SOME PECULIARITIES OF THE CYCLIZATION OF N-POLYNITROALKYL-N-NITROSOAMINOACETIC ACIDS AND THEIR NITRILES TO SYDNONES AND SYDNONIMINES*

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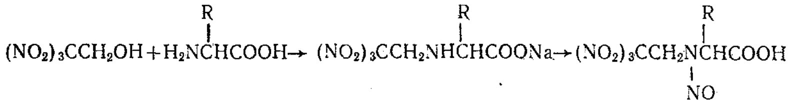
The cyclization of N-polynitroalkyl-N-nitrosoaminoacetic acids to sydnones occurs only under the influence of trifluoroacetic anhydride. Closing to a sydnonimine ring does not occur in the case of N-(2,2,2-trinitroethyl)-N-nitrosoaminoacetonitrile, but N-(2,2,2-trinitroethyl)-N-nitrosoiminoacetic acid imino ester is formed. Removal of the nitro groups in the γ position relative to the nitrosoamino group leads to normal occurrence of the reaction to give polynitroalkylsydnonimines.

The cyclization of N-nitrosoaminoacetic acids and their nitriles to sydnones and sydnonimines has been developed in quite some detail [2, 3]. However, such an important problem as the effect of electron-acceptor substituents on the reactivity of the N—N=O fragment remains unexplained.

In order to study the nucleophilic activity of the oxygen atom of the nitroso group as a function of the character of the polynitroalkyl substituents, we investigated the cyclization of N-polynitroalkyl-N-nitrosoaminoacetic acids and their nitriles to sydnones and sydnonimines.

The starting acids were obtained via the Mannich reaction by reaction of 2,2,2-trinitroethanol with the appropriate amino component in alkaline media with subsequent nitrosation of the condensation product with sodium nitrite in hydrochloric acid.



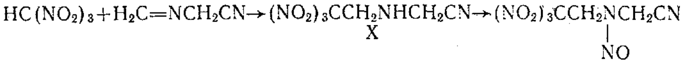
$$(NO_2)_3CCH_2OH + H_2N\overset{R}{C}HCOOH \rightarrow (NO_2)_3CCH_2NH\overset{R}{C}HCOONa \rightarrow (NO_2)_3CCH_2\underset{NO}{N}\overset{R}{C}HCOOH$$

I R=H; II R=CH_3 I, II

N-(2-Halo-2,2-dinitroethyl)-N-nitrosoaminoacetic acids (III and IV, Table 1) were obtained from I as a result of its denitration with potassium iodide and subsequent halogenation of the dipotassium salt of N-(2,2-dinitroethyl)-N-nitrosoaminoacetic acid.

The structure of I-IV was confirmed by nitration of them to the corresponding N-(polynitroalkyl-N-nitroaminoacetic acids (V-VIII, Table 1).

N-(2,2,2-Trinitroethyl)-N-nitrosoaminoacetonitrile (IX) was prepared by the addition of nitroform to methyleneiminoacetonitrile and nitrosation of the reaction product in a mixture of sulfuric and acetic acids.



$$HC(NO_2)_3 + H_2C{=}NCH_2CN \rightarrow \underset{X}{(NO_2)_3CCH_2NHCH_2CN} \rightarrow \underset{IX}{(NO_2)_3CCH_2\underset{NO}{N}CH_2CN}$$

X IX

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*See [1] for the preliminary communication.

