ISSN 1070-3632, Russian Journal of General Chemistry, 2012, Vol. 82, No. 1, pp. 144–148. © Pleiades Publishing, Ltd., 2012.
Original Russian Text © Yu.E. Ivanov, D.E. Stepanov, A.A. Yavolovskii, O.V. Shishkin, V.V. D'yakonenko, G.L. Kamalov, 2012, published in Zhurnal Obshchei Khimii, 2012, Vol. 82, No. 1, pp. 148–151.

Crown Ethers Based on Bis(benzimidazol-2-yl)alkanes and 1,2-Bis(benzimidazol-2-ylsulfanyl)ethane

Yu. E. Ivanov[a], **D. E. Stepanov**[a], **A. A. Yavolovskii**[a], **O. V. Shishkin**[b], **V. V. D'yakonenko**[b], and **G. L. Kamalov**[a]

[a] *Bogatskii Physicochemical Institute, National Academy of Sciences of Ukraine,*
Lyustdorfskaya doroga 86, Odessa, 65080 Ukraine
e-mail: ivanov_u@te.net.ua

[b] *Institute of Single Crystals, National Academy of Sciences of Ukraine, Kharkov, Ukraine*

Received July 20, 2010

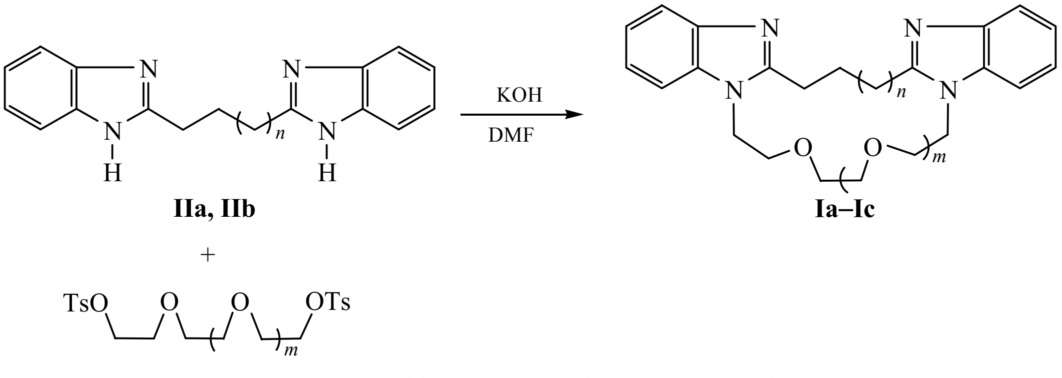
Abstract—Dibenzimidazo crown ethers were synthesized by alkylation of α,ω-bis(benzimidazol-2-yl)alkanes and 1,2-bis(benzimidazol-2-ylsulfanyl)ethane with tri- and tetraethylene glycol bis(4-toluenesulfonates). The structure of 6,7,9,10,12,13,21,22-octahydro[1,14,6,9,4,11]dioxadithiadiazacyclohexadecino[4,5-*a*:11,10-*a*′]dibenzimidazole was studied by X-ray analysis.

DOI: 10.1134/S1070363212010239

Demands in new multidentate ligands with specified properties determine persistent attention to the development of methods of preparation and studies on the structure of macroheterocycles with variable size of the ring and nature and number of donor centers, as well as of those possessing exocyclic coordination centers. In this connection, crown ethers containing a benzimidazole heteroring attract some interest. With a view to synthesize such macrocyclic compounds we used as starting materials a series of α,ω-bis(benzimidazol-2-yl)alkanes and 1,2-bis(benzimidazol-2-ylsulfanyl)ethane; their analogs are known as efficient ligands for coordination to copper(II) ions [1].

The corresponding 15-, 16-, and 18-membered dibenzimidazo crown ethers **Ia**–**Ic** having two or three oxygen atoms in the macroring were synthesized by alkylation of bis(benzimidazol-2-yl)alkanes **IIa** and **IIb** with tri- and tetraethylene glycol bis(4-toluenesulfonates) in dimethylformamide (DMF) in the presence of potassium hydroxide under argon (Scheme 1). The yields of compounds **Ia**–**Ic** were 44–67%. Initial 1,2-bis(1*H*-benzimidazol-2-ylsulfanyl)ethane (**IV**) was prepared by alkylation of 2,3-dihydro-1*H*-benzimidazole-2-thione (**III**) with 1,2-dichloroethane in aqueous sodium hydroxide (Scheme 2).

