Mendeleev Commun., 2013, **23**, 81–83

Mendeleev
Communications

Nitration of carbonic, sulfuric and oxalic acid-derived amides in liquid carbon dioxide

Ilya V. Kuchurov, Igor V. Fomenkov, Sergei G. Zlotin* and Vladimir A. Tartakovsky

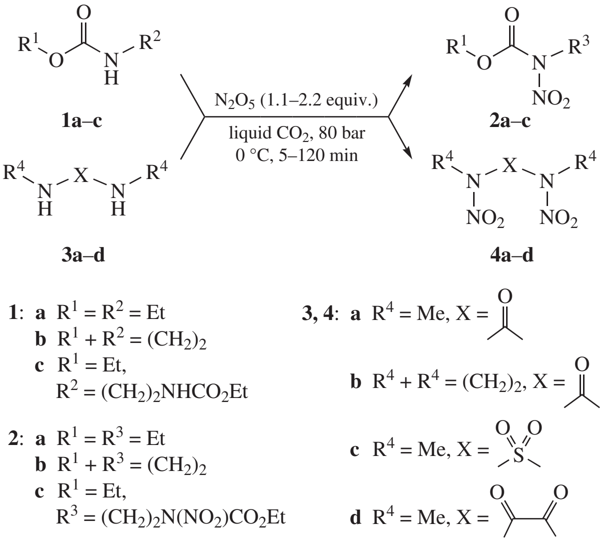
N. D. Zelinsky Institute of Organic Chemistry, Russian Academy of Sciences, 119991 Moscow, Russian Federation.
Fax: +7 499 135 5328; e-mail: zlotin@ioc.ac.ru

DOI: 10.1016/j.mencom.2013.03.008

***N*-Nitro- and *N*,*N*′-dinitroamides of carbonic, sulfuric and oxalic acids have been prepared in 76–99% yield by the nitration of the corresponding amides with dinitrogen pentoxide in liquid carbon dioxide.**

Carbon dioxide, being an available, low cost, nontoxic, nonflammable and thermally stable compound, is increasingly regarded as a ‘green’ solvent in liquid (liq) or supercritical (sc) states for chemical processes.[1,2] Due to the specific physical and chemical properties, CO_2 media are particularly promising for nitration reactions – an extremely important class of chemical reactions widely used for manufacturing of energetic compounds[3,4] and drugs.[5,6] Among these valuable properties are significant nonflammability, resistance to strong oxidants, low viscosity, and high diffusion rates[2] (the latter is particularly useful for nitration of poorly soluble substances such as polyamides or polymers[7–9]). Furthermore, due to a considerably higher heat capacity of liq- or sc-CO_2 as compared to conventional solvents,[10] they effectively trap out exothermic reaction heat to reduce explosion risks of nitration processes. Several successful syntheses of nitroarenes,[11] nitroesters[7–9,12] and *N*,*N*-dialkyl nitroamines[13,14] in liq- or sc-CO_2 have been reported. However, to the best of our knowledge, compressed CO_2 media have not been so far applied to the preparation of *N*-nitroamides, which are used as energetic compounds themselves,[15,16] and can be readily hydrolyzed to primary nitroamines hardly available *via* direct nitration protocols.[4,17,18] Herein we report the first synthesis of carbonic, sulfuric or oxalic acid-derived *N*-nitro- and *N*,*N*′-dinitroamides by nitration of corresponding amide derivatives in liquid CO_2 (Scheme 1), the procedure having been characterized by high product yields and lower explosion risks than conventional nitration processes.

We employed dinitrogen pentoxide (N_2O_5) in these reactions as a highly active, well-soluble in liq- or sc-CO_2 and environment-friendly (recoverable nitric acid is singularly generated as an acidic secondary product[19]) nitrating agent.[20–22] It had been used earlier for nitration of similar amide and imide derivatives in organic solvents, however, yields of corresponding *N*-nitroamides were not always high.[23] We found that urethane **1a** reacted with N_2O_5 (1.1 equiv.) in liq-CO_2 for 30 min to afford the corresponding nitrourethane **2a** in 96% yield (Table 1, entry 1).[†] Under similar conditions, cyclic urethane **1b** produced 3-nitrooxazolidin-2-one **2b**, however, the reaction rate and product yield (entries 2 and 3) were somewhat lower than those in the case of compound **1a**. Very high nitration efficiency was attained in the reaction of linear bis-amide **1c** (2.2 equiv. of the nitrating agent, 30 min) whose both urethane fragments did react to afford bis-nitrocarbamate derivative **2c** in 98% yield (entry 4). *N*,*N*′-Dialkylureas **3a**,**b** also reacted readily to furnish exhaustively nitrated products **4a**,**b** in excellent yields. Among them, linear compound **3a** exhi-



