Organic Chemistry

Reactions of functionalized alkyl halides with *N*-(β-hydroxyalkyl)-*N'*-hydroxydiazene *N*-oxide salts

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Some characteristic features of reactions of *N*-(β-hydroxyalkyl)-*N'*-hydroxydiazene *N*-oxide salts with various α- and β-functionalized alkyl halides were established. Some α- and β-functionalized *N*-(β-hydroxyalkyl)-*N'*-alkoxydiazene *N*-oxides and ethylenebis[*N*-(β-hydroxyalkyl)-*N'*-oxydiazene *N*-oxides] were synthesized for the first time.

Key words: *N*-(β-hydroxyalkyl)-*N'*-hydroxydiazene *N*-oxide salts, α- and β-functionalized *N*-(β-hydroxyalkyl)-*N'*-alkoxydiazene *N*-oxides, ethylenebis[*N*-(β-hydroxyalkyl)-*N'*-oxydiazene *N*-oxides], 1,2-dibromoethane, chloromethyl methyl sulfide, chloromethyl methyl ether, *N*-chloromethyl-*N*-methylnitramine, alkylation, anchimeric assistance.

Previously we have shown[1] that introduction of the hydroxyl group in the β-position of *N*-alkyl-*N'*-hydroxydiazene *N*-oxides (HDO) has virtually no influence on reactions of salts of these compounds with primary and secondary alkyl iodides and bromides; therefore, this procedure can be used to obtain *N*-(β-hydroxyalkyl)-*N'*-alkoxydiazene *N*-oxides (ADO) in relatively high yields (60—80%). In this respect, *N*-(β-hydroxyalkyl) derivatives of *N*-alkyl-*N'*-hydroxydiazene *N*-oxides differ markedly from *N*-β-carboxylate (or alkoxycarbonyl) HDO derivatives. The presence of the above-mentioned groups in the latter compounds results in substantially decreased yields of functionalized *N*-alkyl-*N'*-alkoxydiazene *N*-oxides (evidently, due to the higher contribution of the reaction involving the other reaction site of the ambident *N'*-hydroxydiazene *N*-oxide anion, which yields the corresponding relatively unstable *N*-alkoxy-*N*-nitrosamine derivatives).*

In order to find out whether or not this feature is retained on passing from unsubstituted alkyl halides to their α- and β-functionalized derivatives and to develop methods for the synthesis of previously unknown α- and β-functionalized derivatives at the alkoxy group of *N*-(β-hydroxyalkyl)-*N'*-alkoxydiazene *N*-oxides and ethylenebis[*N*-(β-hydroxyalkyl)-*N'*-oxydiazene *N*-oxides], we studied reactions of *N*-(2-hydroxypropyl)-*N'*-

* See Ref. 2 and references cited therein.

Translated from *Izvestiya Akademii Nauk. Seriya Khimicheskaya*, No. 1, pp. 123—129, January, 1999.

1066-5285/99/4801-0124 $22.00

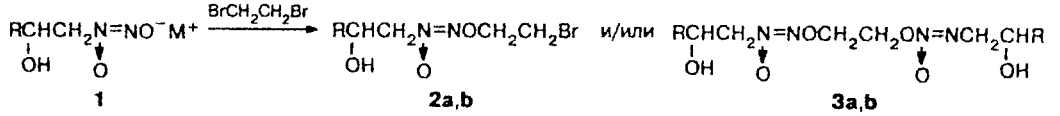
hydroxydiazene *N*-oxide (**1a**) and *N*-(2-hydroxy-3-phenoxypropyl)-*N'*-hydroxydiazene *N*-oxide (**1b**) salts with 1,2-dibromoethane (DBE) and some chloromethane α-derivatives.

Among other reasons, DBE was chosen as the β-substituted alkyl halide due to the fact that study of this reaction could allow one to estimate the effect of not only the β-bromine atom but also the oxydiazene *N*-oxide fragment on its features. In view of the data reported previously,[1] we used alkali metal, ammonium, tetramethylammonium, and silver cations as the counterions in the HDO salts; the reactions were mainly carried out in DMSO or acetonitrile, and in some cases, in ether, benzene, or dichloromethane.

The conclusion about the structures of the resulting stable products was based on their spectral characteristics, data of elemental analysis (Tables 1 and 2), and the qualitative test for the N—NO group.

