Oxidations of 3,6-Diamino-1,2,4,5-tetrazine and
3,6-Bis(S,S-dimethylsulfilimino)-1,2,4,5-tetrazine

M. D. Coburn*, M. A. Hiskey, K.-Y. Lee, D. G. Ott and M. M. Stinecipher

University of California, Los Alamos National Laboratory,
Los Alamos, NM 87545, USA
Received May 10, 1993

Oxidation of 3,6-diamino-1,2,4,5-tetrazine (1) with most peracids gave 3,6-diamino-1,2,4,5-tetrazine 1,4-dioxide (3) as the major product; however, treatment of 1 with peroxytrifluoroacetic acid (PTFA) gave 3,6-diamino-1,2,4,5-tetrazine 1-oxide (4) as the major product along with a small amount of 3-amino-6-nitro-1,2,4,5-tetrazine 2,4-dioxide (5). Oxidation of 3,6-bis(S,S-dimethylsulfilimino)-1,2,4,5-tetrazine (6) with 3-chloroperoxybenzoic acid (MCPBA) gave 3-S,S-(dimethylsulfilimino)-6-nitroso-1,2,4,5-tetrazine (7), which was oxidized further with dimethyldioxirane to 3-(S,S-dimethylsulfoximino)-6-nitro-1,2,4,5-tetrazine (8). All attempts to obtain 3,6-dinitro-1,2,4,5-tetrazine (2) by further oxidation of 7 or 8 failed.

In a previous communication [1] from this laboratory we reported a convenient, high-yield synthesis of 3,6-diamino-1,2,4,5-tetrazine (1) starting initially with triaminoguanidine monohydrochloride and 2,4-pentanedione. This work has made 1 readily available for study as an intermediate to other new 1,2,4,5-tetrazine derivatives.

Our initial goal for investigating the oxidation of 1 was to synthesize 3,6-dinitro-1,2,4,5-tetrazine (2), a compound that has been the goal of energetic materials chemists for several decades. Treatment of 1 with peroxyformic acid under carefully controlled conditions gave pure 3,6-diamino-1,2,4,5-tetrazine 1,4-dioxide (3), whose structure was confirmed by X-ray crystallography [2]. The peracids 3-chloroperoxybenzoic acid (MCPBA), magnesium monoperoxyphthalate (MMP), and potassium monoperoxysulfate (OXONE®) all gave a crude product containing 3 as the major constituent along with a small amount of 3,6-diamino-1,2,4,5-tetrazine 1-oxide (4) that seemed to be occluded in the crystals of 3 (Scheme 1). Pure 3 was obtained from these reactions by recrystallization of the crude product from methyl sulfoxide/water. The use of OXONE® in this reaction was most convenient for preparing large quantities of 3.

In contrast with the results obtained with the peracids previously discussed, 3 was not produced in the oxidation of 1 with peroxytrifluoroacetic acid (PTFA) in trifluoroacetic acid. Instead, 4 was obtained as the major product along with a low yield of 3-amino-6-nitro-1,2,4,5-tetrazine 2,4-dioxide (5), a compound that is very hydrolytically and thermally unstable (Scheme 1). In this reaction, 4 may have been protonated by trifluoroacetic acid, which is much more acidic than the other oxidation media that gave 3, such that further oxidation of 4 to 3 was retarded. In a separate experiment it was demonstrated that 4 could not be oxidized to 5 with PTFA; therefore, we speculate that 4 and 5 result from separate reaction pathways.

The structural assignment of 5 was established by X-ray crystallography [3] and is consistent with its elemental analysis and spectral properties. The ^{13}C nmr spectrum consists of two peaks at 149.3 and 150.4 ppm and the ^{15}N nmr spectrum contains only four peaks at –29.0, –91.2, –94.2, and –309.6 ppm relative to nitromethane. Thus, the four tetrazine nitrogens exist as two pairs of magnetically equivalent nitrogen nuclei. The mass spectrum contains a molecular ion (m/z = 174), a fragment corresponding to loss of oxygen (m/z = 158), and a very intense NO fragment (m/z = 30), which is characteristic of nitro compounds.