Scheme 1

Table 1 Nitration of urethane (**1a**–**c**) and bis-amide (**3a**–**d**) derivatives in liquid CO_2.[a]

Entry	Product	N_2O_5 amount/ equiv.	Time/ min	Isolated yield (%)	Reported yield (%) (nitrating system)
1	**2a**	1.1	30	96	86 (HNO_3/Ac_2O)[24]
2	**2b**	1.1	60	62	80 ($N_2O_5/CHCl_3$)[22]
3			120	76	
4	**2c**	2.2	30	98	95 (HNO_3)[17]
5	**4a**	2.2	5	95	86 (HNO_3/Ac_2O)[15] 60 (HNO_3)[15]
6			15	96	
7			30	99	
8	**4b**	2.2	60	93	93 ($N_2O_5/CHCl_3$)[25] 41 [$NH_4NO_3/(CF_3CO)_2O$][26]
9	**4c**	2.2	30	96	84 (HNO_3)[27]
10	**4d**	2.2	30	63	98 (HNO_3/H_2SO_4)[28]
11			60	86	
12			120	95	

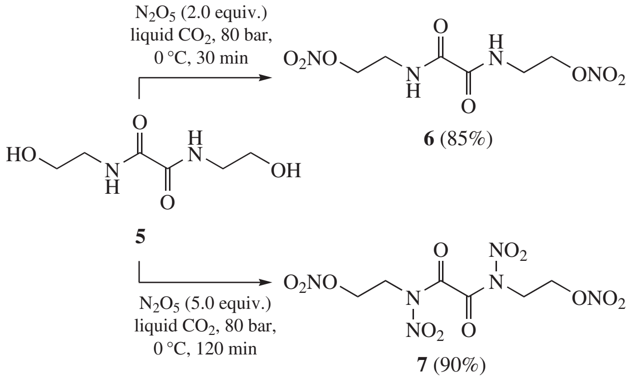
[a] The reactions were carried out using amides **1a**–**c** or **3a**–**d** (10.0 mmol) and N_2O_5 (11.0–22.0 mmol) at 80 bar and 0 °C.

[†] The IR spectra were obtained on a Bruker ALPHA FT-IR spectrometer in a thin film on NaCl plates or in KBr pellets. The ^1H and ^{13}C NMR spectra were recorded on a Bruker AM-300 (300 MHz) instrument in $CDCl_3$ or DMSO-d_6 using TMS as the internal standard. *N*,*N*′-bis(2-hydroxyethyl)oxamide[16] **5** and dinitrogen pentoxide[31] were prepared as described. Starting compounds **1** and **3** were purchased from Acros Organics or Sigma-Aldrich. Carbon dioxide (99.995%) was supplied by Linde Gas (Russia).

bited higher activity than imidazolidin-2-one **3b** (entries 5–8). The proposed conditions were found to be applicable to nitration of sulfuric and oxalic amides **3c**,**d**. In both cases the corresponding bis-amides **4c**,**d** were isolated in 95–96% yield (entries 9–12).

It is possible to further extend the developed procedure to the nitration of polyfunctional compounds bearing hydroxy groups along with the amide fragments. Nitration of *N*,*N′*-bis(2-hydroxyethyl)oxalamide **5** gives either nitro ester **6** or fully nitrated compound **7** in 85% or 90% yield, respectively, depending on the reaction time (30 or 120 min) and the nitrating agent amount (2 or 5 equiv.) (Scheme 2).‡ Product **7** had been earlier synthesized[16] by the action of a mixture of nitric and sulfuric acids on compound **5**, associated with the generation of mixed acid wastes.