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TABLE 1. N-Polynitroalkyl-N-nitroso(nitroaminocarboxylic Acids and Their Nitriles $XC(NO_2)_2CH_2\underset{X_1}{\underset{|}{N}}CHRR_1$

Compound	X	X_1	R	R_1	mp, °C	Empirical formula	Found, %			Calc., %			IR spectrum, cm^{-1}				Yield, %
							C	H	N	C	H	N	$\nu_{C(NO_2)_3}$ $\nu_{C(NO_2)_2}$	ν_{N-NO} ν_{N-NO_2}	ν_{N-N}	$\nu_{C=O}$ $\nu_{C\equiv N}$	
I	NO_2	NO	H	COOH	117—118^a	$C_4H_5N_5O_9$	17,6	1,8	25,8	17,7	1,8	25,8	1600 1305	1510	1018	1730	40
II	NO_2	NO	CH_3	COOH	113—114^b	$C_5H_7N_5O_9$	21,2	2,3	24,8	21,4	2,5	24,9	1610 1305	1480	1025	1725	17
III	Cl	NO	H	COOH	91—92^a	$C_4H_5ClN_4O_7$	18,5	1,9	21,7	18,7	1,9	21,7	1592 1310	1495	1010	1735	90
IV	Br	NO	H	COOH	84—85^a	$C_4H_5BrN_4O_7$	—	—	18,7	—	—	18,6	1590 1310	1496	1018	1730	81
V	Cl	NO_2	H	COOH	135—136^b	$C_4H_5ClN_4O_8$	—	—	20,8	—	—	20,6	1600 1305	1580 1290	—	1730	92
VI	Br	NO_2	H	COOH	137—138^b	$C_4H_5BrN_4O_8$	—	—	17,6	—	—	17,7	1600 1310	1570 1290	—	1728	86
VII	NO_2	NO_2	CH_3	COOH	156—160^a	$C_5H_7N_5O_{10}$	20,1	2,3	23,4	20,2	2,4	23,6	1618 1310	1565 1288	—	1742	89
VIII	NO_2	NO_2	H	COOH	145—147^b	$C_4H_5N_5O_{10}$	—	—	24,9	—	—	24,7	1615 1308	1570 1290	—	1735	92
IX	NO_2	NO	H	CN	59—60^c	$C_4H_4N_6O_7$	19,2	1,5	29,4	19,4	1,6	29,6	1615 1310	1507	1018	2260	68
X	NO_2	H	H	CN	67—68^d	$C_4H_5N_5O_6$	21,3	2,3	32,8	21,9	2,3	33,0	1600 1305	—	—	2255	93

Note: ^{a}From benzene. ^{b}From water. ^{c}From $CHCl_3-CCl_4$ (1 : 1). ^{d}From CCl_4.

TABLE 2. Polynitroalkylsydnones

Compound	X	R	mp, °C	Empirical formula	Found, %			Calc., %			Yield, %
					C	H Cl, Br	N	C	H Cl, Br	N	
XI	NO_2	H	92—93*	$C_4H_3N_5O_8$	18,7	1,1	28,0	19,0	1,2	28,1	98
XII	NO_2	CH_3	73—74	$C_5H_5N_5O_8$	22,6	1,7	26,5	22,8	1,9	26,6	90
XIII	Cl	H	70—71	$C_4H_3ClN_4O_6$	—	— 15,1	23,1	—	— 15,0	23,3	96
XIV	Br	H	59—60	$C_4H_3BrN_4O_6$	—	— 28,1	19,8	—	— 28,3	19,8	86

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*All of the sydnones melt with decomposition.

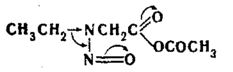
N-(3,3,3-Trinitropropyl)aminoacetonitrile (IXa) and the dinitrile of 3,3-dinitro-1,5-pentane-diaminoacetic acid (IXb) were prepared by condensation of the corresponding polynitroalkylamines with formalin and potassium cyanide.

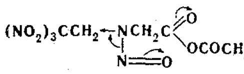
$$(NO_2)_3CCH_2CH_2NH_2 + CH_2O + KCN \rightarrow \underset{IXa}{(NO_2)_3CCH_2CH_2NHCH_2CN}$$

It is known that the cyclization of unsubstituted N-alkyl-N-nitrosoaminoacetic acids to sydnones includes intramolecular reaction of the oxygen atom of the nitroso group with the carbon atom of the carbonyl group under the influence of a dehydrating agent – most often acetic anhydride [2, 3].

