Russian Journal of General Chemistry, Vol. 74, No. 8, 2004, pp. 1267–1276. Translated from Zhurnal Obshchei Khimii, Vol. 74, No. 8, 2004, pp. 1368–1376.

1-Alkyl 3,5-Diallyl Isocyanurates As Synthetic Building Blocks for Sulfur-containing Macroheterocycles

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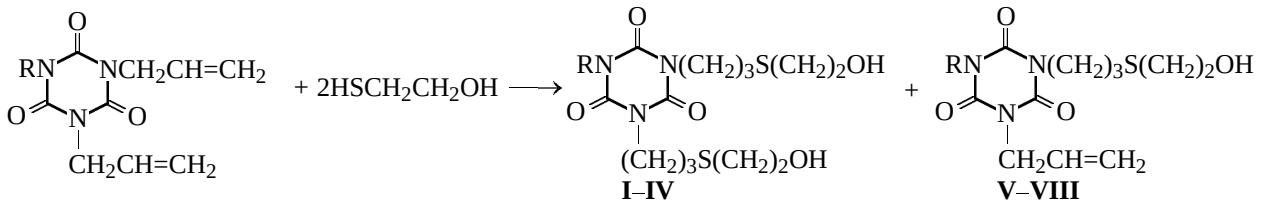
Received July 25, 2002

Abstract — 2-Sulfanylethanol was added to readily available 1-alkyl 3,5-diallyl isocyanurates to obtain 1-alkyl 3,5-bis[3-(2-hydroxyethylsulfanyl)propyl] isocyanurates. Treatment of the products with thionyl chloride gave 1-alkyl 3,5-bis[3-(2-chloroethylsulfanyl)propyl] isocyanurates whose reaction with thiourea followed by hydrolysis resulted in preparation 1-alkyl 3,5-bis[3-(2-sulfanylethylsulfanyl)propyl] isocyanurates. Oxiative cyclization of the latter gave macrocyclic disulfides in 56–75% yields. The composition and structure of the macrocyclic disulfides were established on the basis of the elemental and X-ray diffraction analyses, ^{1}H and ^{13}C NMR and IR spectra, as well as MALDI–TOF and electron impact mass spectra.

Organic sulfur compounds (cystine, cysteine, glutathione, coenzyme A, lipoic acid, sulfur-containing proteins, etc.) play an exceptionally important role in biochemical processes. Therewith, sulfur atoms incorporated in various functional groups act as active centers of biological molecules. Chemically, of particular interest are biological molecules containing SH groups. A distinctive feature of SH groups is their ability to undergo reversible oxidative in mild conditions to form S–S bonds. It is along this pathway that glutathione functions in biological processes to maintain, via oxidation–reduction, a definite cell medium and the reduced state of protein SH groups [1]. Dithiol–disulfide transformations (such as cysteine–cysteine) play a vitally important regulatory role in metabolic processes in the cell [2].

Disulfide groups incorporated in the active centers of certain oxidizing enzymes take part in electron and proton transfer from substrates to receptors, undergoing reversible conversion into dithiols [1].

Sulfur-containing podands and crown ethers occupy a prominent place on supramolecular chemistry in view of their ability to selectively bind transition and heavy metal ions. Moreover, such compounds hold promise as active components of the membranes of ion-selective electrodes and molecular receptors [3, 4]. Crown ethers with disulfide bridges are potential redox and electrochemically switched systems [5–7]. Earlier we reported on the synthesis of macrocyclic disulfides with an isocyanurate fragment and ester groups in the rim [8]. In the present work we have synthesized new compounds of this series, containing in the macroring rim an isocyanurate fragment, sulfur atoms, and a redox switched disufide function. To prepare isocyanurates with sulfide groups in the *N*-alkyl chain, we developed a procedure for addition of 2-sulfanylethanol to readily available 1-alkyl 3,5-diallyl isocyanurates. The reaction was performed in an anhydrous solvent in the presence of an initiator of free-radical reactions in an inert atmosphere. Thus, refluxing diallyl cyanurates with



I–IV **V–VIII**

R = CH_3 (**I, V**), $C_6H_5CH_2$ (**II, VI**), $CH_3OC(O)CH_2$ (**III, VII**), $CNCH_2$ (**IV, VIII**).

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Table 1. Yields, R_f values, and elemental analyses of compounds **I**–**VIII**

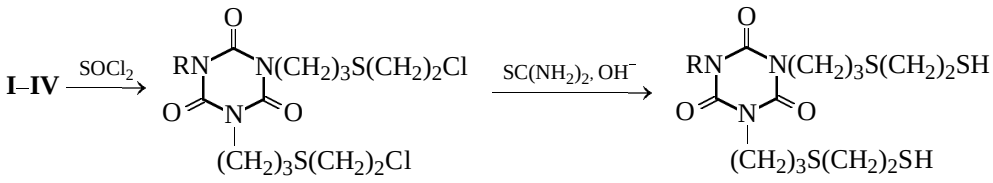
Comp. no	Yield, %	Reaction time, h[a]	R_f (solvent)	Found, %				Formula	Calculated, %			
				C	H	N	S		C	H	N	S
I	66	14	0.32 (ethyl acetate)	44.06	6.72	10.42	17.52	$C_{14}H_{25}N_3O_5S_2$	43.61	6.64	11.07	16.90
V	22	14	0.62 (ethyl acetate)	48.14	6.11	14.07	9.65	$C_{12}H_{19}N_3O_4S$	47.83	6.35	13.94	10.64
II	71	15	0.27 (benzene–ethyl acetate, 1 : 1)	52.57	6.16	9.01	14.48	$C_{20}H_{29}N_3O_5S_2$	52.73	6.42	9.22	14.07
VI	11	15	0.68 (benzene–ethyl acetate, 1 : 1)	57.06	6.02	11.10	8.33	$C_{18}H_{23}N_3O_4S$	57.28	5.78	11.13	8.49
III	65	12	0.30 (ethyl acetate–benzene, 5 : 2)	43.88	6.39	9.45	14.98	$C_{16}H_{27}N_3O_7S_2$	43.92	6.22	9.60	14.16
VII	20	12	0.66 (ethyl acetate–benzene, 5 : 2)	46.57	6.06	11.16	9.05	$C_{14}H_{21}N_3O_6S$	46.77	5.89	11.69	8.92
IV	55	26	0.36 (ethyl acetate)	44.14	5.62	13.78	15.24	$C_{15}H_{24}N_4O_5S_2$	44.54	5.98	13.85	15.85
VIII	27	26	0.77 (ethyl acetate)	47.97	5.31	17.29	9.79	$C_{13}H_{18}N_4O_4S$	47.84	5.56	17.17	9.82