The experiments in an autoclave equipped with sapphire windows show that all studied reactions are heterogeneous under the conditions used. High efficiency of the developed nitration procedure in spite of poor solubility of starting amides and reaction products in liq-CO_2 may be attributed to a high diffusion rate of N_2O_5-solute in the liquid CO_2 medium that results in an efficient nitrating agent delivery to the solid surface of the heterogeneous substrate. The proposed approach may be considered as environmentally benign since it does not employ toxic organic solvents of the non-renewable hydrocarbon origin. The procedure is convenient: after decompression, the products can be isolated from the residue by washing with water and diluted nitric acid as well as volatile carbon dioxide can be, if needed, recycled. Furthermore, an opportunity to prepare starting urea derivatives **3a**,**b** from the corresponding amines (diamines) and sc-CO_2[29] makes the process even more attractive. Synthesized compounds **2a**,**c** and **4a**,**c** are used as precursors of practically important methylnitramine[18,30] and ethylenedinitramine,[17] including production on a commercial scale.[18]



Scheme 2

In summary, an efficient explosion-proof procedure for the syntheses of carbonic, sulfuric and oxalic acid-derived *N*-nitro- and *N*,*N′*-dinitroamides by nitration of corresponding NH-precursors with N_2O_5 in the liquid carbon dioxide medium has been developed. The proposed procedure advantages are the toxic organic solvents exclusion and environmental and technological safety improvement owing to the explosive reaction mixture dilution with inert carbon dioxide.

This work was supported by the Russian Foundation for Basic Research (grant nos. 11-03-12163-ofi_m and 12-03-12012-ofi_m).

References

1 P. T. Anastas and J. C. Warner, *Green Chemistry: Theory and Practice*, Oxford University Press, New York, 2000.
2 P. G. Jessop and W. Leitner, *Chemical Syntheses Using Supercritical Fluids*, Wiley-VCH, Weinheim, 1999.
3 R. Meyer, J. Köhler and A. Homburg, *Explosives,* 6th edn., Wiley-VCH Verlag GmbH, Weinheim, 2007.
4 J. P. Agrawal and R. D. Hodgson, *Organic Chemistry of Explosives*, Wiley Interscience, New York, 2007.
5 M. H. Litchfield, *J. Pharm. Sci.*, 2006, **60**, 1599.
6 J. Ahlner, R. G. Andersson, K. Torfgard and K. L. Axelsson, *Pharmacol. Rev.*, 1991, **43**, 351.
7 R. E. Farncomb and G. W. Nauflett, *Waste Manag.*, 1997, **17**, 123.

General nitration procedure.[12–14] A steel autoclave (25 cm^3) equipped with sapphire windows containing urethane **1c** or amide **3** or **5** (10.0 mmol) was filled with liquid CO_2 to 60 bar pressure and cooled to 0 °C. Then N_2O_5 (2.4 g, 22.0 mmol) solution in liquid CO_2 (~4 g) cooled to 0–5 °C was gradually pressed out from an auxiliary high-pressure cell by a fresh CO_2 flow (2 g min^{-1}) to the reaction autoclave. During the addition, the pressure in the latter raised up to 80 bar. The reaction mixture was stirred at 0–5 °C for the time specified in Table 1. Then, CO_2 was removed by decompression and the residue was poured onto ice water (50 ml). The resulted suspension was extracted with EtOAc (4×20 ml), the combined organic extracts were washed successively with saturated aqueous $NaHCO_3$ (2 × 20 ml) and water (25 ml) and dried over anhydrous Na_2SO_4. The solvent was removed under reduced pressure to afford corresponding nitro compounds **2**, **4** (see Table 1). Compounds **2a**,**b** and **7** were synthesized by similar procedures using 1.2 g (11.0 mmol) or 6.0 g (55 mmol) of N_2O_5, respectively.

N*-Ethyl-*N*-nitrocarbamic acid ethyl ester* **2a**: yellow oil. IR (ν/cm^{-1}): 2988, 2942, 1773, 1742, 1576, 1448, 1377, 1337, 1300, 1242, 1177, 1089, 1023, 991, 876, 808, 750, 610. ^1H NMR (DMSO-d_6) δ: 4.37 (q, 2H, NCH_2Me, *J* 7.1 Hz), 4.11 (q, 2H, OCH_2Me, *J* 6.9 Hz), 1.37 (t, 3H, NCH_2*Me*, *J* 7.1 Hz), 1.27 (t, 3H, OCH_2*Me*, *J* 6.9 Hz). ^{13}C NMR (DMSO-d_6) δ: 13.58 (OCH_2*Me*), 46.63 (O*C*H_2Me), 64.70 (CH_2NNO_2), 149.46 (C=O).

3-Nitro-1,3-oxazolidin-2-one **2b**: white solid, mp 107–109 °C (lit.,[32] 110–111 °C). IR (ν/cm^{-1}): 3436, 1797, 1573, 1560, 1478, 1312, 1286, 1216, 1162, 1098, 1036, 977, 838, 761, 740, 707, 617. ^1H NMR (DMSO-d_6) δ: 4.25–4.46 (m, 4H, NCH_2CH_2O). ^{13}C NMR (DMSO-d_6) δ: 45.37 (CH_2O), 60.91 (CH_2NNO_2).