Scheme 1

[O] = Peroxyformic Acid, MCPBA, MMP, OXONE®
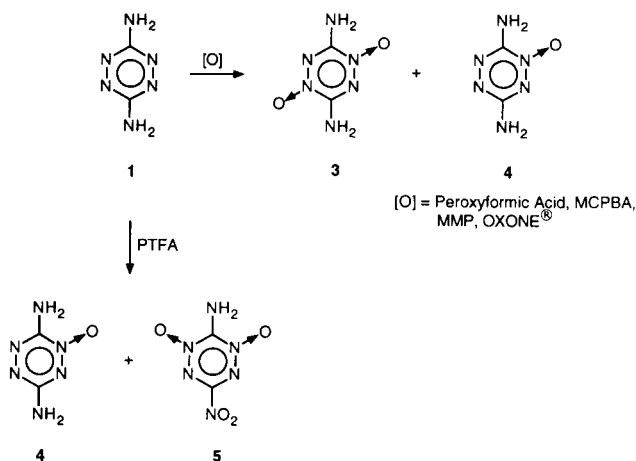
In another approach to obtain 2 we studied the oxidation of 3,6-bis(S,S-dimethylsulfilimino)-1,2,4,5-tetrazine (6) [4]. Treatment of 6 with MCPBA at 0° gave 3-(S,S-dimethylsulfilimino)-6-nitroso-1,2,4,5-tetrazine (7). Further oxidation of 7 with dimethyldioxirane (DMD) [5] and methyltrifluoromethyldioxirane (MTFD) [6], which is reported to be an order of magnitude more reactive than DMD [6], both gave 3-(S,S-dimethylsulfoximino)-6-nitro-1,2,4,5-tetrazine (8). Treatment of 7 or 8 with anhydrous PTFA at 0° resulted in significant evolution of gas and gave a mixture of methyl sulfone and a yellow, sticky semi-solid (Scheme 2).

The absence of a NO fragment ($m/z = 30$) in the mass spectrum of the semi-solid indicates that no nitro compound was present. The presence of methyl sulfone in the product mixture suggests that **2** may have been formed, but immediately decomposed with the liberation of gaseous products. The extreme hydrolytic and thermal instability exhibited by **5** suggests that **2** may be too unstable to isolate, since electronic considerations predict **2** to be less stable than **5**. Although our initial goal of isolating **2** was not accomplished, we have prepared and characterized the first nitro derivatives, **5** and **8**, of 1,2,4,5-tetrazine.

Scheme 2
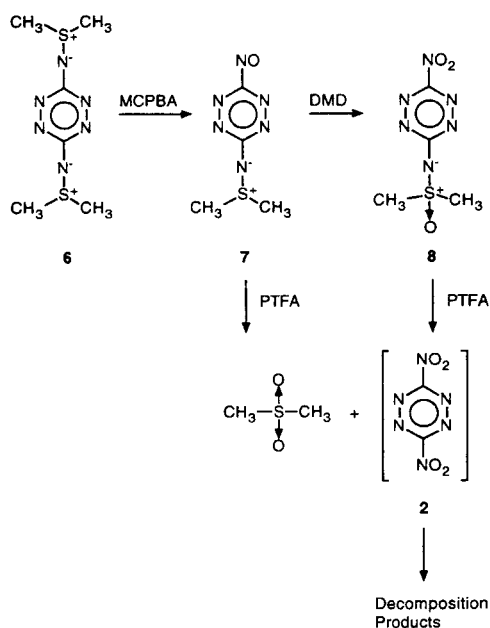
EXPERIMENTAL

Caution! Compounds **3, 4,** and **5** are explosives and should be handled with care.

All nmr spectra were obtained on a JEOL GSX-270 spectrometer. Chemical shifts are relative to internal tetramethylsilane = 0 for the ^{1}H and ^{13}C nmr spectra and to external nitromethane = 0 for the ^{15}N nmr spectra. Microanalyses were performed at Los Alamos National Laboratory by M. J. Naranjo. Mass spectra were obtained by Dr. J. C. Oxley, New Mexico Institute of Mining and Technology. All melting points were determined at 2°/minute with a Mettler FP1 apparatus and are corrected.