We have established that I does not form a sydnone under the influence of acetic anhydride. The reaction proceeds with the liberation of oxides of nitrogen and resinification of the nitroso derivative.

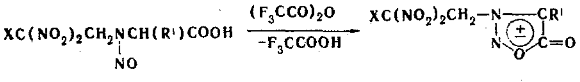
Proceeding from concepts regarding the mechanism of the cyclization [3], one should assume that the negative result in our case is due to the lowered electron density on the oxygen atom of the nitroso group due to the inductive effect of the trinitromethyl group (A and B).


A


B

In order to reinforce the electrophilicity of the carbon atom of the carbonyl group in the mixed anhydrides of N-alkyl-N-nitrosoaminoacetic acids – the intermediates in the cyclization [3, 4] – we chose a dehydrating agent that has strong electron-acceptor properties – trifluoroacetic anhydride. In fact, under the influence of the latter, I-IV react smoothly to give high yields of sydnones (XI-XIV, Table 2).

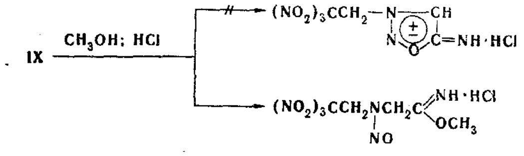
It is characteristic that, in contrast to the previously known types of sydnones, which are usually yellow [2, 3], the polynitroalkylsydnones are colorless. They also explode on rapid heating, are unstable during storage, are sensitive to air moisture, and decompose in alcohols and acetone. The ring closing of nitriles of N-nitrosoaminoacetic acids is based on the polarity of the C=N bond and the nucleophilicity of the oxygen atom of the nitroso group [2-4].


XI–XIV

XI $X=NO_2$, $R^1=H$; XII $X=NO_2$, $R^1=CH_3$; XIII $X=Cl$, $R^1=H$; XIV $X=Br$, $R^1=H$

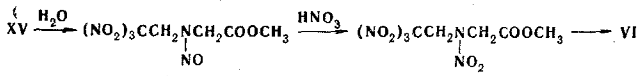
As in the case of sydnones, no attempts to experimentally establish the effect of polarization of the nitroso group, on which the outcome of the reaction depends, are reported in the literature. In this respect, a study of the behavior of the nitriles of N-polynitroalkyl-N-nitrosoaminoacetic acids makes it possible to obtain information of interest to us.

In analogy with the cyclization to sydnones of I-IV, in the case of nitrile IX one also should have expected a decrease in reactivity on cyclization of it to a sydnonimine. In fact, under conditions similar to those in the synthesis of sydnonimines [2-4], we observed not only a decrease in the reactivity of nitrile IX but also a completely different reaction course. Instead of the expected 3-(2,2,2-trinitroethyl)sydnonimine, we isolated methyl N-(2,2,2-trinitroethyl)-N-nitrosoiminoacetate hydrochloride (XV).



XV

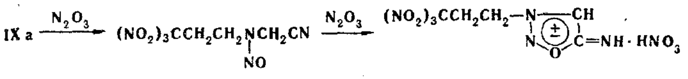
Reactions of this sort have not been reported. The structure of imino ester XV was proved unambiguously by a number of transformations via the scheme



$$\mathrm{XV} \xrightarrow{H_2O} (NO_2)_3CCH_2\underset{\displaystyle NO}{N}CH_2COOCH_3 \xrightarrow{HNO_3} (NO_2)_3CCH_2\underset{\displaystyle NO_2}{N}CH_2COOCH_3 \longrightarrow \mathrm{VIII}$$

The initial step in the reaction of XV with hydrogen chloride in methanol apparently includes attack on the nitrogen atom of the nitrile group by a proton, as in the case of the unsubstituted analogs. The resulting carboimmonium cation $[RN(NO)CH_2C=NH]^+$ undergoes methanolysis, which competes with ring closing. This is possible when the nucleophilic properties of the oxygen atom of the nitroso group are weakened under the influence of a polynitroalkyl substituent.