Scheme 1.

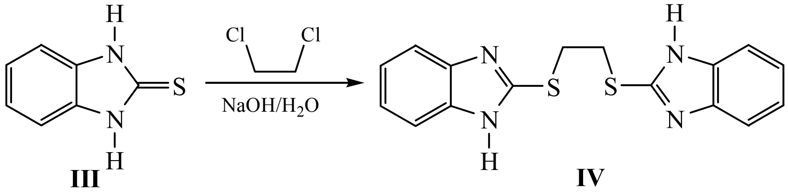


IIa, IIb

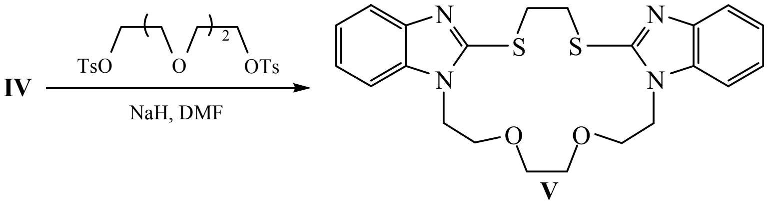
Ia–Ic

$n = 1, m = 1$ (**a**); $n = 1, m = 2$ (**b**); $n = 2, m = 1$ (**c**).

Scheme 2.



Scheme 3.



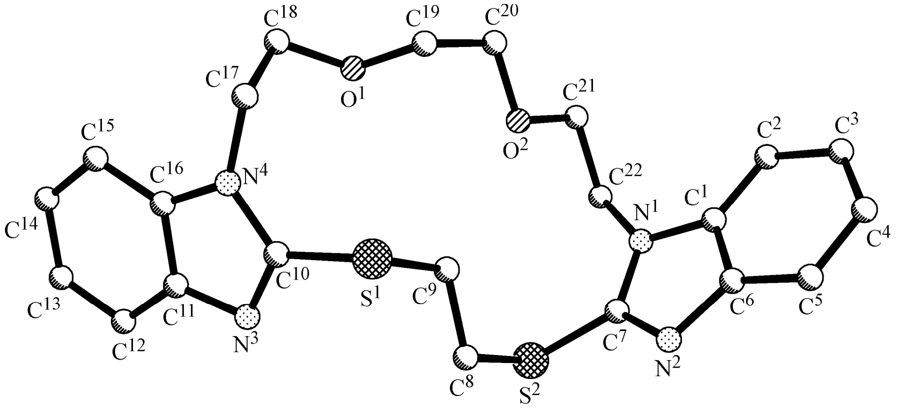
By heating compound **IV** with triethylene glycol bis(4-toluenesulfonate) and sodium hydride in boiling DMF we succeeded in obtaining 16-membered dibenzimidazo dithia crown **V** which was isolated from the reaction mixture by column chromatography in 11% yield (Scheme 3).

Table 1. Bond lengths *d* in the molecule of 6,7,9,10,12,13,21,22-octahydro[1,14,6,9,4,11]dioxadithiadiazacyclohexadecino-[4,5-*a*:11,10-*a*′]dibenzimidazole (**V**)