It was found that the reactions of salts **1a,b** with DBE afford *N*-(2-hydroxypropyl)-*N'*-(2-bromoethoxy)-diazene *N*-oxide (**2a**) and *N*-(2-hydroxy-3-phenoxypropyl)-*N'*-(2-bromoethoxy)diazene *N*-oxide (**2b**)

Scheme 1



1 **2a,b** **3a,b**

R = Me (**a**), $PhOCH_2$ (**b**)

Table 1. Melting points, spectral characteristics, and elemental analysis data for the products of reaction of DBE with hydroxydiazene *N*-oxide salts **1a,b**

Compound	M.p./°C (solvent for crystallization)	IR spectrum, ν/cm^{-1}	NMR spectra			Found / Calculated (%)			Molecular formula
			solvent	^{1}H, δ	^{14}N, δ ($\Delta\nu_{1/2}$/Hz)	C	H	N	
2a[a]	[b]	3430 (OH); 1510, 1315 (N=N–O)	$CDCl_3$	1.12 (d, 3 H, CH_3); 3.63 (t, 2 H, CH_2Br); 3.70 (br.s, 1 H, OH); 3.90 (t, 2 H, CH_2N); 4.25 (m, 1 H, CH); 4.38 (t, 2 H, CH_2O)	−67 (290)	26.83 / 26.43	5.00 / 4.85	12.40 / 12.33	$C_5H_{11}BrN_2O_3$
2b	75—76.5 (hexane—chloroform)	3440 (OH); 1590 (Ph); 1490, 1300 (N=N–O)	$(CD_3)_2CO$	3.68 (t, 2 H, CH_2Br); 4.10 (m, 2 H, CH_2N); 4.30 (d, 2 H, CH_2OPh); 4.50 (t, 2 H, OCH_2CH_2); 4.60 (m, 1 H, CHOH); 5.12 (d, 1 H, OH); 6.95 (m, 3 H, 3,4-Ph); 7.30 (m, 2 H, 2-Ph)	−67 (200)	41.60 / 41.38	4.96 / 4.70	8.82 / 8.78	$C_{11}H_{15}BrN_2O_4$
3a	[b]	3420 (OH); 1510, 1310 (N=N–O)	$CDCl_3$	0.95 (d, 6 H, CH_3); 3.70 (m, 4 H, CH_2N); 3.98 (br.s, 2 H, OH); 4.08 (m, 2 H, CH); 4.27 (s, 4 H, CH_2O)	−56 (1160)	37.04 / 36.09	7.03 / 6.77	21.21 / 21.05	$C_8H_{18}N_4O_6$
3b	124.5—125.0 (AcOH)	3370 (OH); 1600, 1590 (Ph); 1490, 1300 (N=N–O)	$(CD_3)_2CO$	4.00 (d, 4 H, CH_2N); 4.20 (m, 4 H, CH_2OPh); 4.40 (br.s, 2 H, CHOH); 4.50 (s, 4 H, OCH_2CH_2O); 5.70 (br.s, 2 H, OH); 6.95 (m, 6 H, 3,4-Ph); 7.30 (t, 4 H, 2-Ph)	−68 (690)	54.22 / 53.33	6.29 / 5.78	—	$C_{20}H_{26}N_4O_8$

[a] MS, m/z (I_{rel} (%)): 229 $[M + 1]^+$ (3), 228 $[M]^+$ (3), 227 $[M + 1]^+$ (2.5), 226 $[M]^+$ (2.6).
[b] Oil.

Table 2. Chromatographic parameters, spectral characteristics, and elemental analysis data for the products of the reaction of salts **1a** with α-substituted chloromethanes $ClCH_2X$

