Dinitramide and its salts
2.* Dinitramide in Michael- and retro-Michael-type reactions

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Dinitramide readily adds to acrolein, methyl vinyl ketone, and phenyl vinyl ketone, but not to acrylonitrile or methyl acrylate. Treatment of dinitro compounds $(O_2N)_2NCH_2CH_2COR$ (R = H, Me, Ph, OMe) with bases results in dinitramide salts in 66—83 % yields.

Key words: dinitramide salts; *N,N*-dinitramines; Michael- and retro-Michael-type reactions.

In the previous communication[1] we gave the theoretic basis for one of the general approaches to the "organic synthesis" of a new class of inorganic compounds, namely, dinitramide (DNA) and its salts, by treatment of β-derivatives of *N*-alkyl-*N,N*-dinitroamines of the formula $(O_2N)_2NCH_2CH_2X$ (**1**), where X is a strong electron-withdrawing substituent such as NO_2, COR, COOR, CN, *etc.*, with bases. The reaction was carried out starting from compound **1** with X = CN.

In the present work we carried out similar transformations of compounds **1** with other substituents X and studied their effect on the ease of the formation of DNA. It should be noted that, although there are no particular difficulties in the synthesis of the starting compounds **1**, it requires many steps. Meanwhile, after we succeeded in the synthesis of DNA and its salts, it appeared to be possible to synthesize compounds **1** by the addition of DNA to the corresponding α,β-unsaturated compounds. For this purpose we studied Michael- and retro-Michael-type reactions involving DNA and compounds containing an activated double bond.

In the analysis of the data on the addition of primary *N*-nitro derivatives $RN(NO_2)H$ to activated olefins, it is reasonable to consider the following series of compounds with increasing acidity: $AlkN(NO_2)H$, $EtOCON(NO_2)H$, $ArSO_2N(NO_2)H$, $O_2NN(NO_2)H$.

It is known that in the presence of alkaline catalysts $AlkN(NO_2)H$ readily adds to esters, amides, and nitriles of conjugated unsaturated acids, α-nitroolefins, and unsaturated conjugated carbonyl compounds.[2] We have found[3] that when the next two members of the series are considered, the range of activated olefins that can add primary *N*-nitro derivatives gradually narrows. For example, nitrourethane (NU) adds to unsaturated carbonyl derivatives and to α-nitroolefins, but does not add to acrylonitrile or methyl acrylate. *N*-Nitrosulfamides (NSA) readily add to unsaturated carbonyl derivatives, but do not add to acrylonitrile, methyl acrylate, or nitroethylene. The effect of bases on the course of the reactions also changes: they are useful but not necessary in the case of NU, but do not play a noticeable role in the case of NSA. Probably, this feature is explained by the nature of the anions of the *N*-nitro derivatives considered: they are formed more easily in the above series, as their nucleophilicity decreases. It seemed doubtful that the Michael-type addition of DNA is possible at all, if the above tendency is maintained. However, DNA is one of the strongest mineral acids, so the mechanism of the addition could change fundamentally.

We found that DNA adds easily to unsaturated carbonyl derivatives (acrolein, methyl vinyl ketone, and phenyl vinyl ketone) without any catalysts to give the expected aldehyde **1a** and *N,N*-dinitro-β-aminoethylketones **1b,c**.

$$CH_2{=}CH{-}X + HN(NO_2)_2 \rightarrow (O_2N)_2NCH_2CH_2X$$

1a—c

a: X = CHO, **b**: X = COMe, **c**: X = COPh

The reaction occurs when the reagents are mixed in an inert solvent (benzene) and subsequently kept at a temperature slightly lower than room temperature (to prevent the decomposition of compounds **1a—c** formed). The yields of compounds **1b** and **1c** are fairly high (75—85 %). The reaction with acrolein occurs less smoothly (yield 53 %). Compounds **1a,b** are undistillable, slightly yellow oils; **1c** is a low-melting yellowish compound. All of these compounds can be stored at room temperature for a limited period of time. Their structures were confirmed by elemental analysis and IR and ^1H NMR spectroscopic data.

* For part 1, see Ref. 1.