[a] Boiling in dioxane.

2-sulfanylethanol in dioxane in the presence of catalytic amounts of 2,2'-azobisisobutyronitrile under argon gave 55–70% of 1-alkyl 3,5-bis[3-(2-hydroxyethylsulfanyl)propyl] isocyanurates **I**–**IV** (Table 1). In addition, from the reaction mixture we isolated compounds **V**–**VIII** formed by addition 2-sulfanylethanol by one allyl group of the starting isocyanurate.

The ratio of mono- and bis-addition products depends on the reaction temperature and time. The reaction of 1,3-diallyl 5-methyl isocyanurate with 2-sulfanylethanol in THF (80°C, 1 h) resulted in isolation of 3-allyl 1-[3-(2-hydroxyethylsulfanyl)propyl] 5-methyl isocyanurate (**V**) and 1,3-bis[3-(2-hydroxyethylsulfanyl)propyl] 5-methyl isocyanurate (**I**) in a 7 : 3 molar ratio. Increased reaction temperature and time increase the yield of the bis-addition product. With the above reagents in dioxane under reflux (100°C, 14 h), the ratio of the mono- and bis-addition products was 1 : 3.

Compounds **I**–**VIII** are transparent thick oily liquids readily soluble in methanol. The IR spectra of these compounds contain absorption bands at 1700–1680 [ν(C=O)], 760–750 (isocyanurate ring), 1040 [ν(CO)], and 3400 cm^{-1} [ν(OH)]. In addition, the IR spectra of compounds **V**–**VIII** contain bands at 990 and 930 cm^{-1}, characteristic of the allyl group. Treatment of 1-alkyl 3,5-bis[3-(2-hydroxyethylsulfanyl)propyl] isocyanurates with thionyl chloride gives rise to 1-alkyl 3,5-bis[3-(2-chloroethylsulfanyl)propyl] isocyanurates **IX**–**XII**. Reaction of the latter with thiourea followed by hydrolysis afforded 1-alkyl 3,5-bis[3-(2-sulfanylethylsulfanyl)propyl] isocyanurates **XIII**–**XVI**. The composition and structure of the resulting compounds were proved by the elemental analyses (Tables 1 and 2) and ^1H and IR spectra (Tables 3 and 4). Compounds **IX**–**XVI** are yellowish transparent oily liquids. Thiols **XIII**–**XVI** have a characteristic odor. The IR spectra of compounds **IX**–**XVI** contain bands characteristic of the isocyanurate ring. In the spectra of compounds **IX**–**XII**, there is a medium-intensity band at 865–860 cm^{-1}, that probably belongs to the C–Cl bond. The spectra of compounds **XIII**–**XVI** display a weak band at 2560 cm^{-1}, characteristic of thiols. On standing thiols **XIII**–**XVI** are oxidized into oligomeric disulfides. Therewith, the thiol absorption band disappears from the IR spectra.



IX–**XII** **XIII**–**XVI**

R = CH_3 (**IX, XIII**), $C_6H_5CH_2$ (**X, XIV**), $CH_3OC(O)CH_2$ (**XI, XV**), $CNCH_2$ (**XII, XVI**).

Table 2. Yields, R_f values, and elemental analyses of compounds **IX**–**XVI**

Comp. no	Yield, %	R_f (solvent)	Found, %					Formula	Calculated, %				
			C	H	Cl	N	S		C	H	Cl	N	S
IX	48	0.60 (benzene–ethyl acetate, 10 : 1)	40.81	5.13	17.08	10.34	15.74	$C_{14}H_{23}Cl_2N_3O_3S_2$	40.38	5.57	17.03	10.09	15.40
X	58	0.57 (benzene–ethyl acetate, 20 : 1)	49.11	6.02	14.13	8.21	13.35	$C_{20}H_{27}Cl_2N_3O_3S_2$	48.78	5.53	14.40	8.53	13.02
XI	38[a]	0.60 (benzene–ethyl acetate, 5 : 1)	40.36	5.24	14.52	8.56	13.99	$C_{16}H_{25}Cl_2N_3O_5S_2$	40.50	5.30	14.90	8.86	13.52
XII	51	0.42(benzene–ethyl acetate, 10 : 1)	40.74	4.95	15.96	12.21	14.38	$C_{15}H_{22}Cl_2N_4O_3S_2$	40.82	5.02	16.06	12.69	14.53
XIII	30	0.43(benzene–ethyl acetate, 10 : 1)	40.72	5.95	–	10.08	30.94	$C_{14}H_{25}Cl_2N_3O_3S_4$	40.86	6.12	–	10.21	31.15
XIV	63	0.70(benzene–ethyl acetate, 10 : 1)	49.11	5.87	–	8.54	26.12	$C_{20}H_{29}Cl_2N_3O_3S_4$	49.26	5.99	–	8.62	26.29
XV	58	0.71(benzene–ethyl acetate, 5 : 1)	40.81	5.34	–	8.63	27.41	$C_{16}H_{27}Cl_2N_3O_5S_4$	40.92	5.80	–	8.95	27.30
XVI	40	0.56(benzene–ethyl acetate, 5 : 1)	41.12	5.21	–	12.74	29.18	$C_{15}H_{24}Cl_2N_4O_3S_4$	41.26	5.54	–	12.83	29.37

[a] Yield per taken 1,3-diallyl 5-methoxycarbonylmethyl isocyanurate.