In order to follow the effect of polynitroalkyl substituents on the N−N=O fragment, we studied the behavior of nitriles of N-nitrosoaminoacetic acids containing a nitro group in the γ-position with respect to the nitrosoamino group. Under conditions identical to those in the synthesis of imino ester XV, the hydrochloride of the corresponding sydnonimine (XVIII, Table 3) was obtained from nitrile IXc, while the nitrate salt of 3-(3,3,3-trinitropropyl)sydnonimine (XX) is obtained from nitrile IXa on treatment with nitrogen oxides immediately without isolation of the nitroso derivative.



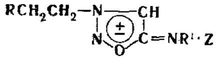
XX

N-exo-Nitroso derivatives (XIX and XXI, Table 3) are formed smoothly on treatment of sydnonimines XVIII and XX with sodium nitrite in acid media; these derivatives are characterized by bright coloration [2, 3]. Sydnonimine XX is converted to N-exo-nitro derivative XXII under the influence of sulfuric acid.

As seen from Table 1, the absorption of the nitroso group in the N-polynitroalkyl-N-nitrosoaminocarboxylic acids and their nitriles is shifted by 50 cm^{-1} to higher frequencies, while the same shift to lower frequencies as compared with the unsubstituted analogs [5] corresponds to the N−N bond. This confirms our previous conclusion regarding the decrease in the degree of p−π conjugation in the nitrosoamine fragment due to the inductive effect of electron-acceptor substituents [4, 6].

An intense band at 3120-3175 cm^{-1}, which is characteristic for the C−H group of the sydnone ring, is observed in the IR spectra of polynitroalkylsydnones and polynitroalkylsydnonimines. An absorption band at 1690-1705 cm^{-1}, which is characteristic for the C=N bond of the sydnonimine ring [2, 3], is observed in the IR spectra of the sydnonimines.

TABLE 3. Polynitroalkylsydnonimines and Their exo Derivatives



Compound	R	R₁	Z	mp, °C	Empirical formula	Found, %			Calc., %			Yield, %
						C	H	N	C	H	N	
XVIII	$C(NO_2)_2$*	H	HCl	217—218†	$C_9H_{14}Cl_2N_8O_6$	32,6	4,1	33,7	32,7	4,2	33,9	38
XIX	$C(NO_2)_2$*	NO	—	101—103	$C_9H_{10}N_{10}O_8$	27,9	2,4	36,2	28,0	2,6	36,3	81
XX	$C(NO_2)_3$	H	HNO_3	115—116	$C_5H_7N_7O_{10}$	18,4	2,0	30,1	18,5	2,2	30,2	73
XXI	$C(NO_2)_3$	NO	—	86—87	$C_5H_5N_7O_8$	20,4	1,6	33,5	20,6	1,7	33,7	86
XXII	$C(NO_2)_3$	NO_2	—	153—154	$C_5H_7N_7O_9$	19,5	1,5	31,8	19,5	1,6	31,9	74

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*The bissydnonimine; yet another sydnonimine residue is attached to the dinitromethyl group.

†All of the sydnonimines melt with decomposition.

The absorption bands of the trinitromethyl, dinitromethyl, and nitroamino groups have the usual characteristics [7, 8].

EXPERIMENTAL

N-(2,2,2-Trinitroethyl)-N-nitrosoaminoacetic Acid (I). A 40-g sample of glycine was dissolved in the minimum amount of water at 90-95°, and the solution was treated with 44 g of sodium bicarbonate. The resulting solution of the sodium salt of glycine was added at 20-25° to 130 g of 70% solution of 2,2,2-trinitroethanol [9]. After 30 min, the reaction mixture was air evaporated to the pasty state and transferred in small portions to 300 ml of cooled (to 0°) hydrochloric acid (sp. gr. 1.23). The mixture was nitrosated at −5 to 0° by the addition of 20 g of $NaNO_2$ in 40 ml of water. After 3 h, the crystalline product was separated and washed with ice water (three 100-ml portions). The yield of I was 39.5 g.