3,6-Diamino-1,2,4,5-tetrazine 1,4-Dioxide (**3**).

A. A slurry of 3,6-diamino-1,2,4,5-tetrazine (**1**) [1] (1.12 g, 0.01 mole) and 98% formic acid (20 ml) in a jacketed flask was heated with steam until a clear solution was obtained. The steam heating was replaced with tap water cooling, the solution was cooled to 25°, and 90% hydrogen peroxide (4.0 ml, 0.15 mole) was added. After one hour, the solution became cloudy and product began to crystallize from the solution. The mixture was allowed to stand overnight with tap water cooling (~25°) to prevent exothermic decomposition of the peracid. The solid was collected by filtra-

tion, washed with water, and dried to yield 0.93 g (65%) of pure **3**, glistening reddish brown crystals that began to decompose without melting at 220° according to differential thermal analysis; ^{1}H nmr (methyl sulfoxide-d$_6$): δ 7.17; ^{13}C nmr (methyl sulfoxide-d$_6$): δ 146.2; ir: ν 3407, 3288, 3139, 1623, 1513, 1371, 1311, 1057, 748; ms: m/z 144 (M$^+$).

Anal. Calcd. for C$_2$H$_4$N$_6$O$_2$: C, 16.67; H, 2.80; N, 58.32. Found: C, 16.63; H, 2.73; N, 58.12.

B. To a solution of OXONE$^®$ (615 g, 1.0 mole) in water (3.0 ℓ) was added **1** (56.0 g, 0.5 mole) at 25°. The mixture was stirred at 25° for 20 hours, then the solid was collected by filtration, washed with water, and dried to give 48.8 g of crude material that contained ~85% **3**, 8% 3,6-diamino-1,2,4,5-tetrazine 1-oxide (**4**), and some unidentified products according to ^{1}H nmr analysis. The crude was dissolved in methyl sulfoxide (7.2 ℓ) at 90°, then water (2.4 ℓ) was added and the resultant solution was allowed to stand at ambient temperature for 24 hours. The crystals that deposited were removed by filtration, washed with water, and dried to yield 26.5 g (37%) of **3**, identical with that obtained by procedure A. above. Similar results were obtained when the oxidation of **1** was performed with 3-chloroperoxybenzoic acid in 1-methyl-2-pyrrolidinone and with magnesium monoperphthalate in both 1-methyl-2-pyrrolidinone and water.

3,6-Diamino-1,2,4,5-tetrazine 1-Oxide (**4**) and 3-Amino-6-nitro-1,2,4,5-tetrazine 2,4-Dioxide (**5**).

To trifluoroacetic acid (20 ml) was added 90% hydrogen peroxide (10.0 ml, 0.37 mole) at 0°, followed by trifluoroacetic anhydride (63.0 ml, 0.45 mole) dropwise at <10°. To the resulting solution was added **1** (4.48 g, 0.04 mole) at 0°. After being stirred at 0° for 0.5 hour, the mixture was held at 25° for 2 hours, during which time solid crystallized from solution. The crystals were collected by filtration, washed with a small amount of trifluoroacetic acid, then with dichloromethane, and dried in a vacuum desiccator over phosphoric anhydride to yield 0.5 g (7%) of **5**, yellow platelets that did not melt, but began to decompose at 110° according to differential thermal analysis; ^{1}H nmr (acetonitrile-d$_3$): δ 7.88; ^{13}C nmr (acetonitrile-d$_3$): δ 149.3, 150.4; ^{15}N nmr (tetrahydrofuran-d$_8$): δ -29.0, -91.2, -94.2, -309.6; ir: ν 3421, 3315, 1649, 1585, 1532, 1432, 1348, 1337, 1125, 840, 819; ms: m/z 174 (M$^+$), 158 (M$^+$ - O), 30 (NO).

Anal. Calcd. for C$_2$H$_2$N$_6$O$_4$: C, 13.80; H, 1.16; N, 48.28. Found: C, 14.00; H, 1.18; N, 47.96.