Table 3. ^{1}H NMR spectra of compounds **I**–**VIII**, δ, ppm ($^3J_{HH}$, Hz); $CDCl_3$

Comp. no	R	Allyl			>$NC^1H_2C^2H_2C^3H_2SC^4H_2C^5H_2OH$				
		NCH_2	=CH	$=CH_2$	C^1H_2	C^2H_2	C^3H_2	C^4H_2	C^5H_2
I	3.32 s (3H, CH_3)	–	–	–	3.98 t (7.0)	1.82–2.15 m	2.48–2.97 m		3.72 t (6.0)
II	5.03 s (2H, CH_2), 7.33 m (5H, C_6H_5)	–	–	–	4.00 t (7.0)	1.83–2.20 m	2.50–2.83 m 2.50–2.83 m		3.70 t (5.5)
III	3.76 s (3H, CH_3), 4.62 s (2H, CH_2)	–	–	–	4.00 t (7.0)	1.82–2.18 m	2.48–2.75		3.71 t (6.0)
IV[a]	4.82 s (2H, CH_2)	–	–	–	4.02 t (7.0)	1.82–2.15 m	2.61 t (6.5)	2.71 t (5.7)	3.71 t (6.0)
V	3.33 s (3H, CH_3)	4.28 d (6.0)	5.73–6.10 m	5.19 d (*cis*, 9.0), 5.22 d (*trans*, 18.0)	3.98 t (7.5)	1.82–2.17 m	2.47–2.80 m		3.70 t (6.5)
VI	5.02 s (2H, CH_2), 7.33 m (5H, C_6H_5)	4.45 d (6.0)	5.72–6.10 m	5.22 d (*cis*, 9.0), 5.25 d (*trans*, 18.0)	4.00 t (7.2)	1.82–2.18 m	2.50–2.80 m		3.70 t (6.0)

Table 3. (Contd.)

Comp. no	R	Allyl			>NC^{1}H$_2$C^{2}H$_2$C^{3}H$_2$SC^{4}H$_2$C^{5}H$_2$OH				
		NCH$_2$	=CH	=CH$_2$	C^{1}H$_2$	C^{2}H$_2$	C^{3}H$_2$	C^{4}H$_2$	C^{5}H$_2$
VII	3.76 s (3H, CH_3), 4.62 s (2H, CH_2)	4.50 d (6.0)	5.70–6.10 m	5.21 d (*cis*, 9.0), 5.24 d (*trans*, 18.0)	4.00 t (7.0)	1.82–2.17 m	2.48–2.75 m		3.71 t (6.0)
VIII[a]	4.76 s (2H, CH_2)	4.48 d (6.1)	5.78–5.93 m	5.28 d (*cis*, 10.3), 5.35 d (*trans*, 17.2)	4.02 t (7.0)	1.82–2.16 m	2.60 t (7.0)	2.71 t (6.1)	3.70 t (5.9)

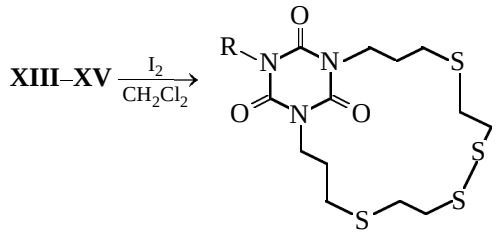
[a] The spectra of compounds **IV** and **VIII** were recorded on a WM-250 instrument (250 MHz), and the spectra of the other compounds, on a T-60 instrument (60 MHz).

Table 4. ^{1}H NMR spectra of compounds **IX**–**XVI**, δ, ppm ($^3J_{HH}$, Hz); $CDCl_3$

Comp. no	R	>NC^{1}H$_2$C^{2}H$_2$C^{3}H$_2$SC^{4}H$_2$C^{5}H$_2$X					
		C^{1}H$_2$	C^{2}H$_2$	C^{3}H$_2$	C^{4}H$_2$	C^{5}H$_2$	SH(X)
IXa	3.32 s (3H, CH_3)	3.99 t (6.0)	1.82–2.15 m	2.61 t (6.8)	2.83 t (7.7)	3.59 t (7.7)	–
X	5.00 s (2H, CH_2), 7.23 m (5H, C_6H_5)	3.97 t (6.5)	1.80–2.10 m	2.48–2.90 m		3.57 t (8.0)	–
XI	3.78 s (3H, CH_3), 4.52 s (2H, CH_2)	3.83–4.13 m	1.89–2.10 m	2.47–3.00 m		3.40–3.78 m	–
XIIa	4.78 s (2H, CH_2)	4.02 t (7.0)	1.94–2.06 m	2.62–2.89 m		3.63 t (8.0)	–
XIIIa	3.33 s (3H, CH_3)	3.90–4.00 m	1.90–1.98 m	2.50–2.73 m			1.68 t (7.4)
XIVa	5.02 s (2H, CH_2), 7.15–7.33 m (5H, C_6H_5)	3.98 t (6.6)	1.90–1.98 m	2.56 t (7.0)	2.67–2.70 m		1.67 t (7.4)
XVa	3.78 s (3H, CH_3), 4.63 s (2H, CH_2)	1.94–4.07 m	1.92–1.97 m	2.58 t (7.0)	2.70–2.80 m		1.70–1.77 m
XVIa	4.76 s (2H, CH_2)	4.00 t (6.9)	1.93–1.99 m	2.60 t (6.9)	2.69–2.84 m		1.69 t (7.5)

[a] The spectra of compounds **IX** and **XII**–**XVI** were recorded on a WM-250 instrument (250 MHz), and the spectra of compounds **X** and **XI**, on a T-60 instrument (60 MHz).

