.5 h. The reaction mixture was diluted with water (50 mL) and neutralized with solid sodium carbonate. The organic layer was separated and the aqueous solution was extracted twice with chloroform. The combined organic solutions were evaporated and the residue was chromatographed on a column using hexane as an eluent. The yellow eluate was evaporated and the solid residue was crystallized from ethanol-water mixture. Yellowish product (5.13 g; 82 %), m.p. 30-31.5° was obtained (Lit. 32-33°[17a]; 29-30°[17b]). ^{1}H NMR (δ, ppm): 0.88 (3H, t, J=6.5 Hz); 1.20-1.40 (10H, m); 1.50-1.70 (2H, m) 2.60 (2H, t, J=7.6 Hz); 7.07 (1H, d, J=8.6 Hz); 7.41 (1H, dd, J_1=2.2 Hz; J_2=8.6 Hz); 7.90 (1H, d, J=2.2 Hz); 10.47 (1H, s).

3-Nitrobiphenyl-4-ol

This compound was prepared analogously by nitration of 4-hydroxybiphenyl. The crude compound was purified by column chromatography using a mixture of cyclohexane and methylene chloride (10:1) and crystallized from cyclohexane or ethanol. Yield 85 %; m.p. 66-67° (Lit. m.p. 66°[18]). ^{1}H NMR (δ, ppm): 7.25 (1H, d, J=8.7 Hz); 7.35-7.61 (5H, m); 7.84 (1H, dd, J_1=2.5 Hz; J_2=8.7 Hz); 8.33 (1H, d, J=2.5 Hz); 10.60 (1H, s).

1,8-Bis(4-*tert*-butyl-2-nitrophenoxy)-3,6-dioxaoctane (18)

A mixture of 4-*tert*-butyl-2-nitrophenol[4a] (9.4 g; 48 mmol), 1,8-dichloro-3,6-dioxaoctane (3.8 mL; 24 mmol), anhydrous potassium carbonate (10 g) and dimethylformamide (14 mL) was refluxed for 8 hrs. The mixture was poured into water and the product was extracted with chloroform. The organic layer was washed with water, 1 molar KOH solution and dried. After evaporation of the solvent it remains 11.3 g (93.5 %) of a crude product, which was purified by chromatography using cyclohexane-methylene chloride (5:1) mixture as eluent. Yield of a pure oily product was 10.15 g (84 %). ^{1}H NMR (δ, ppm): 1.31 (18H, s); 3.76 (4H, s); 3.90 (4H, t, J=4.8 Hz); 4.25 (4H, t, J=4.8 Hz); 7.04 (2H, d, J=8.8 Hz); 7.53 (2H, dd, J_1=2,5 Hz; J_2=8.8 Hz); 7.82 (2H, d, J=2.5 Hz).

1,8-Bis(4-*n*-octyl-2-nitrophenoxy)-3,6-dioxaoctane (19)

A mixture of 4-*n*-octyl-2-nitrophenol (3.01 g; 12 mmol), 1.8-dichloro-3,6-dioxaoctane (0.96 mL; 6 mmol), anhydrous potassium carbonate (1.7 g) and N,N-dimethylformamide (3 mL) was heated at 100-110° for 20 h. The mixture was diluted with water, the product was extracted with CH_2Cl_2, the solvent was evaporated and the residue was chromatographed. The unreacted substrates were removed with hexane and the desired product was eluted with hexane-methylene chloride mixture. The product was crystallized from hexane; yield 2.8 g (76 %), m.p. 38-40°. ^{1}H NMR (δ, ppm): 0.88 (6H, t, J=6.5 Hz); 1.27 (20H, narrow m); 1.48-1.66 (4H, m); 2.58 (4H, t, J=7.7 Hz); 3.76 (4H, s); 3.90 (4H, t, J=4.8 Hz); 4.24 (4H, t, J=4.8 Hz); 7.02 (2H, d, J=8.7 Hz); 7.31 (2H, dd, J_1=2.2 Hz; J_2=8.5 Hz); 7.63 (2H, d, J=2.2 Hz).