Compound	R_f (eluent)	IR spectrum, ν/cm^{-1}	NMR spectra: solvent	^1H, δ	^{13}C, δ[b]	^{14}N, δ ($\Delta\nu_{1/2}$/Hz)	Found / Calculated (%) C	H	N	Molecular formula
7	0.31 (ether)	3450 (OH); 1505 (N=N–O); 1305 (C–S)	$CDCl_3$	1.13 (d, 3 H, CH_3); 2.15 (s, 3 H, CH_3S); 3.92 (d, 2 H, CH_2N); 4.30 (m, 2 H, CH+OH); 5.20 (s, 2 H, CH_2O)		−66 (N→O) (360)	33.63 / 33.33	7.05 / 6.67	15.46 / 15.56	$C_5H_{12}N_2O_3S$
8	0.16 (ether)	3460 (OH); 1320, 1515 (N=N–O); 1110 (C–O)	$CDCl_3$	1.00 (d, 3 H, CH_3); 3.20 (s, 3 H, CH_3O); 3.80 (m, 3 H, CH_2N+CH); 4.10 (m, 1 H, OH); 5.00 (q, 2 H, CH_2O)		−66 (N→O) (490)	36.27 / 36.59	7.41 / 7.32	16.51 / 17.07	$C_5H_{12}N_2O_4$
9[a]	0.36 ($CHCl_3$–MeOH, 9 : 1)	3470 (OH); 1537,1350 ($N–NO_2$); 1520, 1305 (N=N–O)	$(CD_3)_2CO$	1.20 (d, 3 H, $C\underline{H}_3CH$); 3.50 (s, 3 H, CH_3N); 3.62 (br.s, 1 H, OH); 4.00 (m, 2 H, CH_2N); 4.30 (m, 1 H, CH); 5.82 (q, 2 H, CH_2O)	21 ($\underline{C}H_3CH$); 38 (CH_3N); 64 (CH); 71 (CH_2N); 81 (CH_2O)	−29 ($N–NO_2$) (40); −62 (N→O) (220)	29.01 / 28.85	5.74 / 5.77	27.24 / 26.92	$C_5H_{12}N_4O_5$
10	0.43 (ether)	1320, 1515 (N=N–O); 1110 (C–O)	$CDCl_3$	0.90 (d, 3 H, $C\underline{H}_3CH$); 2.90 (s, 3 H, CH_3O); 3.10 (s, 3 H, CH_3O); 3.70 (m, 2 H, CH_2N); 4.01 (m, 1 H, CH); 4.25 (dd, 2 H, $C\underline{H}_2OCH$); 4.90 (s, 2 H, OCH_2O)	17.1 ($\underline{C}H_3CH$); 54.5 (CH_3O); 56.0 (CH_3O); 67.7 (CH_2N); 68.6 (CH); 94.6 ($\underline{C}H_2OC$); 97.2 (OCH_2O)	−67 (N→O) (400)	40.48 / 40.38	7.71 / 7.69	13.59 / 13.46	$C_7H_{16}N_2O_5$
11	0.41 (CH_3Cl–MeOH, 9 : 1)	1550, 1535, 1385 ($N–NO_2$); 1505, 1305 (N=N–O)	$(CD_3)_2CO$	1.30 (d, 3 H, CH_3); 3.30 (s, 3 H, CH_3N); 3.50 (s, 3 H, CH_3N); 4.15 (m, 2 H, CH_2N); 4.35 (m, 1 H, CH); 5.22 (dd, 2 H, $C\underline{H}_2OCH$); 5.88 (s, 2 H, CH_2ON)		−28 ($N–NO_2$) (40); −62 (N→O) (200)	29.71 / 28.38	5.89 / 5.41	28.67 / 28.38	$C_7H_{16}N_6O_7$
12	0.58 (ether)	3480 (OH); 1430 (N–NO); 1305 (C–S)	$(CD_3)_2SO$	1.10 (d, 3 H, $C\underline{H}_3CH$); 2.25 (s, 2 H, CH_3C); 4.05 (m, 2 H, CH_2N); 4.20 (m, 1 H, CH); 5.10 (d, 1 H, OH); 5.15 (s, 2 H, CH_2O)						
13	0.25 (ether)	3480 (OH); 1480 (N–NO); 1105 (C–O)	CD_3Cl	1.30 (s, 3 H, $C\underline{H}_3CH$); 3.40 (s, 3 H, CH_3O); 3.60 (br.s, 1 H, OH); 4.30 (m, 3 H, CH_2N+CH); 4.70 (s, 2 H, CH_2O)						
14	0.67 ($CHCl_3$–MeOH, 9 : 1)	1595, 1345 ($N–NO_2$); 1450 (N–NO)	$(CD_3)_2CO$	1.25 (d, 3 H, CH_3); 3.40 (s, 3 H, CH_3N); 3.60 (br.s, 1 H, OH); 4.08 (m, 1 H, CH); 4.50 (m, 2 H, CH_2N); 5.28 (q, 2 H, CH_2O)	17.1 ($\underline{C}H_3C$); 38.8 (CH_3N); 72.7 (CH); 76.6 (CH_2N); 80.1 (CH_2O)	−28 ($N–NO_2$) (20)				

[a] M.p. 87–91 °C.