Compound II was similarly obtained from α-aminopropionic acid and 2,2,2-trinitroethanol.

N-(2-Halo-2,2-dinitroethyl)-N-nitrosoaminoacetic Acids (III, IV). A) Dipotassium Salt of N-(2,2-Dinitroethyl)-N-nitrosoaminoacetic Acid. A 2.7-g sample of I was dissolved in 50 ml of methanol, and 5 g of potassium iodide was added slowly at 15-20°. After 1-1.5 h, the mixture was diluted with 30 ml of ether, and the yellow precipitate was separated and washed with ether to give 2.05 g (68%) of a salt with mp 110-111° (dec.). The salt was used for the subsequent syntheses without purification.

B) Chlorination. A solution of 3 g of the dipotassium salt of N-(2,2-dinitroethyl)-N-nitrosoaminoacetic acid in 30 ml of methanol was treated with chlorine gas at 10-15° until the reaction mixture became colorless. The inorganic precipitate was separated, and the filtrate was air dried to give 2.4 g of colorless crystals of III.

C) Bromination. This reaction was carried out as in the case of chlorination. After bromination, the reaction mixture was acidified with hydrochloric acid. The yield of IV was 1.65 g.

N-(2,2,2-Trinitroethyl)-N-nitroaminoacetic Acid (VIII). A 2-g sample of I was dissolved at 10-15° in 15 ml of 98% nitric acid, and the solution was held at 20-25° for 2 h. A large portion of the nitric acid was then evaporated, and the residue was diluted with 30 ml of cold water. The resulting precipitate was separated and washed with cold water to give 1.9 g of acid VIII. The product was identified by a mixed-melting point determination with a genuine sample of the acid [10].

N-[2-Chloro(bromo)-2,2-dinitroethyl]-N-nitroaminoacetic and N-2,2,2-trinitroethyl)-N-nitroamino-α-methylpropionic acids (V, VI, and VII) [10, 11] were similarly obtained from II, III, and IV.

3-(2,2,2-Trinitroethyl)sydnone (XI). A 5-g sample of I was dissolved in 50 ml of ether, and 8 ml of trifluoroacetic anhydride was added slowly dropwise to the solution. The mixture was stirred at 15-20° for 1 h, after which it was cooled to 0°, and the resulting precipitate was removed by filtration and purified by precipitation from ethyl acetate by the addition of hexane. The yield was 4.8 g.

Sydnones XII-XIV were similarly obtained.

N-(2,2,2-Trinitroethyl)-N-nitrosoaminoacetonitrile (IX). A 9.5-g sample of methyleneiminoacetonitrile [12] was added to a 40% aqueous solution of 20 g of nitroform at 15-20°. After 30 min, the precipitate was separated, washed with water, and dried to give 27.5 g of X. A 10-g sample of X was dissolved in a mixture of 50 ml of acetic acid and 10 ml of sulfuric acid (sp. gr. 1.84), the solution was cooled to 0-5°, and 5 g of sodium nitrite was added with vigorous stirring. After 2-2.5 h, the mixture was poured over 150 g of crushed ice, and the resulting precipitate was separated and washed with water to give 6.9 g of IX.

Methyl N-(2,2,2-Trinitroethyl)-N-nitrosoiminoacetate Hydrochloride (XV). A 4-g sample of IX was dissolved at 0-5° in 75 ml of methanol saturated with hydrogen chloride, and the mixture was held at this temperature for 2 days. Two-thirds of the alcohol was removed by distillation at reduced pressure (30-40 mm, mercury standard), and 50 ml of ether was added to the residue. The precipitated substance was separated and washed with ether to give 2.3 g (45%) of a product with mp 88-89° (dec.). Found: C 18.9; H 2.8; N 26.4%. $C_5H_9ClN_6O_8$. Calculated: C 18.9; H 2.8; N 26.5%. IR spectrum: 1608, 1310 [$\nu_{C(NO_2)_3}$]; 1488 ($\nu_{N=O}$); 1000, 1020 (ν_{N-N}), and 1710 ($\nu_{C=N}$) cm^{-1}.