Oxidative cyclization of thiols **XIII**–**XV** [8] gave macrocyclic disulfides **XVII**–**XIX** in 56–75% yields. Compounds **XVII**–**XIX** were purified by column chromatography. They are colorless transparent oily liquids crystallizing on standing, soluble in chloroform and methylene chloride, and insoluble in water and alcohols. The composition and structure of the products were established by the elemental analyses and ^{1}H and ^{13}C NMR and IR spectra (Tables 5 and 6), as well as MALDI–TOF and electron impact mass spectra.



XVII–**XIX**

R = CH_3 (**XVII**), $C_6H_5CH_2$ (**XVIII**), $CH_3OC(O)CH_2$ (**XIX**).

The structure of compound **XVIII** was proved by X-ray diffraction analysis (Fig. 1, Tables 7 and 8). The compound crystallizes in a monoclinic cell with one independent molecule in the asymmetric part.

Table 5. ^{1}H NMR spectra of compounds **XVII**–**XIX**, δ, ppm ($^3J_{HH}$); $CDCl_3$

Comp. no	R	>NC^{1}H$_2$C^{2}H$_2$C^{3}H$_2$SC^{4}H$_2$C^{5}H$_2$S				
		C^{1}H$_2$	C^{2}H$_2$	C^{3}H$_2$	C^{4}H$_2$	C^{5}H$_2$
XVII	3.36 s (CH_3)	4.08 t (6.4)	1.97–2.02 m	2.60–2.67 m	2.80–2.94 m	
XVIII	5.05 s (CH_2), 7.26–7.49 m (C_6H_5)	4.07 t (6.4)	1.94–2.05 m	2.62 t (7.0)	2.75–2.92 m	
XIX	3.80 s (CH_3), 4.65 s (CH_2)	4.09 t (6.6)	1.95–2.06 m	2.64 t (7.0)	2.80–2.91 m	

Table 6. ^{13}C NMR spectra of compounds **XVII**–**XIX**, δ, ppm; $CDCl_3$

Comp. no	R	Isocyanurate ring	>NC^{1}H$_2$C^{2}H$_2$C^{3}H$_2$SC^{4}H$_2$C^{5}H$_2$S				
			C^1	C^2	C^3	C^4	C^5
XVII	CH_3: 29.39 q (142.2)	149.25 (2C), 149.41 (1C)	42.08 t (142.4)	27.47 t (130.0)	29.70 t (138.3)	39.50 t (143.4)	31.43 t (140.4)
XVIII	CH_2: 46.16 t (142.43); Ph: 128.14 d.t C_n (160.5; 7.9), 128.61 d.d C_o (159.4; 7.9), 129.07 d.t C_m (159.4; 5.6; 4.0), 135.84 t C_i	149.14 (2C), 149.30 (1C)	42.14 t (143.5)	27.40 t (130.0)	29.64 t (139.0)	39.31 t (142.4)	31.31 t (140.2)
XIX	CH_2: 43.27 t (144.6) CH_3: 52.64 q (147.7)	148.86 (2C), 149.18 (1C)	42.28 t (143.3)	27.48 t (130.0)	29.58 t (138.7)	39.45 t (142.6)	31.42 t (140.6)

[a] The methylene proton signals were assigned by the sum of substituent increments for alkanes and the $^2J_{CCH}$ and $^3J_{CCCH}$ constants.

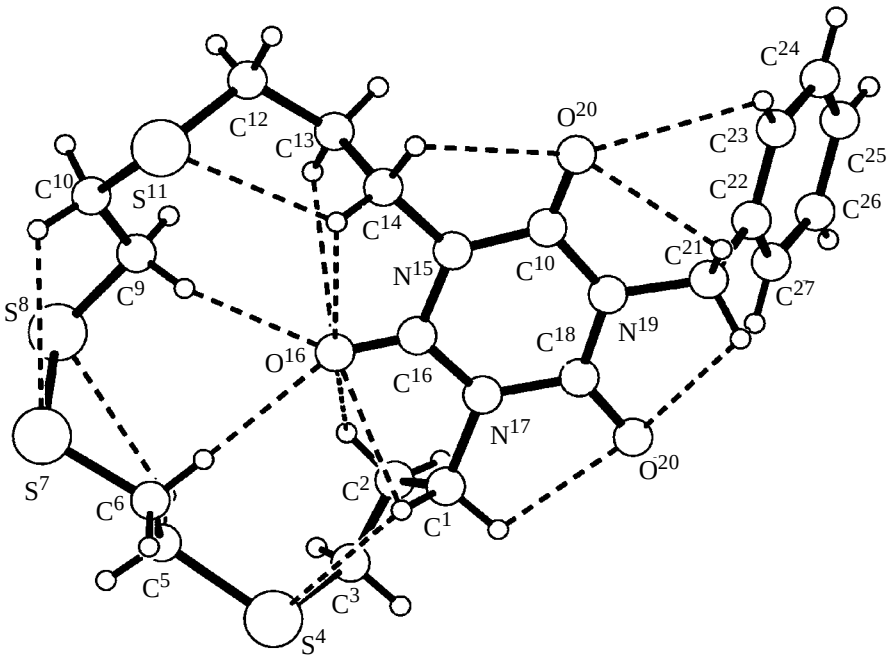


Fig. 1. Molecular geometry of compound **XVIII** in crystal. Dashed lines show intramolecular hydrogen bonds.