1,8-Bis[4-(1,1,3,3-tetramethylbutyl-2-nitrophenoxy)]-3,6-dioxaoctane (20)

This compound was prepared analogously to compound **18** from 4-tetramethylbutyl-2-nitrophenol[4a] (3 g; 12 mmol), 1,8-dichloro-3,6-dioxaoctane (0.96 mL; 6 mmol), anhydrous potassium carbonate (2.5 g) and dimethylformamide (4 mL). Yield of an oily product 3.3 g (89 %). ^{1}H NMR (δ, ppm): 0.73 (18H, s); 1.36 (12H, s); 1.73 (4H, s); 3.78 (4H, s); 3.92 (4H, t, J=4.8 Hz); 4.26 (4H, t, J=4.8 Hz); 7.03 (2H, d, J=8.8 Hz); 7.52 (2H, dd, J_1=2.5 Hz; J_2=8.8 Hz); 7.83 (2H, d, J=2.5 Hz).

1,8-Bis(4-*n*-dodecyl-2-nitrophenoxy)-3,6-dioxaoctane (21)

was prepared analogously to compound **19** from 4-*n*-dodecyl-2-nitrophenol.[4a] A product, m.p. 61-62°, was obtained with 89 % yield. ^{1}H NMR (δ, ppm): 0.88 (6H, t, J=6.7 Hz); 1.26 (36H, narrow m); 1.50-1.65 (4H, m); 2.58 (4H, t, J=7.7 Hz); 3.77 (4H, s); 3.90 (4H, t, J=4.8 Hz); 4.24 (4H, t, J=4.8 Hz); 7.01 (2H, d, J=8.6 Hz); 7.31 (2H, dd, J_1=2.3 Hz; J_2=8.7 Hz); 7.63 (2H, d, J=2.2 Hz).

1,8-Bis(4-phenyl-2-nitrophenoxy)-3,6-dioxaoctane (22)

was synthesized analogously to compound **19** from 3-nitrobiphenyl-4-ol. The product was crystallized

from ethyl acetate-methanol or methylene chloride-hexane mixture. Yield 73 %, m.p. 106-107°. ^{1}H NMR (δ, ppm): 3.80 (4H, s); 3.95 (4H, t, J=4.7 Hz); 4.32 (4H, t, J=4.7 Hz); 7.18 (2H, d, J=8.8 Hz); 7.32-7.58 (10H, m); 7.72 (2H, dd, J_1=2.4 Hz, J_2=8.7 Hz); 8.05 (2H, d, J=2.4 Hz).

Compound 23

was described elsewhere[9]

Compound 24

was prepared like compound **23** from 4-*tert*-butyl-2-nitrophenol. The product was extracted with chloroform and purified by chromatography. Yield 97 % of an oil, which slowly crystallized; m.p. 80-82°. ^{1}H NMR (δ, ppm): 1.31 (18H, s); 4.38-4.50 (8H, m); 6.94-7.06 (4H, m); 7.13 (2H, d, J=8.8 Hz); 7.53 (2H, dd, J_1=2.5 Hz; J_2=8.8 Hz); 7.81 (2H, d, J=2.5 Hz).

Compounds (1) and (2)

Their syntheses and separation of isomers of **1** was published elsewhere[12]

Synthesis of bis(*tert*-butylbenzo)-16-azocrown-6 (3)