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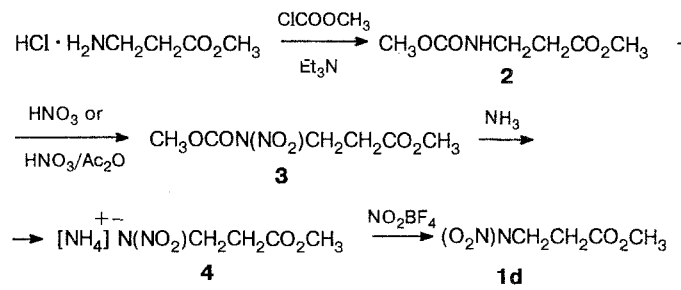
Scheme 1



The addition of DNA to methyl acrylate and acrylonitrile could not be accomplished either in the absence or in the presence of basic catalysts. Thus, DNA behaves similarly to NSA[3] in reactions involving activated olefins.

Since the dinitramine **1d** (X = $COOCH_3$) required for the next stage of the investigation could not be obtained by the addition reaction, the following scheme was elaborated for its synthesis (Scheme 1).

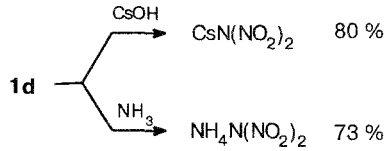
The condensation of β-alanine methyl ester hydrochloride with methyl chloroformate in the presence of dry silver oxide has been described in the literature,[4] but the yield of compound **2** has not been reported. We did not obtain satisfactory results in the synthesis of **2** by this route. However, this compound is readily formed in high yields (up to 95 %) when the reaction is carried out in an inert solvent in the presence of Et_3N. Amide **2** can be nitrated into the *N*-nitro derivative **3** by treatment with concentrated HNO_3 or its mixture with Ac_2O. The yield of compound **3** depends essentially on the nitration conditions, in particular, on the composition of the nitrating mixture, the temperature, and the reaction time; moreover, there is an extremum on the plot of the yield *vs.* the reaction time. Nitroamide **3** reacts smoothly with ammonia in inert solvents to give the ammonium salt of *N*-nitro-β-alanine methyl ester (**4**) (yield 90—97 %) which is a white, highly hygroscopic powder. Nitration of compound **4** with nitronium tetrafluoroborate in acetonitrile gave dinitro derivative **1d** (yield 77 %) as a slightly yellowish oil (the structure and purity of the product was confirmed by IR and ^1H NMR spectroscopic data).

We also considered the possibility of the use of compounds **1a—d** in the retro-Michael reaction. For this purpose, solutions of compounds **1a—d** in EtOH (15—20 %) were treated at 0—5 °C with a small excess of a ~15 % solution of KOH in EtOH, and the precipitate of the potassium salt of DNA (PDNA) was filtered off. The results are presented in Table 1.

One can see that in all the cases studied, the retro-Michael reaction occurs in rather high yields and permits the synthesis of high-quality PDNA.

1a—d + KOH → $KN(NO_2)_2$

We also showed that this method makes it possible to obtain other salts, in particular, the cesium salt. The ammonium salt of DNA (ADNA) can be obtained almost in the same yield by treatment of compound **1d** with excess NH_3.



However, the reaction proceeds rather slowly and its completion requires many hours, which is inferior to the similar reaction of ammonia with compound **1** (X = CN).

Thus, it was confirmed experimentally that the retro-Michael reaction is a general method for the synthesis of DNA salts.

Experimental

^1H NMR spectra were recorded on a Perkin-Elmer R-12 spectrometer (60 MHz). IR spectra were obtained on a UR-10 spectrophotometer without a solvent (for liquid compounds) or in KBr pellets (for solids).

***N,N*-Dinitro-β-aminopropanal (1a).** Dry HCl was bubbled at 5—10 °C with vigorous stirring through a suspension of PDNA (1 g) in dry benzene (30 mL). The KCl that formed was filtered off, and N_2 was bubbled through the filtrate until the excess HCl was removed (a test with NH_3). Freshly distilled acrolein (2 g) was added dropwise at 3—5 °C with stirring to the solution of DNA obtained and the mixture was stirred for 3 h. The reaction mixture was washed with ice water to neutral pH and dried overnight with $MgSO_4$ in a refrigerator. The solvent and excess acrolein were removed *in vacuo* (30 °C/1 Torr) and the residue (0.75 g) was chromatographed in a $CHCl_3$—CCl_4 mixture (4 : 1) on a column with silica gel to give 0.6 g (53 %) of compound **1a**,

Table 1. Yields and melting points of PDNA formed by treatment of **1a—d** with KOH in EtOH

Dinitro derivative	Yield of KDNA (%)	M.p./°C
1a	66	121—125
1b	83	127—131
1c	72	127—131
1d	80	120—124

n^{26}_D 1.4824. Found (%): C, 22.29; H, 3.72. $C_3H_5N_3O_5$. Calculated (%): C, 22.09; H, 3.09. IR (ν/cm^{-1}): 1610—1645, 1245 (NO_2); 1752 (CO). ^{1}H NMR (C_6H_6), δ: 1.6 (t, 2 H, $COCH_2$); 3.05 (t, 2 H, NCH_2); 8.5 (s, 1 H, CHO).