[b] The ^{13}C NMR spectra were interpreted using the DEPT-135 program.

Table 3. Effect of the conditions of the reactions of *N*-(β-hydroxyalkyl)-*N'*-hydroxydiazene *N*-oxide salts $RCH(OH)CH_2N(O)=NO^-M^+$ with 1,2-dibromoethane on the yields of $RCH(OH)CH_2N(O)=NOCH_2CH_2Br$ (**2a,b**) and $[RCH(OH)CH_2N(O)=NO]_2CH_2$ (**3a,b**)

R	M^+	Reaction conditions				Yield (%)	
		salt : DBE	solvent	*t*/°C	τ /h	**2a** or **2b**	**3a** or **3b**
Me	Ag	2 : 2	Ether	20	216	—	9
Me	K	2 : 1	DMSO	60	48	—	7
Me	K	2 : 1	DMSO	60	120	1.5	11
Me	NH_4	2 : 1	DMSO	60	40	—	63
Me	Me_4N	2.0 : 1.5	MeCN	20	96	30	33
Me	Me_4N	2 : 1	MeCN	80	168	24	36
$PhOCH_2$	NH_4	2 : 1	DMSO	20	72	17	22
$PhOCH_2$	NH_4	2.0 : 1.9	DMSO	60	20	—	47
$PhOCH_2$	NH_4*	2.0 : 1.9	DMSO	60	40	—	59
$PhOCH_2$	NH_4	2.0 : 1.9	DMSO	80	2	6	31
$PhOCH_2$	NH_4	2.0 : 1.9	DMSO	90	42	—	49
$PhOCH_2$	NH_4	2 : 20	DMF	65	72	9	—
$PhOCH_2$	NH_4*	2 : 8	DMSO	40	6	9	—
$PhOCH_2$	NH_4	2 : 40	DMSO	65	45	5	—

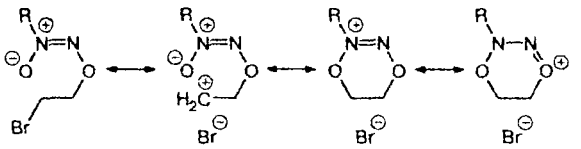
* In the presence of Na_2CO_3.

and/or 2,13-dihydroxy-6,9-dioxa-4,5,10,11-tetraazatetradeca-4,10-diene 4,11-dioxide (**3a**) and 2,13-dihydroxy-1,14-diphenoxy-6,9-dioxa-4,5,10,11-tetraazatetradeca-4,10-diene 4,11-dioxide (**3b**), respectively (Scheme 1). The yields of the products and their proportions in the final mixture depend appreciably on the ratio of the initial reactants, the nature of the cation in salts **1a** and **1b**, and the reaction conditions (Table 3).

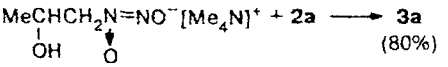
The use of silver salt **1a** (M = Ag) at room temperature does not give alkylation products in satisfactory yields. Even after storage for 9 days, the reaction product can be isolated only in ~9% yield. In essence, the outcome is the same when potassium salt **1a** reacts in DMSO at 60 °C for 3—4 days. Conversely, the use of ammonium salts **1a** and **1b** in DMSO allows preparation of the alkylation products in quite satisfactory yields over an acceptable period of time. The addition of Na_2CO_3 to the reaction mixture has a rather favorable influence on the yields of alkylation products; the effect of this additive may be due to the partial formation of sodium salts, which decreases decomposition of the *N*-hydroxydiazene *N'*-oxides resulting from dissociation of ammonium salts. Regarding the rate of accumulation of the reaction products, the reaction of tetramethylammonium salts of hydroxydiazene *N*-oxides in acetonitrile is virtually equivalent to the use of ammonium salts in DMSO. It was found by the method of competing reactions that in this case, DBE is approximately 4 times less reactive than ethyl bromide. The highest yields of the reaction products attained are ~60—70%. Depending mostly on the ratio of the reactants, these products, as noted above, include the products of substitution of one or two Br atoms by the *N*-(β-hydroxyalkyl)-*N'*-oxydiazene *N*-oxide fragment. We were unable to isolate the products of alkylation of the ambident hydroxydiazene *N*-oxide **1a,b** anions at other oxygen atoms (this would result in relatively labile *N*-nitrosohydroxylamine derivatives). Apparently, the rate of decomposition of these compounds is higher than the rate of their formation.