Water (40 mL) was added portionwise to a vigorously stirred mixture of dinitro derivative **18** (4.8 g; 9.5 mmol), stannous chloride dihydrate (9.3 g; 41.2 mmol), potassium hydroxide (16 g) and acetone (45 mL). Boiling began within few minutes. Boiling was continued for 3 hrs. Toluene (30 mL) was added to the cooled reaction mixture and the organic red colored layer was separated. The organic layer was washed with water and the solvent was removed under reduced pressure. The crude product (4.6 g) was chromatographed on a short silica gel column using methylene chloride and chloroform as eluents to remove polymers and diacetone alcohol. The eluate after evaporation (4.0 g) was rechromatographed on potassium chloride impregnated silica gel using chloroform as eluent. The red potassium chloride complex of the crown ether remains on the column, whereas all impurities were washed out. The complex was eluted using acetone-methanol mixture. The eluate was evaporated and the residue dissolved in methylene chloride, washed with water to destroy the complex and the organic solution was evaporated. The residue was crystallized from ethyl ether-hexane. Yield 500 mg (12 %) of the *E* isomer **3**, m.p. 158-159°.

Analogous reduction performed with sodium stannite yielded 380 mg (9 %) of the same product.

E-Azocrown ether **3** $C_{26}H_{36}N_2O_4$ (440.59) MS: m/e = 440; HRMS: calcd 440.26752, found 440.26850. ^{1}H NMR [δ ppm]: 1.36 (18H, s); 3.74 (4H, s); 3.95 (4H, t, J=4.5 Hz); 4.25 (4H, t, J=4.5 Hz); 6.99 (2H, d, J=8.7 Hz); 7.37 (2H, dd, J_1=2.5 Hz, J_2=8.7 Hz); 7.70 (2H, d, J=2.5 Hz).

Z-Azocrown ether **3**. To characterize this isomer the above *E* compound was dissolved in methanol. After few days the solvent was evaporated and the NMR spectrum was immediately registered. ^{1}H NMR [δ ppm]: 1.13 (18H, s); 3.80 (4H, s); 3.83-4.01 (8H, m); 6.72 (2H, d, J=8.7 Hz); 6.86 (2H, d, J=2.4 Hz); 7.09 (2H, dd, J_1=2.5 Hz; J_2=8.7 Hz). The signals ascribed to this form were selected from spectrum of a mixture of isomers (45% *Z*, and 55% *E*).

Azoxycrown ether (4)

A mixture of 100 mg of azocrown ether **3**, 4 mL acetic acid and 2 mL 30 % H_2O_2 was heated for 2 h at 70°. The solvents were evaporated, the residue was extracted with chloroform and the product was purified

on a short silica gel column. It was obtained 70 mg (67 %) of an oily product.

Azoxycrown ether **4** $C_{26}H_{36}N_2O_5$ (456.58) MS: m/e = 456. HRMS: calcd 456.26242, found 456.26156. ^{1}H NMR [δ ppm]: 1.33 (9H, s); 1.34 (9H, s); 3.67 (4H, s); 3.87-3.96 (4H, m); 4.20-4.30 (4H, m); 6.96 (1H, d, J=8.8 Hz); 7.01 (1H, d, J=9 Hz); 7.31 (1H, dd, J_1=2.4 Hz, J_2=8.7 Hz); 7.42 (1H, dd, J_1=2.5 Hz. J_2=8.8 Hz); 7.67 (1H, d, J=2.4 Hz); 7.75 (1H, d, J=2.4 Hz)

Bis-(tetramethylbutylbenzo)-16-azocrown-6 (5) and azoxycompound (6)

To a solution of dinitroderivative **20** (3.08 g, 5 mmol) in 20 mL acetone stannous chloride dihydrate (4.52 g, 20 mmol) and potassium hydroxide (8.4 g) was added. To the stirred mixture water (20 mL) was added portionwise. The mixture was stirred and heated at 55-60° for 2 h. Then the separated organic layer was diluted with toluene (20 mL) and washed with water. The solvent was removed under reduced pressure and the residue was chromatographed on silica gel column. The first eluted (CH_2Cl_2) fraction contains azoxycrown ether which was purified by rechromatography. Yield 180 mg (6 %) of an oily product.