Methyl (*N,N*-dinitro-β-aminoethyl) ketone (1b). Methyl vinyl ketone (4 g) was added dropwise at 3—5 °C to a solution of DNA (obtained from 2 g of PDNA) in benzene. The reaction mixture was stirred for several hours and left overnight in a refrigerator. Then the solution was worked-up as in the case of compound **1a**. Removal of the benzene and excess methyl vinyl ketone gave 1.91 g (78.5 %) of compound **1b** as a yellowish oil, $n^{19.5}_D$ 1.4702. Found (%): C, 27.25; H. 3.77. $C_4H_7N_3O_5$. Calculated (%): C, 27.12; H, 3.76. IR (ν/cm^{-1}): 1600—1640, 1250 (NO_2); 1720 (CO). ^{1}H NMR (CCl_4), δ: 2.1 (s, 3 H, CH_3); 2.8 (t, 2 H, $COCH_2$); 4.27 (m, 2 H, NCH_2).

Phenyl (*N,N*-dinitro-β-aminoethyl) ketone (1c). A procedure similar to the synthesis of compound **1b** starting from phenyl vinyl ketone (1.27 g) and DNA (obtained from 1.4 g of PDNA) followed by removal of the benzene gave 2.07 g of a mixture of an oil and crystals. The crystalline portion was pressed out on a porous porcelain plate to give 1.55 g (85.5 %) of compound **1c**, m.p. 42—44 °C (from ether with freezing). Found (%): C, 45.11; H, 3.72. $C_9H_9N_3O_5$. Calculated (%): C, 45.19; H, 3.79. IR (ν/cm^{-1}): 1600—1640, 1250 (NO_2); 1680 (CO). ^{1}H NMR (CCl_4), δ: 3.25 (t, 2 H, $COCH_2$); 4.40 (t, 2 H, NCH_2); 7.1—7.8 (m, 5 H, Ph).

***N*-Methoxycarbonyl-β-alanine methyl ester (2).** Methyl chloroformate (10.4 g, 8.55 mL) in ether (150 mL) was added dropwise over 20 min at 20—25 °C to a suspension of β-alanine methyl ester hydrochloride (15.32 g) in $CHCl_3$ (220 mL), and the reaction mixture was stirred for 15 min. A solution of Et_3N (22.2 g, 30.2 mL) was then added over 15 min at 20—25 °C. The mixture was stirred for 1.5 h at 10 °C, and the precipitate of $Et_3N \cdot HCl$ was filtered off. Distillation of the filtrate gave 14.03 g (79.5 %) of ester **2**, b.p. 124.5—126 °C (12 Torr), n^{17}_D 1.4455, m.p. 32.5—33.5 °C (*cf.* Ref. 4: b.p. 140 °C (15 Torr), m.p. 33.5 °C). ^{1}H NMR, δ: 2.4 (t, 2 H, $COCH_2$); 3.25 (t, 2 H, NCH_2); 3.5 (s, 3 H, OCH_3); 3.55 (s, 3 H, OCH_3); 5.4 (br.s, 1 H, NH).

N*-Methoxycarbonyl-*N*-nitro-β-alanine methyl ester (3).** ***A. Ester **2** (4 g) was added over 10 min at 8—10 °C to 99 % HNO_3 (8 mL). The mixture was stirred for 30 min at 8—10 °C and poured onto 50 g of finely crushed ice. The resulting precipitate was filtered off, washed with water, and dried over P_2O_5 in a vacuum desiccator to give 3.48 g of ester **3**, m.p. 22—23.5 °C (from a CCl_4—hexane mixture, 1 : 1). The aqueous mother liquor and washings were combined and extracted with CCl_4 (3×50 mL). The extracts were washed with water and dried with $MgSO_4$. Removal of the solvent gave an additional 1.71 g of compound **3**, b.p. 102 °C (2 Torr), n^{17}_D 1.4669. The overall yield of **3** was 5.19 g (100 %). Found (%): C, 35.04; H, 4.94; N, 13.81. $C_6H_{10}N_2O_6$. Calculated (%): C, 34.91; H, 4.88; N, 13.59. IR (ν/cm^{-1}): 1770, 1725 (CO); 1570, 1370 (NO_2). ^{1}H NMR (CCl_4), δ: 2.65 (t, 2 H, $COCH_2$); 3.6 (s, 3 H, OCH_3); 3.85 (s, 3 H, OCH_3); 4.25 (t, 2 H, NCH_2).