Table 7. Coordinates ($\times 10^4$) of non-hydrogen atoms and equivalent isotropic thermal parameters U_{iso} ($\times 10^3$) $U = 1/3 \sum_{i=1}^{3} \sum_{j=1}^{3} (a_i a_j) U(i, j)$ (Å^2) in compound **XVIII**

Atom	*x*	*y*	*z*	*U*
S^4	3062(10)	5071(9)	–135(5)	146(4)
S^7	5499(6)	3071(9)	1572(5)	126(3)
S^8	4750(6)	1597(7)	1936(4)	113(3)
S^{11}	5097(5)	3447(8)	4236(4)	94(2)
O^{16}	3180(11)	5173(13)	2380(7)	61(5)
O^{18}	211(12)	7217(14)	1467(8)	81(6)
O^{20}	1317(10)	6285(16)	4077(10)	84(6)
N^{15}	2262(14)	5670(15)	3242(10)	45(5)
N^{17}	1680(16)	6138(18)	1904(12)	55(6)
N^{19}	766(16)	6815(19)	2803(13)	67(6)
C^1	1860(16)	6126(21)	1099(14)	74(7)
C^2	1698(14)	4698(23)	716(13)	76(6)
C^3	1923(24)	4551(26)	–35(13)	140(13)
C^5	4005(20)	3777(24)	428(17)	113(11)
C^6	4609(23)	4314(25)	1115(18)	139(14)
C^9	4388(19)	2293(27)	2775(15)	128(11)
C^{10}	5119(16)	2213(24)	3454(15)	103(10)
C^{12}	3972(13)	3095(21)	4498(11)	86(8)
C^{13}	2991(15)	3638(24)	3944(12)	76(6)
C^{14}	3064(13)	5144(22)	3870(12)	49(6)
C^{16}	2428(20)	5625(24)	2484(19)	54(4)
C^{18}	814(17)	6718(26)	2021(17)	54(4)
C^{20}	1435(18)	6234(25)	3416(20)	54(4)
C^{21}	–56(17)	7567(21)	2959(13)	74(7)
C^{22}	–949(11)	6692(14)	3047(14)	60(7)
C^{23}	–1127(12)	6433(16)	3778(10)	72(8)
C^{24}	–1971(16)	5716(17)	3839(10)	85(9)
C^{25}	–2638(11)	5259(14)	3168(16)	103(11)
C^{26}	–2460(14)	5518(17)	2437(11)	95(11)
C^{27}	–1616(18)	6234(17)	2376(9)	81(9)

Table 8. Selected bond lengths (*d*, Å) and bond angles (ω, deg) in compound **XVIII**

Bond	*d*	Bond	*d*
S^4–C^3	1.70(3)	N^{17}–C^{16}	1.37(2)
S^4–C^5	1.92(3)	N^{17}–C^1	1.49(2)
S^7–C^6	1.79(3)	N^{19}–C^{20}	1.37(3)
S^7–S^8	1.980(10)	N^{19}–C^{18}	1.40(2)
S^8–C^9	1.80(2)	N^{19}–C^{21}	1.44(2)
S^{11}–C^{12}	1.76(2)	C^1–C^2	1.56(2)
S^{11}–C^{10}	1.85(2)	C^2–C^3	1.44(2)
O^{16}–C^{16}	1.18(2)	C^5–C^6	1.40(3)
O^{18}–C^{18}	1.23(2)	C^9–C^{10}	1.37(2)
O^{20}–C^{20}	1.21(3)	C^{12}–C^{13}	1.56(2)
N^{15}–C^{20}	1.37(2)	C^{13}–C^{14}	1.50(2)
N^{15}–C^{16}	1.41(3)	C^{21}–C^{22}	1.54(2)
N^{15}–C^{14}	1.46(2)	N^{17}–C^{18}	1.38(2)
Angle	**ω**	**Angle**	**ω**
$C^3S^4C^5$	105.9(12)	$C^{13}C^{12}S^{11}$	117.3(14)
$C^6S^7S^8$	107.2(9)	$C^{14}C^{13}C^{12}$	109.2(18)
$C^9S^8S^7$	104.5(10)	$N^{15}C^{14}C^{13}$	111.4(19)
$C^{12}S^{11}C^{10}$	103.7(10)	$O^{16}C^{16}N^{17}$	124.1(31)
$C^{20}N^{15}C^{16}$	123.8(27)	$O^{16}C^{16}N^{15}$	120.3(29)
$C^{20}N^{15}C^{14}$	119.9(22)	$N^{17}C^{16}N^{15}$	115.6(24)
$C^{16}N^{15}C^{14}$	116.2(21)	$O^{18}C^{18}N^{17}$	119.8(27)
$C^{18}N^{17}C^{16}$	124.7(23)	$O^{18}C^{18}N^{19}$	125.0(26)
$C^{18}N^{17}C^1$	119.1(22)	$N^{17}C^{18}N^{19}$	114.8(22)
$C^{16}N^{17}C^1$	116.1(22)	$O^{20}C^{20}N^{15}$	122.6(27)
$C^{20}N^{19}C^{18}$	124.5(24)	$O^{20}C^{20}N^{19}$	121.3(26)
$C^{20}N^{19}C^{21}$	118.9(24)	$N^{15}C^{20}N^{19}$	116.0(31)
$C^{18}N^{19}C^{21}$	116.6(23)	$N^{19}C^{21}C^{22}$	114.5(17)
$N^{17}C^1C^2$	112.2(17)	$C^{23}C^{22}C^{21}$	121.1(20)
$C^3C^2C^1$	116.7(20)	$C^{27}C^{22}C^{21}$	118.8(20)
$C^2C^3S^4$	118.1(20)	$C^{10}C^9S^8$	113.7(20)
$C^6C^5S^4$	112.6(21)	$C^9C^{10}S^{11}$	118.2(19)
$C^5C^6S^7$	109.5(20)		

The dihedral angle between the isocyanurate and benzene rings is 58.63(2)°. Comparison of the crystal structure of compound **XVIII** with those of previously studied compounds of the same series [8] shows that the macroring conformation changes essentially in going from molecules with two methylene groups to molecules with four methylene groups and depending on the nature of the substituent in the isocyanurate fragment. It should also be noted that the crystals studied differ in the type of intermolecular contacts and packing.