The second red fraction containing azocrown was evaporated and the residue dissolved in methanol. To this solution an excess of potassium chloride was added, the solvent was evaporated, the crown complex was dissolved in methylene chloride and applied on potassium chloride impregnated silica gel. The column was thoroughly eluted with CH_2Cl_2 and then the complex was eluted with acetone. The solvents were removed, the residue dissolved in methylene chloride and washed with water, 0.01 M HCl and water. The solvent was removed and the residue (470 mg, 17 %) crystallized "in mass". The red *E*-azocrown ether melts at 85-86°.

To obtain the *Z* isomer the above azocrown ether dissolved in methylene chloride was left for 1 day at room temperature, the solvent was removed and the residue was crystallized from hexane at low temperature. M.p. of the *Z*-azocrown ether 127-128°C.

E-Azocrown ether **5**. For $C_{34}H_{54}N_2O_4$ (552.70) MS: m/e = 552. HRMS: calcd 552.39270, found 552.39210. ^{1}H NMR [δ ppm]: 0.76 (18H, s); 1.41 (12H, s); 1.77 (4H, s); 3.74 (4H, s); 3.94-4.01 (4H, m); 4.22-4.29 (4H, m); 6.97 (2H, d, J=8.7 Hz); 7.36 (2H, dd, J_1=2.5 Hz, J_2=8.7 Hz); 7.72 (2H, d, J=2.5 Hz).

Z-Azocrown ether **5**. ^{1}H NMR [δ ppm]: 0.69 (18H, s); 1.21 (12H, s); 1.7 (4H, broad); 3.75-4.07 (12H, m); 6.74 (2H, d, J=8.7 Hz); 6.91 (2H, d); 7.12 (2H, dd, J_1=1.2 Hz, J_2=8 Hz).

Azoxycrown ether (6)

The azoxycrown ether was obtained also by oxidation of the parent crown ether **5** with hydrogen peroxide - acetic acid mixture at 100° for 0.5 h. Yield 89 % of an oily product. For $C_{34}H_{54}N_2O_5$ (568.70) MS: m/e = 568. HRMS: calcd 568.38763, found 568.38871. ^{1}H NMR [δ ppm]: 0.76 (9H, s); 0.78 (9H, s); 1.38 (12H, s); 1.74 (2H, s); 1.75 (2H,s); 3.68 (4H, s); 3.88-3.97 (4H, m); 4.22-4.30 (4H, m); 6.93 (1H, d, J=8.8 Hz); 6.98 (1H, d, J=8.9 Hz); 7.28 (1H, dd, J_1=2.5 Hz, J_2=8.7 Hz); 7.41 (1H, dd, J_1=2.5 Hz, J_2=8.6 Hz); 7.66 (1H, d, J=2.4 Hz); 7.73 (1H, d, J=2.4 Hz).

Bis(*n*-octylbenzo)-16-azocrown-6 (7) and azoxycrown (8)

Reduction was performed in a way similar to the synthesis of compound **5**. The products were separated on a silica gel column. The first fraction contains azoxycrown ether **8** (15 %), the second red fraction contains azocrown ether **7** (8.5 %). Both crown ethers were additionally purified by preparative TLC.

The azoxycrown ether **8** was crystallized from hexane, m.p. 58-59°. The azocrown ether **7** crystallized in mass; m.p. 37-39°.

Azocrown **7** $C_{34}H_{52}N_2O_4$ (552.70) MS: m/e = 552. HRMS: calcd 552.39270, found 552.38831. Mixture of isomers of **7**: ^{1}H NMR [δ ppm]: 0.89 (6H, t, J=6.3 Hz); 1.10-1.48 (20H, m); 1.53-1.73 (4H, m); 2.40 (~1.2H, t, J=7.3 Hz); 2.61 (~2.8H, t, J=7.2 Hz); 3.73 (~2.8H, s); 3.80 (~1.2H, s); 3.90-4.04 (4H, m); 4.21-4.31 (4H, m); 6.63 (~0.6H, d, J=2.2 Hz); 6.69 (~0.6H, d, J=8.4 Hz); 6.88 (~0.6H, dd, J_1=2.1 Hz, J_2=8.4 Hz); 6.96 (~1.4H, d, J=8.4 Hz); 7.16 (~1.4H, dd, J_1=2.3 Hz, J_2=8.4 Hz); 7.48 (~1.4H, d, J=2.2 Hz).