B. Conc. HNO_3 (d = 1.5 g cm^{-3}) was added at −5 to 0 °C to Ac_2O (6 mL), then ester **2** (1 g) was added at 7—10 °C. The reaction mixture was stirred for ~3 h at 15 °C, poured onto 70 g of finely crushed ice, and neutralized with a solution of Na_2CO_3. The product was extracted with CCl_4 (5×30 mL), and the extract was washed with water and dried with $MgSO_4$. The solvent was removed *in vacuo* (1 Torr) to give 1.06 g (83 %) of compound **3** as an oil, n^{19}_D 1.4642.

Ammonium salt of *N*-nitro-β-alanine (4). Dry NH_3 was passed for 10 min at ~0 °C through a solution of compound **3** (9.88 g) in dry ether (120 mL). The resulting precipitate was filtered off, washed with dry ether, and dried in a vacuum desiccator to give 6.4 g (81 %) of salt **4**, m.p. 75—78 °C. Found (%): C, 29.01; H, 6.66. $C_4H_{11}N_3O_4$. Calculated (%): C, 29.1; H, 6.67. IR (ν/cm^{-1}): 1730 (CO), 1575, 1340, 975, 845.

***N,N*-Dinitro-β-alanine methyl ester (1d).** Nitronium tetrafluoroborate (15.2 g) and salt **4** (18.9 g) were successively added in small portions at −10 °C with vigorous stirring to dry MeCN (75 mL). The reaction mixture was vigorously stirred for 1 h at −10 °C and for 1 h at 0 °C, poured into water, and extracted with CH_2Cl_2. The combined extracts were washed with water and dried with $MgSO_4$ in a refrigerator for 2 h. The solvent was removed in the vacuum of a water-jet pump to give 17.0 g (77 %) of compound **1d** as a yellowish oil, n^{16}_D 1.4640—1.4648. IR (ν/cm^{-1}): 1610—1645, 1245, 855 (NO_2); 1740 (CO). ^{1}H NMR (CCl_4), δ: 2.7 (t, 2 H, $COCH_2$); 3.6 (s, 3 H, OCH_3); 4.35 (t, 2 H, NCH_2).

Potassium salt of DNA (PDNA). ***A.*** KOH (0.12 g) in ethanol (1 mL) was added at 0—3 °C with vigorous stirring to a solution of compound **1b** (0.35 g) in ethanol (2.5 mL). The mixture was stirred for 1 h at 0—3 °C. Filtration gave 0.24 g (83 %) of PDNA.

B. KOH (1.7 g) in ethanol (10 mL) was added at 0—2 °C to a solution of compound **1d** (5.6 g) in ethanol (27 mL). The mixture was stirred for 1 h, then 3.37 g (80.3 %) of PDNA was filtered off.

Cesium salt of DNA (CDNA) was obtained similarly to PDNA starting from compound **1d** (2.02 g) in ethanol (20 mL) and CsOH (1.6 g) in ethanol (5 mL). Yield 2.0 g (80 %), m.p. 84—87 °C (after two recrystallizations from ethanol).

Ammonium salt of DNA (ADNA). Dry NH_3 was passed at 8—10 °C for 3 h through a solution of compound **1d** (2.9 g) in dry dioxane (25 mL). The reaction mixture was stirred for 2.5 h at 5—8 °C and kept for 17 h at 15 °C, then dry N_2 was bubbled through the mixture until complete removal of the NH_3 (a test with HCl). The precipitate of ADNA was filtered off and washed with dry dioxane to give 0.91 g (48.9 %) of a salt with m.p. 88—92 °C. The dioxane was distilled off from the filtrate. The residue was washed with dry ether and dry methyl acetate and kept *in vacuo* (1 Torr, 25 °C) for 1.5 h to give 1.35 g of a yellow oil, which was identified as ADNA based on its IR and UV spectra. Treatment of the oil with CsOH in ethanol gave 0.87 g of CDNA. The overall yield of ADNA was 73 %.

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