Bond	*d*, Å	Bond	*d*, Å
S^1–C^{10}	1.755(2)	O^2–C^{21}	1.413(3)
S^1–C^9	1.822(2)	C^1–C^6	1.392(4)
S^2–C^7	1.760(2)	C^1–C^2	1.400(4)
S^2–C^8	1.815(3)	C^2–C^3	1.383(5)
N^1–C^7	1.368(3)	C^3–C^4	1.393(6)
N^1–C^1	1.373(3)	C^4–C^5	1.372(5)
N^1–C^{22}	1.458(3)	C^5–C^6	1.405(4)
N^2–C^7	1.316(3)	C^8–C^9	1.494(3)
N^2–C^6	1.387(4)	C^{11}–C^{12}	1.384(3)
N^3–C^{10}	1.312(3)	C^{11}–C^{16}	1.388(3)
N^3–C^{11}	1.399(3)	C^{12}–C^{13}	1.375(4)
N^4–C^{10}	1.363(3)	C^{13}–C^{14}	1.388(4)
N^4–C^{16}	1.375(3)	C^{14}–C^{15}	1.377(4)
N^4–C^{17}	1.460(3)	C^{15}–C^{16}	1.398(3)
O^1–C^{18}	1.416(3)	C^{17}–C^{18}	1.514(4)
O^1–C^{19}	1.417(3)	C^{19}–C^{20}	1.494(4)
O^2–C^{20}	1.408(3)	C^{21}–C^{22}	1.500(4)

Table 2. Bond angles in the molecule of 6,7,9,10,12,13,21,22-octahydro[1,14,6,9,4,11]dioxadithiadiazacyclohexadecino-[4,5-*a*:11,10-*a*′]dibenzimidazole (**V**)

Angle	ω, deg	Angle	ω, deg
$C^{10}S^1C^9$	99.8(3)	$N^2C^7S^2$	123.8(2)
$C^7S^2C^8$	100.2(3)	$N^1C^7S^2$	122.7(2)
$C^7N^1C^1$	106.5(2)	$C^9C^8S^2$	112.0(3)
$C^7N^1C^{22}$	128.4(2)	$C^8C^9S^1$	113.2(2)
$C^1N^1C^{22}$	125.1(2)	$N^3C^{10}N^4$	113.5(2)
$C^7N^2C^6$	104.0(2)	$N^3C^{10}S^1$	124.6(2)
$C^{10}N^3C^{11}$	104.5(2)	$N^4C^{10}S^1$	121.8(2)
$C^{10}N^4C^{16}$	1063(3)	$C^{12}C^{11}C^{16}$	120.6(2)
$C^{10}N^4C^{17}$	128.1(2)	$C^{12}C^{11}N^3$	129.9(2)
$C^{16}N^4C^{17}$	125.4(2)	$C^{16}C^{11}N^3$	109.5(2)
$C^{18}O^1C^{19}$	113.7(2)	$C^{13}C^{12}C^{11}$	117.7(3)
$C^{20}O^2C^{21}$	110.8(2)	$C^{12}C^{13}C^{14}$	121.5(3)
$N^1C^1C^6$	105.4(2)	$C^{15}C^{14}C^{13}$	121.8(3)
$N^1C^1C^2$	132.1(3)	$C^{14}C^{15}C^{16}$	116.4(3)
$C^6C^1C^2$	122.5(3)	$N^4C^{16}C^{11}$	106.2(2)
$C^3C^2C^1$	116.1(4)	$N^4C^{16}C^{15}$	131.8(2)
$C^2C^3C^4$	121.8(3)	$C^{11}C^{16}C^{15}$	122.0(2)
$C^5C^4C^3$	122.1(3)	$N^4C^{17}C^{18}$	111.9(2)
$C^4C^5C^6$	117.4(4)	$O^1C^{18}C^{17}$	113.5(2)
$N^2C^6C^1$	110.6(2)	$O^1C^{19}C^{20}$	109.7(2)
$N^2C^6C^5$	129.3(3)	$O^2C^{20}C^{19}$	111.3(2)
$C^1C^6C^5$	120.1(3)	$O^2C^{21}C^{22}$	109.5(3)
$N^2C^7N^1$	113.5(2)	$N^1C^{22}C^{21}$	113.3(2)



Structure of the molecule of 6,7,9,10,12,13,21,22-octahydro[1,14,6,9,4,11]dioxadithiadiazacyclohexadecino[4,5-*a*:11,10-*a*′]dibenzimidazole (**V**) according to the X-ray diffraction data.