The system of hydrogen bonds in the crystal of compound **XVIII** is rich and diverse in spite of the absence of classical hydrogen bonds. This system includes both intra- and intermolecular C–H···O and C–H···S contacts, as well as π···π and C–H···π interactions. The totality of intramolecular contacts appears to stabilize the molecular conformation in crystal and determines the macroring geometry (Fig. 1). The donor–acceptor distances span the range 2.32–2.89 Å, and most short contacts are many-center. The crystal packing is probably determined by π–π interactions between the benzene and isocyanurate rings. The mutual arrangement of molecules is so that the benzene and isocyanurate rings of one molecule interact with the same rings of neighboring molecules related to the initial one by the glide reflection plane

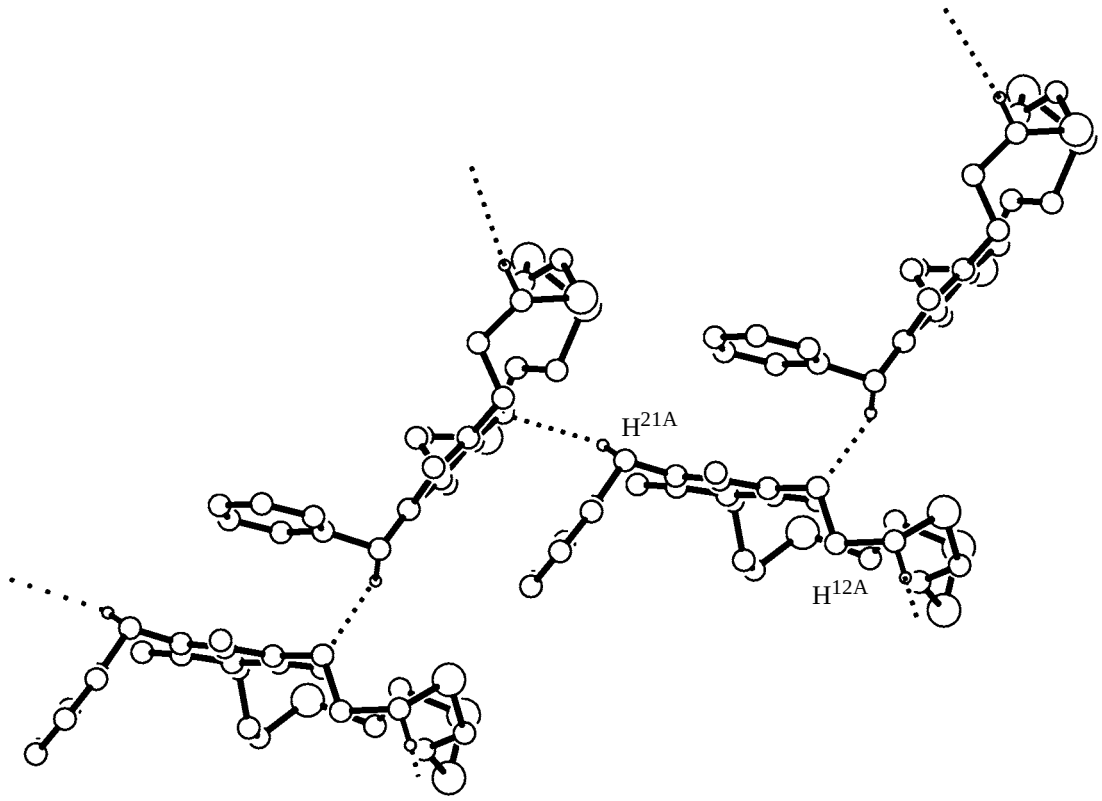


Fig. 2. Zigzag chain of C–H···O- and π···π-bonded molecules **XVIII** in crystal. Shown are only hydrogen atoms involved in hydrogen bonding (dashed lines).

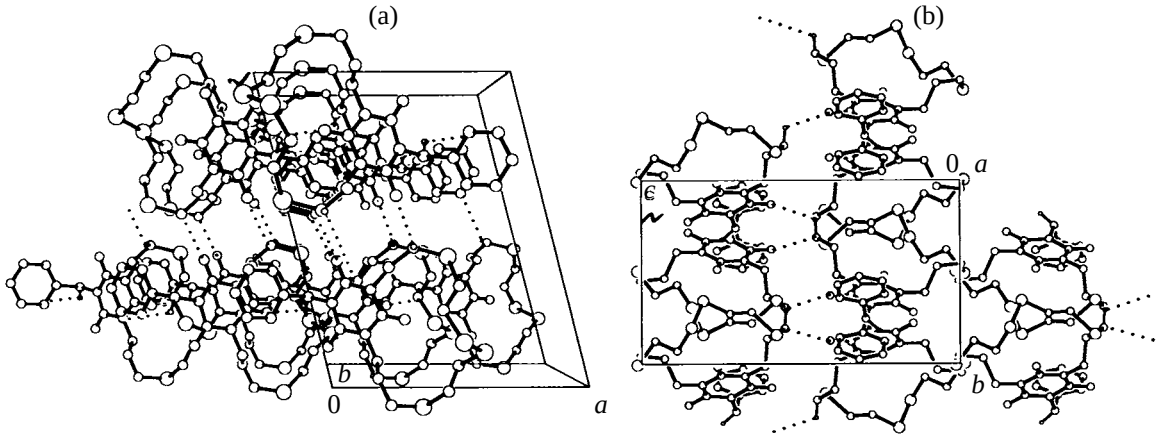


Fig. 3. Packing of molecules **XVIII** in crystal. Hydrogen atoms are not shown, except for those involved in hydrogen bonding. View along the (a) 0*x* and (b) 0*y* axes, hydrogen bonds are shown by dashed lines.