Azoxycompound **8**. For $C_{34}H_{52}N_2O_5$ (568.70) MS: m/e = 568. HRMS: calcd 568.38763, found 568.38727. ^{1}H NMR [δ ppm]: 0.89 (6H, t, J=6.4 Hz); 1.19-1.40 (20H, m); 1.52-1.70 (4H, m); 2.59 (4H, t, J=7.7 Hz); 3.69 (4H, s); 3.87-3.98 (4H, m); 4.19-4.29 (4H, m); 6.93 (1H, d, J=8.8 Hz); 6.97 (1H, d, J=8.8 Hz); 7.10 (1H, dd, J_1=2.2 Hz, J_2=8.4 Hz); 7.20 (1H, dd, J_1=2.2 Hz, J_2=8.5 Hz); 7.47 (1H, d, J=2.2 Hz); 7.58 (1H, d, J=2.2 Hz).

Bis(*n*-dodecylbenzo)-16-azocrown-6 (9) and azoxycrown ether (10)

Method 1. Water (11 mL) was added to a mixture of podand **21** (2.08 g, 2.6 mmol), stannous chloride dihydrate (2.7 g), KOH (5.04 g) and acetone (11 mL). The mixture was boiled for 4 h. The organic layer was separated, diluted with toluene (10 mL), washed with water and evaporated under reduced pressure. The residue was chromatographed on silica gel column with methylene chloride. The azoxycrown ether **10** was separated, the solvent was removed and the residue was crystallized from methanol containing small amount of methylene chloride. Yield 0.46 g (26 %), m.p. 68-70°.

The azocrown **9** was eluted from the column with methylene chloride and was purified using preparative thin layer chromatography. It was isolated 0.03 g (1.7 %) of a compound which slowly crystallize in mass. The crystals mainly consisting of *E*-azocrown were washed with methanol. Recrystallization from hexane afforded pure isomer *E*; m.p. 52-54°C.

Method 2. The reduction was performed at 50° for 2 h. Applying similar procedure it was isolated 19 % of azoxycrown ether **10** and 5 % of azocrown **9**.

Azocrown ether **9**. For $C_{42}H_{68}N_2O_4$ (664.92) MS: m/e = 664. HRMS: calcd 664.51788, found 664.51580.

Azocrown **9**, isomer *E*. ^{1}H NMR [δ ppm]: 0.88 (6H, t, J=6.3 Hz); 1.16-1.40 (36H, m); 1.54-1.70 (4H, m); 2.61 (4H, t, J=7.6 Hz); 3.73 (4H, s); 3.92-3.98 (4H, m); 4.23-4.28 (4H, m); 6.96 (2H, d, J=8.5 Hz); 7.16 (2H, dd, J_1=8.4 Hz, J_2=2.2 Hz); 7.47 (2H, d, J=2.1 Hz).

Azocrown **9**, isomer *Z*. The above crystalline isomer *E* was dissolved in methylene chloride and left overnight at room temperature. The solvent was removed and NMR spectrum of mixture of isomers was registered immediately after dissolution in $CDCl_3$. The signals characteristic for isomer *Z* were selected. ^{1}H NMR [δ ppm]: 0.88 (6H, t, J=6.3 Hz); 1.16-1.40 (36H, m); 1.54-1.70 (4H, m); 2.40 (4H, t, J=7.6 Hz); 3.80 (4H, s); 3.90-4.0 (8H, m); 6.63 (2H, d, J=2.1 Hz); 6.69 (2H, d, J=8.3 Hz); 6.88 (2H, dd, J_1=2.1; J_2=8.4 Hz).