The newly synthesized compounds were identified by elemental analysis, mass spectrometry, and ^{1}H NMR, and the structure of compound **V** was determined by X-ray analysis (Tables 1, 2; see figure). The macrocyclic fragment of molecule **V** has a *chair*-like conformation. Its central part consisting of the C^{19}, C^{20}, O^2, C^{21}, C^2, S^2, C^8, C^9, and S^1 atoms is almost planar; deviations of these atoms from the mean-square plane do not exceed 0.08 Å. The C^{10}, N^4, C^{17}, C^{18}, and O^1 atoms deviate from the same plane by –1.54, –2.09, –1.47, –1.92, and –1.52 Å, respectively, and the N^1 and C^7 atoms, by 1.25 and 1.28 Å. The ether fragment adopts *synclinal* (*sc–sc–sc*) conformation with the torsion angles $N^4C^{17}C^{18}O^1$ –64.2(3)°, $O^1C^{19}C^{20}O^2$ –73.4(3)°, and $O^2C^{21}C^{22}N^1$ –64.3(3)°, whereas the thioether fragment is characterized by *antiperiplanar* (*ap*) conformation with the torsion angle $S^2C^8C^9S^1$ 179.2(3)°. Such conformation of X–C–C–X fragment (X = N, O, S) is not typical of crown ethers which usually display alternating +*sc* and –*sc* structures of the dioxyethylene fragments O–C–C–O [2]. The SCH_2CH_2S moiety is characterized by an appreciable steric strain, which follows from the presence of shortened intramolecular contacts $S^1\cdots H^{17A}$ 2.75 Å (sum of the van der Waals radii 3.00 Å [3]), $S^2\cdots H^{9A}$ 2.87, $S^2\cdots H^{9B}$ 2.88, $S^2\cdots H^{22A}$ 2.75, and $H^{18B}\cdots H^{1B}$ 2.14 Å (2.32 Å).

Molecules **V** in crystal give rise to stacks along the [010] crystallographic axis, where the neighboring molecules ware linked through weak hydrogen bond $C^{22}–H^{22}\cdots C^{1'}(\pi)$ (*x*, 1 + *y*, *z*; H···C 2.85 Å, ∠CHC 132°). In addition, shortened intermolecular contacts $S^1\cdots S^{2'}$ 3.583 Å (3.68 Å) (*x*, 1 + *y*, *z*) were observed between the same molecules.

EXPERIMENTAL

Initial α,ω-bis(1*H*-benzimidazol-2-yl)alkanes **IIa** and **IIb** were synthesized according to the procedures described in [4], 2,3-dihydro-1*H*-benzimidazole-2-thione (**III**) was prepared as reported in [5], and tri- and tetraethylene glycol bis(*p*-toluenesulfonates) were obtained according to a procedure analogous to [6]. The solvents used in this work were purified by standard procedures [7]. Dithio crown **V** was isolated by column chromatography on neutral aluminum oxide (50–200 μm, Merck).

The mass spectra (electron impact, 70 eV) were recorded on an MKh-1321 mass spectrometer with direct sample admission into the ion source heated to 220°C. The ^{1}H NMR spectra were measured on a Varian WXP-300 instrument at 299.95 MHz using DMSO-d_6 as solvent and tetramethylsilane as internal reference.

Single crystals of compound **V** suitable for X-ray analysis were obtained by crystallization from ethanol. Monoclinic crystal system; $C_{22}H_{24}N_4O_2S_2$; unit cell parameters (21°C): a = 12.892(3), b = 4.951(2), c = 16.530 Å; β = 93.258(4)°; V = 1053.4(5) Å^3; M_R = 440.57; Z = 2; space group Pc; d_{calc} = 1.389 g/cm^3; μ (MoK_α) = 0.280 mm^{-1}; F(000) 464. The unit cell parameters and intensities of 8277 reflections (4765 independent reflections with R_{int} = 0.033) were measured on an Xcalibur-3 diffractometer (MoK_α irradiation, CCD detector, graphite monochromator, ω-scanning, $2\theta_{max}$ = 60°). The structure was solved by the direct method using SHELXTL software package [8]. The positions of hydrogen atoms were determined by difference synthesis of electron density and were refined according to the riding model ($U_{iso} = nU_{eq}$ for non-hydrogen atom linked to a given hydrogen atom; $n = 1.2$ for carbon atoms). The structure was refined with respect to F^2 by full-matrix least-squares procedure in anisotropic approximation for nonhydrogen atoms; $wR_2 = 0.076$ (4732 reflections), $R_1 = 0.043$ [3309 reflections with $F > 4\sigma(F)$]; $S = 0.968$. The bond lengths and bond angles are given in Tables 1 and 2. The coordinates of atoms and complete sets of bond lengths and bond angles were deposited to the Cambridge Crystallographic Data Centre (entry no. CCDC 768121).