and shifted along the 0*x* axis by –1/2 and +1/2. The interaction parameters are the same: the interplanar dihedral angle is 6.0° and the distance between the aromatic ring centers is 3.569 Å. As a result, a zigzag chain of molecules, running along the 0*a* axis is formed (Fig. 2). Therewith, the arrangement of the aromatic rings proves favorable for intermolecular hydrogen bonding between the carbonyl O^{16} atom and the methylene H^{21A} proton of neighboring molecules of the same chain [$O^{16}\cdots H^{21A'}$ distance 2.62(2) Å, $C^{16}–O^{16}\cdots H^{21A'}$ angle 118°; Fig. 2].

These chains of C–H···O- and π···π-bonded molecules (the top view of these chains is shown in Fig. 3a) are not directly involved in short contacts with neighboring chains running along the 0*y* axis. However, there is one more C–H···O interaction between the carbonyl O^{20} atoms and methylene H^{12A}

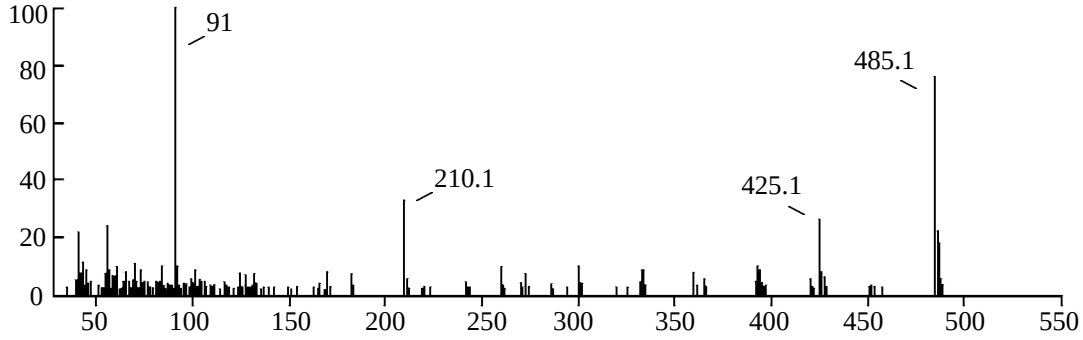


Fig. 4. Electron impact mass spectrum of compound **XVIII**.

protons in molecules related to each other by the 21 screw axis along the 0*y* direction ($O^{20}\cdots H^{16A''}$ distance 2.67 Å, $C^{20}–O^{20}\cdots H^{16A''}$ angle 164°). This interaction combines antiparallel molecular chains into a zigzag bilayer.

Together the above contacts form 2*D* bilayer supramolecular structures (Fig. 3b). Therewith, molecular fragments containing donor–acceptor groups are arranged in the inner part of the bilayers, whereas the more hydrophobic sulfur-containing fragments of the macrorings, between them, i.e. here, too, we observe localization of predominantly hydrophilic and predominantly hydrophobic fields. In whole the crystal packing represents similar bilayer supramolecular structures packed in parallel along the 0*z* axis; therewith, a fairly tight crystal packing is attained (packing coefficient 0.67). Such structure may cause an appreciable anisotropy in the properties of these crystals.

The mass spectrum of compound **XVIII** (Fig. 4) has a strong molecular ion peak *M* 485.09456 (calculated *M* 485.09351 for the molecular formula $C_{20}H_{27}\cdot N_3O_3S_4$). The mass spectrum also contains a $C_{18}H_{23}\cdot N_3O_3S_3$ ion peak, *m/z* 425 (calculated 425.09015, found 425.09088), formed from the molecular ion by expulsion of a C_2H_4S molecule. The strong peak at *m/z* 210 belongs to a $C_9H_{12}N_3O_3$ ion (calculated 210.08786, found 210.08792). The ion peak at *m/z* 91 is formed by a $C_7H_7^+$ ion that is expected by the structure of the compound.

It should be noted that the MALDI–TOF spectum of compound **XVIII** contains two peaks separated by 60 amu, which corresponds to a C_2H_4S fragment. The same pattern is observed with compounds **XVII** and **XIX**.

EXPERIMENTAL

The IR spectra were recorded on a Specord IR-75 instrument for thin films or suspensions in mineral oil. The ^1H NMR spectra were taken on a WM-250 instrument at 250 MHz, internal reference TMS. The 13C NMR spectra were obtained on an MSL-400 instrument at 100 MHz. Thin-layer chromatography was performed on Silufol plates, development in iodine vapor.

The MALDI–TOF spectra were obtained on a Finnigan Maldi–TOF-Dynamo mass spectrometer for 10^{-5}–10^{-3} M solutions in CH_2Cl, matrix 1,8,9-trihydroxyanthracene. The electron impact mass spectrum was obtained on a Finnigan MAT-212 mass spectrometer with direct inlet (130°C), ionizing voltage 60 V, emission current 0.5 mA. Data treatment was performed using the "Maspec II[32]" software. The mass spectra were obtained at a resolution (*R*) of 1000, and the exact masses were obtained at *R* 10000.