To prepare the products of replacement of one Br atom in DBE in the highest yield, a multiple excess of the latter is needed. When the reactant ratio is close to stoichiometric, the product of substitution of both Br atoms in DBE is usually formed as an obviously predominant or, in some cases, virtually the only product. This fact implies that the rate of nucleophilic substitution of the Br atom in DBE is lower than that in the bromoethoxy derivatives **2a,b** thus formed. This finding should be regarded as unexpected if one takes into account the tendency of variation of the rates of the reactions studied following the introduction of an electronegative substituent into the alkylating reagent and also the fact that, according to general considerations, the electronegativity of the oxydiazene *N*-oxide group should be markedly higher than that of the Br atom. The latter conclusion is also supported by the proton chemical shifts observed in the ^1H NMR spectra of these compounds compared to those of DBE. In our opinion, this unexpected result is due to the anchimeric assistance of the oxydiazene *N*-oxide group, stabilizing the partial positive charge, which is generated on the carbon atom attached to the Br atom during alkylation. The mechanism of this anchimeric assistance (Scheme 2) can be shown by a set of canonical structures.

Scheme 2



It was shown in a special experiment that the yield of the alkylation product in the second step is ~80%.

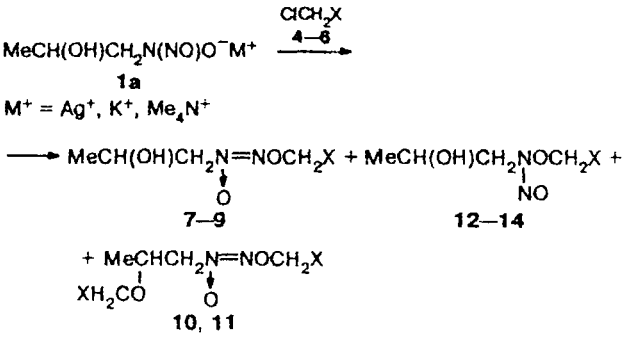


The results obtained make it possible to conclude that the introduction of electronegative substituents in the β-position of alkyl halides either accelerates or retards the alkylation but has no significant influence on the course of their reactions with *N*-(β-hydroxyalkyl)-*N'*-hydroxydiazene *N*-oxide salts. This enables the synthesis of *N*-(β-hydroxyalkyl)-*N'*-alkoxydiazene *N*-oxides functionalized at the β-position of the alkoxyl radical in satisfactory yields.

As α-functionalized alkyl halides, we used chloromethyl methyl sulfide (**4**), chloromethyl methyl ether (**5**), and *N*-chloromethyl-*N*-methylnitramine (**6**), *i.e.*, compounds containing heteroatoms with a lone electron pair in the α-position in relation to the halogen. It is well known that this combination of heteroatoms facilitates the formation of carbocationic centers during alkylation. On the one hand, this substantially increases the reactivity of halo derivatives, but on the other hand, this often changes the character of the transition state and, as a consequence, regularities of the process. These features were also manifested in this particular case. Thus it was found that compounds **4**—**6**, unlike alkyl chlorides, react with salts **1a** relatively readily. The reactions normally give three types of compounds: functionalized *N*-(β-hydroxyalkyl)-*N'*-alkoxydiazene *N*-oxides, *viz.*, *N*-(2-hydroxypropyl)-*N'*-(2-thiapropoxy)-diazene *N*-oxide (**7**), *N*-(2-hydroxypropyl)-*N'*-(2-oxapropoxy)diazene *N*-oxide (**8**), and *N*-(2-hydroxypropyl)-*N'*-(2-nitro-2-azapropoxy)diazene *N*-oxide (**9**); products of their subsequent alkylation at the hydroxyl group, *viz.*, *N*-[2-(2'-oxapropoxy)propyl]-*N'*-(2-oxapropoxy)-diazene *N*-oxide (**10**), and *N*-[2-(2'-nitro-2'-azapropoxy)propyl]-*N'*-(2-nitro-2-azapropoxy)diazene *N*-oxide (**11**); and functionalized *N*-(β-hydroxyalkyl)-*O*-alkyl-*N*-nitrosohydroxylamines, *viz.*, *N*-(2-hydroxypropyl)-*O*-(2-thiapropyl)-*N*-nitrosohydroxylamine (**12**), *N*-(2-hydroxypropyl)-*O*-(2-oxapropyl)-*N*-nitrosohydroxylamine (**13**), and *N*-(2-hydroxypropyl)-*O*-(2-nitro-2-azapropyl)-*N*-nitrosohydroxylamine (**14**) (Scheme 3).