N,N*′-Dinitro-*N,N*′-ethanediylbis(carbamic acid) diethyl ester* **2c**: white solid, mp 80–82 °C (lit.,[17] 82–82.5 °C). IR (ν/cm^{-1}): 3411, 1735, 1723, 1707, 1644, 1586, 1434, 1280, 1249, 1098, 990, 972, 892, 844, 760, 714, 591, 565. ^1H NMR (DMSO-d_6) δ: 4.39 (s, 4H, CH_2NNO_2), 4.25 (q, 4H, OCH_2Me, *J* 7.1 Hz), 1.24 (t, 6H, OCH_2*Me*, *J* 7.1 Hz). ^{13}C NMR (DMSO-d_6) δ: 13.58 (OCH_2*Me*), 46.63 (O*C*H_2Me), 64.70 (CH_2NNO_2), 149.46 (C=O).

N,N*′-Dimethyl-*N,N*′-dinitrourea* **4a**: yellow oil. IR (ν/cm^{-1}): 2955, 1775, 1719, 1570, 1514, 1390, 1315, 1253, 1163, 1041, 989, 883. ^1H NMR ($CDCl_3$) δ: 3.64 (s, 6H, $MeNNO_2$). ^{13}C NMR ($CDCl_3$) δ: 36.51 ($MeNNO_2$), 148.43 (C=O).

N,N*′-Dinitro-1,3-diazacyclopentan-2-one* **4b**: white solid, mp 211–212 °C (lit.,[26] 213 °C). IR (ν/cm^{-1}) 3434, 1796, 1582, 1561, 1315, 1282, 1245, 1218, 1159, 1140, 1101, 757, 741, 717, 705. ^1H NMR (DMSO-d_6) δ: 4.12 (s, 4H, CH_2NNO_2). ^{13}C NMR (DMSO-d_6) δ: 41.18 (CH_2NNO_2), 142.22 (C=O).

N,N*′-Dimethyl-*N,N*′-dinitrosulfamide* **4c**: white solid, mp 89–90 °C (lit.,[27] 89.5–90 °C). IR (ν/cm^{-1}): 3421, 1598, 1411, 1292, 1193, 1117, 904, 794, 747, 650, 572. ^1H NMR (DMSO-d_6) δ: 3.76 (s, 6H, $MeNNO_2$). ^{13}C NMR (DMSO-d_6) δ: 38.96 ($MeNNO_2$).

N,N*′-Dimethyl-*N,N*′-dinitrooxalamide* **4d**: white solid, mp 123–124 °C (lit.,[28] 124 °C). IR (ν/cm^{-1}): 3414, 2964, 1732, 1706, 1600, 1572, 1419, 1345, 1254, 1181, 1098, 999, 952, 824, 767, 724, 574. ^1H NMR (DMSO-d_6) δ: 3.65 (s, 6H, $MeNNO_2$). ^{13}C NMR (DMSO-d_6) δ: 32.51 ($MeNNO_2$), 158.62 (C=O).

[‡] N,N*′-Bis(2-nitryloxyethyl)oxalamide* **6**: white solid, mp 147–149 °C (lit.,[16] 148.2 °C). IR (ν/cm^{-1}): 3316, 1659, 1632, 1529, 1436, 1363, 1279, 1121, 1005, 879, 852, 756, 669, 563. ^1H NMR (DMSO-d_6) δ: 8.98 [s, 2H, C(O)N*H*CH_2], 4.61 (t, 4H, CH_2ONO_2, *J* 5.0 Hz), 3.51 (t, 4H, NC$H_2$$CH_2$, *J* 5.3 Hz). ^{13}C NMR (DMSO-d_6) δ: 36.47 (N*C*$H_2$$CH_2$), 71.66 ($CH_2ONO_2$), 160.07 (C=O).

N,N*′-Bis(2-nitryloxyethyl)-*N,N*′-dinitrooxalamide* **7**: white solid, mp 90–92 °C (lit.,[16] 91–92 °C). IR (ν/cm^{-1}): 3411, 1735, 1707, 1644, 1586, 1434, 1280, 1249, 1098, 990, 972, 892, 844, 760, 714, 665, 591, 565. ^1H NMR (DMSO-d_6) δ: 4.87 (t, 4H, NC$H_2$$CH_2$, *J* 4.5 Hz), 4.62 (t, 4H, CH_2ONO_2, *J* 4.5 Hz). ^{13}C NMR (DMSO-d_6) δ: 43.43 (CH_2ONO_2), 68.85 (N*C*$H_2$$CH_2$) 158.09 (C=O).