Azoxycrown **10** For $C_{42}H_{68}N_2O_5$ (680.92) MS: m/e = 680. HRMS: calcd 680.51282, found 680.50730. ^{1}H NMR [δ ppm]: 0.83-0.94 (6H, m); 1.26 (36H, s); 1.51-1.70 (4H, m); 2.59 (4H, t, J=7.5 Hz); 3.69 (4H, s); 3.87-3.96 (4H, m); 4.20-4.28 (4H, m); 6.92 (1H, d, J=8.7 Hz); 6.97 (1H, d, J=9.2 Hz);

7.095 (1H, dd, J_1=2.2 Hz, J_2=8.4 Hz); 7.195 (1H, dd, J_1=2.2 Hz, J_2=8.6 Hz); 7.46 (1H, d, J=2.1 Hz); 7.57 (1H, d, J=2.0 Hz).

Bis(phenylbenzo)-16-azocrown-6 (11) and azoxycrown ether (12)

To a vigorously stirred suspension of dinitrocompound **22** (2.46 g, 4.5 mmol), stannous chloride dihydrate (4.5 g) in acetone (18 mL) a solution of KOH (8.4 g) in water (18 mL) was added portionwise. The mixture was heated at 60° and stirred for 1.5 h. The organic layer was separated and worked up in usual way. The azoxycrown ether **12** eluted from silica gel column with methylene chloride was crystallized from methanol - methylene chloride (5:1); yield 320 mg (14 %), m.p. 171-173°.

The crude azocrown ether **11** (300 mg) obtained from the column was purified twice more on a column or using preparative chromatographic plates and crystallized from methanol containing traces of methylene chloride. Yield 7 %, m.p. 126-130° of a mixture of isomers. A pure isomer *Z* was obtained by crystallization from hexane at low temperature; m.p. 139-141°.

Azocrown ether **11**. For $C_{30}H_{28}N_2O_4$ (480.57) MS: m/e = 480. HRMS: calcd 480.20490, found 480.20649.

Azocrown ether **11**, isomer *Z*. ^{1}H NMR [δ ppm]: 3.82 (4H, s); 3.90-3.98 (4H, m); 4.06-4.13 (4H, m); 6.95 (2H, d, J=8.6 Hz); 7.22 (2H, d, J=2.3 Hz); 7.28-7.35 (10H, m); 7.42 (2H, dd, J_1=2.3; J_2=8.6 Hz).

Azocrown ether **11**, isomer *E*. ^{1}H NMR [δ ppm] (the signals were selected from a spectrum of oily residue consisting of approximately 70 % of isomer *E*): 3.78 (4H, s); 3.97-4.08 (4H, m); 4.31-4.40 (4H, m); 7.11-7.19 (2H, m); 7.35-7.52 (6H, m); 7.60-7.70 (6H, m); 7.99 (2H, d, J=2.4 Hz).

Azoxycrown ether **12**. For $C_{30}H_{28}N_2O_5$ (496.57) MS: m/e = 496. HRMS: calcd 496.19983, found 496.20247. ^{1}H NMR [500 MHz, δ ppm]: 3.74 (4H, s); 3.97-4.05 (4H, m); 4.33-4.38 (4H, m); 7.13 (1H, d, J=8.3 Hz); 7.18 (1H, d, J=8.7 Hz); 7.32-7.40 (2H, m); 7.43-7.50 (4H, m); 7.57 (1H, dd, J_1=2.4 Hz, J_2=8.8 Hz); 7.59-7.65 (4H, m); 7.67 (1H, dd, J_1=2.5 Hz, J_2=8.3 Hz); 7.94 (1H, d, J=2.4 Hz); 8.04 (1H, d, J=2.4 Hz).

Tribenzo-16-azocrown-6 (13)

was described elsewhere.[9] Both isomers crystallize from ethyl acetate. The *Z* isomer crystallizes slowly from diluted solution giving orange product; m.p. 142-143°. The second isomer was crystallized from concentrated solution of *E* form immediately after chromatographic separation. Red compound; m.p. 128-129°.