The resulting compounds **7**—**14** are normally thick noncrystallizable oils. Unlike the rest of the products, nitrosohydroxylamines **12**—**14** are quite unstable. The conclusion about their structures was based on NMR and IR spectra, which exhibit absorption in the region typical of nitrosohydroxylamines (1430—1480 cm^{-1}), and on the qualitative color test for the N—NO group (instantaneous dark blue coloring on treatment with a diphenylamine—H_2SO_4(conc.) mixture). The total yield

Scheme 3



of the reaction products and their ratio depend strongly on the alkylating reagent used and on the cation in salt **1a** (Table 4). The reactions occur most smoothly with silver salts **1a** in ether or tetramethylammonium salts in acetonitrile. When working with potassium salts, it is expedient to use phase transfer catalysts, quaternary ammonium salts or macrocyclic polyethers. The total yield of *N*-alkoxydiazene *N'*-oxide type products **7**—**9** and **10**, **11** amounts to 25—55% and is usually 2—5 times higher than the yield of nitrosohydroxylamines **12**—**14**. As a rule, the yields of the later increase on passing from onium to silver salts.

As noted above, the higher reactivity of the chloromethyl derivatives studied, compared with unsubstituted alkyl halides, results in the formation of double alkylation products. This is especially pronounced in the case of the most reactive chloromethyl ether **5**, less pronounced for chloromethylnitramine **6**, and is not manifested at all in the reaction of tetramethylammonium salt **1a** with chloromethyl sulfide **4**. The data presented

Table 4. Effect of the conditions of the reactions of *N*-(2-hydroxypropyl)-*N'*-hydroxydiazene *N*-oxide salts $MeCH(OH)CH_2N_2O_2^-M^+$ with $ClCH_2R$ derivatives on the yields of alkylation products **7**—**14** (at 20 °C)

R	M^+	Reaction conditions			Yield (%)		
		solvent	τ/h	catalyst	**7—9**	**10, 11**	**12—14**
MeS	Me_4N	MeCN	168	None	36	—	22
MeO	Ag	Ether	24	The same	15	35.5	12
MeO	Me_4N	MeCN	168	»	29	3	<0.1
$MeN(NO_2)$	Ag	Ether	24	»	18	7.5	12
$MeN(NO_2)$	Me_4N	MeCN	96	»	43	13	20
$MeN(NO_2)$	Li	MeCN	48	»	—	—	—
$MeN(NO_2)$	K	CH_2Cl_2	24	$Me_3PhCH_2N^+Cl^-$	46	6	11
$MeN(NO_2)$	K	Benzene	24	DB18C6	23	—	—
$MeN(NO_2)$	K	Benzene	24	PEG*	17	15	17

* PEG is poly(ethylene glycol) (M ≈ 3000 rel. units).

in Table 4 demonstrate that this process can be controlled. Thus on going from Ag salt **1a** to the tetramethylammonium salt in the reaction with chloromethyl ether **5**, the yield of the double alkylation product **10** decreases 10-fold; the product of the same type **11** is not formed at all if potassium salt **1a** is alkylated in benzene in the presence of crown ether DB18C6.