A 0.5-g sample of XV was added slowly to 10 ml of water, and the resulting oil was extracted with methylene chloride (two 5-ml portions). The extract was dried over magnesium sulfate, the solvent was removed by distillation, and 5 ml of 98% nitric acid was added to the residue at 0-5°. After 2 h, the mixture was poured over ice, and the precipitate was separated and dried. The yield of methyl ester of acid VIII was 0.4 g (80%). The ester was saponified with a 1:1 mixture of acetic and hydrochloric acids to acid VIII. The product was identified by means of a mixed-melting-point determination.

3,3-Dinitropentamethylenebis(sydnonimine) Dihydrochloride (XVIII). A) Dinitrile of 3,3-Dinitro-N,N'-dinitroso-1,5-pentanediaminoacetic Acid (IXc). A 3-g sample of 3,3-dinitro-1,5-pentanediamine [13] was dissolved in 50 ml of water, and 1.5 g of potassium cyanide in 10 ml of water and 3 ml of 36% formalin were added successively at 10-15°. After 3 h, 30 ml of hydrochloric acid (sp. gr. 1.23) was added to the mixture. It was then cooled to 0° and treated with an aqueous solution of 3 g of sodium nitrite. The resulting oily product was extracted with methylene chloride (three 30-ml portions), and the extract was dried over magnesium sulfate. The solvent was evaporated to give 2.5 g (70%) of IXc as a viscous yellow oil. The substance was subjected to further transformations without purification.

B) Sydnonimine XVIII. A 2-g sample of dinitrile IXc was dissolved in 30 ml of methanol saturated with hydrogen chloride, and the mixture was allowed to stand at 15-20° for 2 days. The precipitated dihydrochloride of sydnonimine XVIII was removed by filtration, washed with ether, and dried to give 1.05 g of product. IR spectrum: 1565, 1320 [$\nu_{C(NO_2)_2}$]; 1690 ($\nu_{C=N}$); 3150 ($\nu_{\text{ring CH}}$) cm^{-1}.

3-(3,3,3-Trinitropropyl)sydnonimine Nitrate (XX). A 2-g sample of N-(3,3,3-trinitropropyl)aminoacetonitrile nitrate (IXb), obtained from 3,3,3-trinitropropylamine [14], potassium cyanide, and formalin as in the case of IXa, was treated at 0-5° with 2 g of sodium nitrite (in 10 ml of water) in 20 ml of 57% nitric acid. After 2 h, the precipitate was separated, air dried, and purified by precipitation from hot methanol by the addition of ethyl acetate. The yield was 1.8 g. IR spectrum: 1595, 1305 [$\nu_{C(NO_2)_3}$]; 1705 ($\nu_{C=N}$); 3175 ($\nu_{\text{ring CH}}$) cm^{-1}.

N-exo-Nitroso Derivative of 3-(3,3,3-Trinitropropyl)sydnonimine (XXI). A 0.5-g sample of XX was added at 0° to a solution of 0.5 g of sodium nitrite in 5 ml of water, and the mixture was acidified with 0.5 ml of 57% nitric acid and stirred for 1 h. The bright-red crystals of XXI were separated and washed with water to give 0.43 g of product. The compound was purified by precipitation from methanol solution by the addition of water.

N-exo-Nitroso derivative XIX was similarly obtained from XVIII.

N-exo-Nitro Derivative of 3-(3,3,3-Trinitropropyl)sydnonimine (XXII). A 4-g sample of sydnonimine XX was added at 5-10° to 20 ml of sulfuric acid (sp. gr. 1.84), and the mixture was heated to 20-25° and held at this temperature for 4-5 h. It was then poured over 150 g of crushed ice, and the precipitate was separated and recrystallized from aqueous methanol to give 3.0 g of product.

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