Tribenzo-16-azoxycrown-6 (14)

A mixture of azocrown ether **13** (0.1 g),[9] 4 mL acetic acid and 2 mL 30 % hydrogen peroxide was heated at 70° for 1 h. The solvents were evaporated, the residue dissolved in chloroform and the product was purified on silica gel column using methylene chloride as eluent. The azoxycrown was crystallized from methanol. Yield 93 mg (89 %), m.p. 174-176°.

For $C_{22}H_{20}N_2O_5$ (392.41) MS: m/e = 392. HRMS: calcd 392.13721, found 392.13705. ^{1}H NMR [δ ppm]: 4.39-4.47 (8H, m); 6.92 (4H, s); 6.98-7.10 (4H, m); 7.32-7.43 (2H, m); 7.64 (1H, dd, J_1=1.8 Hz,

J_2=8 Hz); 7.97 (1H, dd, J_1=1.6 Hz, J_2=8 Hz).

Di(*tert*-butyl)-tribenzo-16-azocrown-6 (15) and azoxycrown ether (16)

Water (30 mL) was added portionwise to a stirred mixture of dinitrocompound **24** (3.31 g, 6 mmol), stannous chloride dihydrate (5.9 g), potassium hydroxide (10.9 g) and acetone (30 mL). After 2.5 h boiling and stirring the organic layer was worked up and the mixture of products was separated twice on silica gel column using methylene chloride as eluent. It was obtained 0.64 g (22 %) of azocrown ether **15** in form of a freezing oil and 0.13 g (4.3 %) of azoxycrown **16**, m.p. 206-207° (from methanol).

Azoxycrown ether **16** was also obtained by oxidation of the azocrown and isolated and purified in usual way. Yield 58 %.

Azocrown ether **15**. For $C_{30}H_{36}N_2O_4$ (488.63) MS m/e = 488. HRMS: calcd 488.26752, found 488.26728. ^{1}H NMR [δ ppm]: 1.14 and 1.35 (18H, 2s); 4.16 and 4.43 (8H, 2t, J=4.2 Hz); 6.77 and 7.00 (2H, 2d, J=8.6 Hz); 6.83 and 7.61 (2H, 2d, J=2.5 Hz); 6.90-6.96 and 7.00-7.03 (4H, 2m); 7.09 and 7.36 (2H, 2dd, J_1=2.5 Hz, J_2=8.6 Hz). The spectrum corresponds to a mixture of *E* and *Z* isomers. The following signals could be ascribed to the *E* form: 1.35, 6.90-6.96, 7.00, 7.36 and 7.61 ppm. The respective bands for *Z* form are: 1.14, 6.77, 6.83, 7.00-7.03 and 7.09 ppm.

Azoxycrown **16** For $C_{30}H_{36}N_2O_5$ (504.63) MS: m/e = 504. HRMS: calcd 504.26242, found 504.26308. ^{1}H NMR [δ ppm]: 1.31 and 1.33 (18H, 2s); 4.40 (8H, s); 6.91 (4H, s); 6.93 (1H, d, J=9 Hz); 6.98 (1H, d, J=8.7 Hz); 7.31 (1H, dd, J_1=2.4 Hz, J_2=8.6 Hz); 7.40 (1H, dd, J_1=2.4 Hz, J_2=8.7 Hz); 7.66 (1H, d, J=2.5 Hz); 8.00 (1H, d, J=2.5 Hz).

Supplementary Material Available

Crystallographic data, atomic parameters for non-hydrogen atoms, their anisotropic displacement parameters, atomic and thermal parameters for hydrogen atoms, bond distances, valence and torsion angles (8 pages) in the structure and listing of observed and calculated structure factors (14 pages) have been deposited at the Cambridge Crystallographic Data Center, Lensfield Road, Cambridge, CB2 1EW, UK.

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