In general it can be stated that alkylation of *N*-(β-hydroxyalkyl)-*N'*-hydroxydiazene *N*-oxide salts with halogen derivatives containing atoms with a lone electron pair in the α-position is less selective than that with the studied unsubstituted or β-substituted alkyl halides. Nevertheless, in this case, too, it is still possible to obtain the desired *N*-(β-hydroxyalkyl)-*N'*-alkoxydiazene *N*-oxide derivatives but their yields decrease from 70—80% to 35—45%.

Experimental

IR spectra were recorded on UR-20, Specord M-60, and Specord M-82M spectrophotometers in KBr pellets or in thin films using KBr glasses. NMR spectra were run on Bruker AM-300, Bruker WM-250, and Bruker AC-200C spectrometers (^{1}H, 300.13, 255.13, and 200.13 MHz; ^{14}N, 21.69 MHz; ^{13}C, 62.9 and 50.32 MHz). The ^{1}H and ^{13}C chemical shifts (in the δ scale) were referred to the solvent (acetone-d_6, 2.07 and 30.0 ppm; DMSO-d_6, 2.5 and 39.5 ppm; chloroform-d_1, 7.25 and 77.0 ppm); those in the ^{14}N NMR spectrum were referred to $MeNO_2$ (external standard). Mass spectra were measured on a Kratos MS-30 instrument by direct sample injection (EI, 70 eV). Melting points were determined between glasses on a Boëtius hot-stage apparatus.

Preparative TLC was carried out on Silpearl UV-254 silica gel or Silufol UV-254 plates with applied silica gel.

Solvents were purified by standard procedures. *N*-(2-Hydroxypropyl)-*N'*-hydroxydiazene *N*-oxide (**1a**) and *N*-(2-hydroxy-3-phenoxypropyl)-*N'*-hydroxydiazene *N*-oxide (**1b**) salts and *N*-chloromethyl-*N*-methylnitramine (**6**) were prepared by previously described procedures.[1,3,4]

Alkylation of the *N*-(β-hydroxyalkyl)-*N'*-hydroxydiazene *N*-oxide salts $RCH(OH)CH_2N(NO)O^-M^+$ 1a,b (general procedures)

1. Alkylation of the silver salt of *N*-(2-hydroxypropyl)-*N'*-hydroxydiazene *N*-oxide (1a, M = Ag). The appropriate alkylating reagent (2 mmol) (see Tables 3, 4) was added to a suspension of silver salt **1a** (2 mmol) in 10 mL of anhydrous ether. The reaction mixture was stirred at ~20 °C and filtered. The solid precipitate was washed by 5 mL of ether, and the filtrate was concentrated *in vacuo*. The oily residue was separated by preparative TLC (for compounds **2a**, **3a**, a 9 : 1 $CHCl_3$—MeOH mixture was used as the eluent; the eluents for products **7**—**14** are listed in Table 2). The yields and some physicochemical characteristics of compounds **2a**, **3a**, and **7**—**14** are presented in Tables 1—4.

2. Alkylation of the alkali metal salts of *N*-(2-hydroxypropyl)-*N'*-hydroxydiazene *N*-oxide (1a). ***A.*** A mixture of lithium or potassium salt **1a** (2.5 mmol) with the corresponding amount of the alkylating reagent in 10 mL of a solvent was stirred for a definite period of time (see Tables 3, 4) in the atmosphere of dry nitrogen. Then the solvent was evaporated *in vacuo*, and the residual oil was separated by preparative TLC (for compounds **2a**, **3a**, a 9 : 1 $CHCl_3$—MeOH mixture was used as the eluent, for the eluents used for products **7**—**14**, see Table 2). The reaction conditions and the product yields are presented in Tables 3 and 4. The physicochemical characteristics of the compounds synthesized by this procedure were identical to those of compounds obtained upon alkylation of silver salt **1a**.

B. A suspension of potassium salt **1a** (3 mmol), finely powdered K_2CO_3 (3.2 mmol), and $Me_3PhCH_2N^+Cl^-$ (0.15 mmol) in 20 mL of CH_2Cl_2 was stirred for 15 min. Then compound **6** (3 mmol) was added, and the mixture was kept for a definite period of time (see Table 4). The solid residue was separated and the filtrate was concentrated *in vacuo*. Preparative TLC of the residue gave products **9**, **12**, and **14**. Reaction conditions are given in Table 4.