X-ray diffraction analysis of compound **XVIII** was performed on an Enraf-Nonius CAD-4 automated four-circle diffractometer. Crystals of compound **XVIII**, $C_{20}H_{27}O_3N_3S_4$, monoclinic. At 20°C, *a* 13.810(4), *b* 9.890(3), *c* 17.60(1) Å, β 103.67(3)°, *V* 2335.5(4) Å^3, *Z* 4, d_{calc} 1.38 g cm^{-3}, space group $P2_1/a$. The unit cell parameters and the intensities of 1658 reflections, 514 of which had $I \geq 2\sigma$, were measured at 20°C (λMoK_α radiation, graphite monochromator, $\omega/2\theta$ scanning, $\theta \leq 19.9°$). No intensity decay of three control reflections was observed during measurements. No corrections for absorption were applied because of its negligibility (λMo 4.3 cm^{-1}). The structure was solved by the direct method by the SHELX [9], WingX [10], and SIR programs [11] and refined by the SHELX program first isotropically and then anisotropically. Hydrogen atoms were located by difference synthesis and refined with fixed positional and isotropic thermal parameters. The structure was refined to *R* 0.046 and R_W 0.100 on 514 unique reflections with $F^2 \geq 2\sigma$. The drawing were performed using the PLATON program [12].

1-R-3,5-Bis[3-(2-hydroxyethylsulfanyl)propyl]-1,3,5-triazine-2,4,6(1*H*,3*H*,5*H*)-triones I–IV. 2-Sulfanylethanol, 0.066 mol, and 0.0006 mol of 2,2'-azobisisobutyronitrile were added to a solution of 0.03 mol of 1-R 3,5-diallyl isocyanurate in 150 ml of absolute dioxane. The reaction mixture was heated under reflux under argon for 12–14 h (26 h at R = CH_2CN). The solvent was removed in a vacuum, and the residue was subjected to column chromatography on silica gel, eluents benzene (A) and benzene–methanol, 10 : 1 (B).

1-R-3,5-Bis[3-(2-chloroethylsulfanyl)propyl]-1,3,5-triazine-2,4,6(1*H*,3*H*,5*H*)-triones IX–XII. A solution of 0.057 mol of thionyl chloride in 10 ml of absolute 1,2-dichloroethane was added to a solution of 0.025 mol of compound **I–IV** in 100 ml of the same solvent. The reaction mixture was left overnight, after which is was first heated at 40°C for 4 h and then refluxed for 1 h. Excess thionyl chloride was decomposed with water. The organic layer was washed with water (2×50 ml) and dried with $MgSO_4$. The solvent was removed, and the residue was subjected to column chromatography on silica gel, eluent benzene–ethyl acetate, 10 : 1.

1-R-3,5-Bis[3-(2-sulfanylethylsulfanyl)propyl]-1,3,5-triazine-2,4,6(1*H*,3*H*,5*H*)-triones XIII–XVI. Equimolar amounts of compound **IX–XII** and thionyl chloride was heated under reflux in absolute 2-propanol for 10–16 h. The solvent was removed in a vacuum. The residue was diluted with water, and aqueous K_2CO_3 was added to the mixture with stirring, after which it was heated for 1h on a boiling water bath. The reaction products were extracted with hot benzene, and the extract was dried with $MgSO_4$. The solvent was removed, and the residue was subjected to column chromatography on silica gel, eluent benzene–ethyl acetate, 10 : 1.

18-R-1,16,18-Triaza-5,8,9,12-tetrathiabicyclo-[14.3.1]eicosane-17,19,20-triones XVII–XIX. Solutions of 0.005 mol of thiol **XIII–XVI** in 60 ml of absolute dichloromethane and 1.27 g of iodine in 150 ml of absolute dichloromethane were added dropwise with vigorous stirring at 18–20°C to a solution of 1.1 g of triethylamine in 60 ml of absolute dichloromethane so that the reaction mixture changes from colorless to yellowish (10–15 ml of iodine remained each time). The mixture was stirred for 4 h more, washed in succession with 50 ml of water with a few crystals of sodium thiosulfate added, 50 ml of 0.1 N HCl, and water (2×50 ml), and dried with $MgSO_4$. The solvent was removed by distillation, and the residue was subjected to column chromatography on silica gel, eluent benzene and benzene–ethyl acetate, 10 : 1.

18-Methyl-1,16,18-triaza-5,8,9,12-tetrathiabicyclo[14.3.1]eicosane-17,19,20-trione (XVII). Yield 75%, mp 112–117°C (triturated with ether). R_f 0.45 (benzene–ethyl acetate, 10 : 1). MALDI–TOF mass spectrum: H 410 (*M* + H), calculated *M* 409; H 350 (*M* + H). Found, %: C 40.94; H 5.58;N 10.11; S 31.25. $C_{14}H_{23}N_3O_3S_4$. Calculated, %: C 41.06; H 5.66; N 10.56; S 31.30.

18-Benzyl-1,16,15-triaza-5,8,9,12-tetrathiabicyclo[14.3.1]eicosan-17,19,20-trione (XVIII). Yield 56%, mp 102–104°C ($CHCl_3$–CH_3OH). R_f 0.63 (benzene–ethyl acetate, 10:1). MALDI–TOF mass spectrum: H 486 (*M* + H), calculated *M* 485; H 426 (*M* + H). Found, %: C 49.30; H 5.73; N 8.47; S 26.36. $C_{20}H_{27}N_3O_3S_4$. Calculated, %: C 49.46; H 5.60; N 8.65; S 26.40.

Methyl 2-(17,19,20-trioxo-1,16,18-triaza-5,8,9,12-tetrathiabicyclo[14.3.1]eicosan-18-yl)acetate (XIX). Yield 62%, mp 112–113°C ($CHCl_3$–CH_3OH). R_f 0.38 (benzene–ethyl acetate, 10 : 1). MALDI–TOF mass spectrum: H 468 (*M* + H), calculated *M* 467; H 408 (*M* + H). Found, %: C 41.46; H 5.41; N 8.94; S 27.56. $C_{16}H_{25}N_3O_3S_4$. Calculated, %: C 41.10; H 5.39; N 8.99; S 27.20.

ACKNOWLEDGMENTS

The work was financially supported by the Russian Foundation for Basic Research (project no. 02-03-32 280).

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