7,8,15,16,18,19,21,22-Octahydro-6*H*-[1,4,7,13]-dioxadiazacyclopentadecino[7,8-*a*:13,12-*a′*]dibenzimidazole (Ia). Compound **IIa**, 1.38 g, was dissolved in 120 ml of DMF distilled over calcined CaO, 2.8 g of potassium hydroxide was added under stirring, and the mixture was heated for 30–40 min at 50–60°C. A solution of 2.29 g of triethylene glycol bis(*p*-toluenesulfonate) in 30 ml of DMF was added over a period of 40 min to the resulting suspension, and the mixture was stirred for 18 h at 60–70°C under argon. The solvent was removed on a rotary evaporator, and the residue was washed with 100 ml of water, dried at 100–110°C, and recrystallized from isopropyl alcohol. Yield 1.1 g (56%), mp 255–257°C (decomp.). ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 2.55 quint (2H, $CH_2C\mathbf{H}_2CH_2$, $J = 6.9$), 3.00 t (4H, $C\mathbf{H}_2CH_2C\mathbf{H}_2$, $J = 6.9$), 3.16 s (4H, OCH_2CH_2O), 3.61 t (4H, $NCH_2C\mathbf{H}_2O$, $J = 4.35$), 4.31 t (4H, $NC\mathbf{H}_2CH_2O$, $J = 4.35$), 7.14–7.60 m (8H, H_{arom}). Mass spectrum: *m*/*z* 390 $[M]^+$. Found, %: C 70.48; H 6.64; N 14.06. $C_{23}H_{26}N_4O_2$. Calculated, %: C 70.77; H 6.67; N 14.36.

7,8,15,16,18,19,21,22,24,25-Decahydro-6*H*-[1,4,7,10,16]trioxadiazacyclooctadecino[10,11-*a*:16,15-*a′*]dibenzimidazole (Ib) was synthesized in a similar way from 1.38 g of compound **IIa** and 2.51 g of tetraethylene glycol bis(*p*-toluenesulfonate). Yield 0.96 g (44%), mp 224–225°C (from *i*-PrOH). ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 2.44 quint (2H, $CH_2C\mathbf{H}_2CH_2$, $J = 7.50$), 3.13 t (4H, $C\mathbf{H}_2CH_2C\mathbf{H}_2$, $J = 7.50$), 3.26 t (4H, $OCH_2C\mathbf{H}_2OC\mathbf{H}_2CH_2O$, $J = 6.00$), 3.33 t (4H, $OC\mathbf{H}_2CH_2OCH_2C\mathbf{H}_2O$, $J = 6.00$), 3.66 t (4H, $NCH_2C\mathbf{H}_2O$, $J = 3.75$), 4.39 t (4H, $NC\mathbf{H}_2CH_2O$, $J = 3.75$), 7.12–7.60 m (8H, H_{arom}). Mass spectrum: *m*/*z* 434 $[M]^+$. Found, %: C 70.38; H 6.89; N 12.63. $C_{25}H_{30}N_4O_3$ Calculated %: C 69.10; H 6.96; N 12.89.

6,7,8,9,16,17,19,20,22,23-Decahydro[1,4,7,14]-dioxadiazacyclohexadecino[7,8-*a*:14,13-*a′*]dibenzimidazole (Ic) was synthesized in a similar way from 1.45 g of compound **IIb** and 2.29 g of triethylene glycol bis(*p*-toluenesulfonate). Yield 1.35 g (67%), mp 260–262°C (from *i*-PrOH). ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 2.09 t [4H, $CH_2(C\mathbf{H}_2)_2CH_2$, $J = 7$], 2.98 t (4H, $C\mathbf{H}_2(CH_2)_2C\mathbf{H}_2$, $J = 7$), 3.33 s (4H, OCH_2CH_2O), 3.67 t (4H, $NCH_2C\mathbf{H}_2O$, $J = 4.4$), 4.32 t (4H, $NC\mathbf{H}_2CH_2O$, $J = 4.4$), 7.10–7.56 m (8H, H_{arom}). Mass spectrum: *m*/*z* 404 $[M]^+$. Found %: C 71.30; H 6.88; N 13.80. $C_{24}H_{28}N_4O_2$ Calculated %: C 71.29; H 6.93; N 13.86.