C. A suspension of potassium salt **1a** (3 mmol) and DB18C6 or PEG (0.1 mmol) in 20 mL of anhydrous benzene was stirred for 2 h at ~20 °C. Then compound **6** (3 mmol) was added and stirring was continued (see Table 4). After the mixture had been kept for the required time, the solid phase was separated and the filtrate was concentrated *in vacuo*. Preparative TLC of the residue gave products **9**, **11**, and **12**.

3. Alkylation of the ammonium salts of *N*-(β-hydroxyalkyl)-*N'*-hydroxydiazene *N*-oxides (1a,b). A mixture of compound **1a** or **1b** (5 mmol) and the appropriate amount of 1,2-dibromoethane in ~20 mL of DMSO was stirred at a definite temperature (see Table 3). After the mixture had been kept for the required time, the solid precipitate was separated and washed with 5 mL of MeCN, and the filtrate was concentrated *in vacuo*. Preparative TLC of the residue (a 9 : 1 $CHCl_3$—MeOH mixture as the eluent) gave products **2** and **3**.

4. Alkylation of the tetramethylammonium salt of *N*-(2-hydroxypropyl)-*N'*-hydroxydiazene *N*-oxide (1a). ***A.*** A suspension of 2 mmol of *N*-(2-hydroxypropyl)-*N'*-hydroxydiazene *N*-oxide tetramethylammonium salt (**1a**) and the corresponding alkylation reagent in 20 mL of anhydrous MeCN was stirred in an atmosphere of dry nitrogen (see Tables 3, 4), and the precipitate was filtered off and washed on the filter with 5 mL of anhydrous MeCN. The filtrate was concentrated *in vacuo*, and the oily residue was suspended in 20 mL of acetone and allowed to stand for 30 min. Then the precipitate was filtered off and washed with 5 mL of acetone, the filtrate was concentrated *in vacuo*, and the residue was separated by preparative TLC (for compounds **2a**, **3a**, a 9 : 1 $CHCl_3$—MeOH mixture was used as the eluent; the eluents used for products **7**—**14** are listed in Table 2).

The reaction of *N*-(2-hydroxypropyl)-*N'*-(2-bromoethoxydiazene) *N*-oxide (2a) with tetramethylammonium salt 1a. Compound **2a** (0.3 g, 1.3 mmol) was added to a suspension of tetramethylammonium salt **1a** (0.26 g, 1.3 mmol) in 20 mL of anhydrous MeCN, and the reaction mixture was stirred for 45 h at ~80 °C.* The solid residue was separated, the mother liquor was concentrated *in vacuo*, the oily residue was suspended in 20 mL of acetone, and the suspension was allowed to stand for 30 min. The resulting solid precipitate was separated. Preparative TLC (with a 9 : 1 $CHCl_3$—MeOH mixture as the eluent) of the remaining solution gave 0.28 g (79.6%) of compound **3a** (85.3% based on the converted **2a**).

Determination of the relative reactivities of ethyl bromide and 1,2-dibromoethane toward alkylation of *N*-(2-hydroxypropyl)-*N'*-hydroxydiazene *N*-oxide salts by the method of competing reactions. 1,2-Dibromoethane (18.8 g, 0.1 mol) and ethyl bromide (10.9 g, 0.1 mol) were added with stirring at

* After ~10—12 h of stirring, the reaction mixture was left overnight and then stirred again for ~10—12 h, and so on. The total reaction time was 120 h.

20 °C to a solution of ammonium salt **1a** (1.36 g, 10 mmol) in 50 mL of anhydrous DMSO. The resulting solution was stirred for 20 h at ~60 °C and concentrated *in vacuo*. The pasty residue was triturated with $CHCl_3$ for 2 h. The insoluble residue was separated, the filtrate was concentrated *in vacuo*, and the remaining red-brown oil was passed through a short column filled with silica gel (with $CHCl_3$—MeOH (9 : 1) as the eluent). The solvent was evaporated *in vacuo*. According to ^1H NMR, the resulting red-yellow oil contained product **2a** and $MeCH(OH)CH_2N_2O_2CH_2Me$ in 1 : 4 ratio.

This work was financially supported by the Russian Foundation for Basic Research (Project No. 96-15-97332).

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Received February 26, 1998;
in revised form July 27, 1998