8 G. W. Nauflett and R. E. Farncomb, *JANNAF Propellant Development & Characterization Subcommittee and Safety & Environmental Protection Subcommittee Joint Meeting*, US, 1998, p. 14.

9 R. E. Farncomb and G. W. Nauflett, *US Patent 6177033*, 2001 (*Chem. Abstr.*, 2001, **134**, 118045).

10 R. Span and W. Wagner, *J. Phys. Chem. Ref. Data*, 1996, **25**, 1509.

11 N. Chanhan, M. E. Colclough and J. Hamid, *Proceedings of the 6th Meeting on Supercritical Fluids*, Nottingham, UK, 1999.

12 I. V. Kuchurov, I. V. Fomenkov, S. G. Zlotin and V. A. Tartakovsky, *Mendeleev Commun.*, 2012, **22**, 67.

13 I. V. Kuchurov, I. V. Fomenkov and S. G. Zlotin, *Izv. Akad. Nauk, Ser. Khim.*, 2009, 1995 (*Russ. Chem. Bull., Int. Ed.*, 2009, **58**, 2058).

14 I. V. Kuchurov, I. V. Fomenkov and S. G. Zlotin, *Izv. Akad. Nauk, Ser. Khim.*, 2010, 2093 (*Russ. Chem. Bull., Int. Ed.*, 2010, **59**, 2147).

15 K. Shiino and S. Ikinuma, *US Patent 2997501*, 1962 (*Chem. Abstr.*, 1962, **56**, 12828).

16 R. S. Stuart and G. F. Wright, *Can. J. Res.*, 1948, **26B**, 401.

17 W. E. Bachmann,W. J. Horton, E. L. Jenner, N. W. MacNaughton and C. E. Maxwell, *J. Am. Chem. Soc.*, 1950, **72**, 3132.

18 G. W. Nauflett, *US Patent 4513148*, 1985 (*Chem. Abstr.*, 1985, **98**, 182087).

19 R.W. Millar, M. E. Colclough, A. W. Arber, R. P. Claridge, R. M. Endsor and J. Hamid, in *Energetic Materials: Chemistry, Hazards and Environmental Aspects*, eds. J. R. Howell and T. E. Fletcher, Nova Science Pub. Inc., New York, 2010.

20 P. Golding, R. W. Millar, N. C. Paul and D. H. Richards, *Tetrahedron Lett.*, 1988, **29**, 2731.

21 P. Golding, R. W. Millar, N. C. Paul and D. H. Richards, *Tetrahedron*, 1993, **49**, 7051.

22 R. W. Millar and S. P. Philbin, *Tetrahedron*, 1997, **53**, 4371.

23 J. von Runge and W. Triebs, *J. Prakt. Chem.*, 1962, **15**, 233.

24 H. M. Curry and J. P. Mason, *J. Am. Chem. Soc.*, 1951, **73**, 5043.

25 G. V. Caesar and M. Goldfrank, *US Patent 2400288*, 1946 (*Chem. Abstr.*, 1946, **40**, 23123).

26 S. C. Suri and R. D. Chapman, *Synthesis*, 1988, **9**, 743.

27 O. V. Anikin, L. G. Gareeva, I. E. Chlenov, V. A. Tartakovskii, Yu. T. Struchkov, V. S. Kuz’min and Yu. N. Burtsev, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1989, 1812 (*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1989, **38**, 1659).

28 O. C. W. Allenby and G. Wright, *Can. J. Res.*, 1947, **25B**, 295.

29 C. Wu, H. Cheng, R. Liu, Q. Wang, Y. Hao, Y. Yu and F. Zhao, *Green Chem.*, 2010, **12**, 1811.

30 M. S. Chang and R. S. Orndoff, *US Patent 394218*, 1983 (*Chem. Abstr.*, 1983, **98**, 182088).

31 *Inorganic Syntheses*, ed. L. F. Audrieth, McGraw-Hill, New York, 1950, vol. III, p. 78.

32 R. L. Willer, C. G. Campbell and R. F. Storey, *J. Heterocycl. Chem.*, 2012, **49**, 421.

Received: 23rd January 2013; Com. 13/4053