1,2-Bis(benzimidazol-2-ylsulfanyl)ethane (IV). Compound **III**, 1.5 g, was added to a solution of 0.4 g of sodium hydroxide in 10 ml of water, the mixture was stirred until dissolution, 0.5 g of 1,2-dichloroethane was added, and the mixture was heated for 1 h under reflux with stirring. After cooling, the precipitate was filtered off through a Schott filter, washed with water, dried at 80–100°C, and crystallized from ethanol. Yield 0.53 g (32.5%), mp 255–257°C (decomp.). ^{1}H NMR spectrum, δ, ppm: 3.70 s (4H, SCH_2CH_2S), 7.13–7.48 m (8H, H_{arom}), 12.76 s (2H, NH). Mass spectrum: *m*/*z* 326 $[M]^+$. Found, %: C 58.86; H 4.34; N 17.17. $C_{16}H_{14}N_4S_2$. Calculated, %: C 58.87; H 4.33; N 17.16.

6,7,9,10,12,13,21,22-Octahydro[1,14,6,9,4,11]dioxadithiadiazacyclohexadecino[4,5-*a*:11,10-*a′*]dibenzimidazole (V). Compound **IV**, 0.5 g, was dissolved in 15 ml of DMF distilled over calcined CaO, 0.075 g of sodium hydride was added, the mixture was stirred until it became homogeneous, 0.7 g of triethylene glycol, bis(*p*-toluenesulfonate) was added, and the mixture was stirred for 6 h at heating on a boiling water bath. The solvent was removed, the residue was dissolved in 20 ml of hot benzene, and the solution was filtered. The product was isolated by column chromatography on neutral alumina using benzene–ethyl acetate (1 : 1) as eluent, followed by recrystallization from ethanol. Yield 0.075 g (11%), mp 145–146°C. ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 3.38 s (4H, OCH_2CH_2O), 3.64 t (4H, $NCH_2C\mathbf{H}_2O$, $J = 5.1$), 3.80 s (4H, SCH_2CH_2S), 4.19 t (4H, $NC\mathbf{H}_2CH_2O$, $J = 5.1$), 7.10–7.45 m (8H, H_{arom}). Mass spectrum: *m*/*z* 440 $[M]^+$. Found, %: C 59.99; H 5.49; N 12.73. $C_{22}H_{24}N_4O_2S_2$. Calculated, %: C 59.98; H 5.49; N 12.72.

REFERENCES

1. Craig, J.M., Clegg, W., Elsegood, M.R.G., Leese, T.A., Thorp, D., Thornton, P., and Lockhart, J.C., *J. Chem. Soc., Dalton Trans*, 1996, no. 8, p. 1531.

2. Hiraoka, M., *Crown Compounds. Their Characteristics and Applications*, Tokyo: Kodansha, 1982.
3. Zefirov, Yu.V. and Zorkii, P.M., *Usp. Khim.*, 1989, vol. 58, no. 5, p. 713.
4. Preston, P.N., *Chem. Rev.*, 1974, vol. 74, no. 3, p. 279.
5. Busev, A.I., *Sintez novykh organicheskikh reagentov dlya neorganicheskogo analiza* (Synthesis of New Organic Reagents for Inorganic Analysis), Moscow: Mosk. Gos. Univ., 1972, p. 114.
6. Dale, J. and Kristiansen, P.O., *Acta Chem. Scand.*, 1972, vol. 26, no. 4, p. 1471.
7. Gordon, A.J. and Ford, R.A., *The Chemist's Companion*, New York: Wiley, 1972. Translated under the title *Sputnik khimika*, Moscow: Mir, 1976, p. 437.
8. Sheldrick, G.M., *Acta Crystallogr., Sect. A*, 2008, vol. 64, no. 1, p. 112.