The filtrate was evaporated to dryness with a rotating evaporator and the residue was recrystallized from water to give 3.58 g (70%) of **4**, orange platelets that did not melt, but began to decompose at 150° according to differential thermal analysis; ^{1}H nmr (methyl sulfoxide-d$_6$): δ 6.56, 7.10; ^{13}C nmr (methyl sulfoxide-d$_6$): δ 149.3, 158.8; ^{15}N nmr (methyl sulfoxide-d$_6$): δ -61.6, -81.9, -86.9, -93.3, -316.2, -322.2; ir: ν 3415, 3294, 3175, 1629, 1462, 1394, 1295, 1044, 835, 742; ms: m/z 128 (M$^+$).

Anal. Calcd. for C$_2$H$_4$N$_6$O: C, 18.75; H, 3.15; N, 65.61. Found: C, 18.73; H, 2.96; N, 65.59.

3-(S,S-Dimethylsulfilimino)-6-nitroso-1,2,4,5-tetrazine (**7**).

A solution of 3,6-bis(S,S-dimethylsulfilimino)-1,2,4,5-tetrazine (**6**) [4] (2.32 g, 0.01 mole) in dichloromethane (100 ml) was treated with purified 3-chloroperoxybenzoic acid (3.8 g, 0.022 mole) at 0° under argon. The mixture was stirred at 0° for one hour, then diluted with anhydrous ether (500 ml) to dissolve 3-chlorobenzoic acid and precipitate the product, which was collected by filtration, washed with ether, and dried in a vacuum desiccator over

December 1993
Oxidations of 3,6-Diamino-1,2,4,5-tetrazine and
3,6-Bis(S,S-dimethylsulfilimino)-1,2,4,5-tetrazine
1595

phosphoric anhydride to give 1.74 g (94%) of **7**, mp 124°; ¹H nmr (methyl sulfoxide-d₆): δ 3.06; ¹³C nmr (methyl sulfoxide-d₆): δ 31.7, 161.1, 177.8; ¹⁵N nmr (methyl sulfoxide-d₆): δ −215.1, 478.1 [7]; ir: ν 3020, 2930, 1538, 1505, 1482, 1431, 1373, 1304, 1181, 1069.

Anal. Calcd. for $C_4H_6N_6OS$: C, 25.80; H, 3.25; N, 45.14. Found: C, 25.77; H, 3.60; N, 44.69.

3-(S,S-Dimethylsulfoximino)-6-nitro-1,2,4,5-tetrazine (**8**).

To a freshly prepared [5] acetone solution of dimethyldioxirane (∼6 mmoles), which was dried over type 4A molecular sieves, was added **7** (0.12 g, 0.6 mmole) and the resulting solution was allowed to stand at ambient temperature overnight. An equal volume of chloroform was added and the solution was concentrated until crystallization began to occur, then the mixture was chilled in the freezer. Filtration provided 0.11 g (85%) of **8**, mp 169° dec. Recrystallization from acetonitrile/chloroform produced the analytical sample, mp 176° dec; ¹H nmr (nitromethane-d₃): δ 3.64; ¹³C nmr (nitromethane-d₃): δ 43.1, 164.4, 167.4; ir: ν 3012, 3005, 2920, 1570, 1530, 1480, 1410, 1400, 1359, 1318, 1300, 1236, 1051, 1030, 980, 936, 805, 747, 711.

Anal. Calcd. for $C_4H_6N_6O_3S$: C, 22.02; H, 2.77; N, 38.52. Found: C, 22.10; H, 2.67; N, 38.88.

REFERENCES AND NOTES

[1] M. D. Coburn, G. A. Buntain, B. W. Harris, M. A. Hiskey, K.-Y. Lee and D. G. Ott, *J. Heterocyclic Chem.*, **28**, 2049 (1991).

[2] D. T. Cromer, Los Alamos National Laboratory, unpublished results.

[3] R. Gilardi, Naval Research Laboratory, unpublished results.

[4] M. D. Coburn, H. H. Hayden, C. L. Coon and A. R. Mitchell, *Synthesis*, 490 (1986).

[5] R. W. Murray and R. Jeyaraman, *J. Org. Chem.*, **50**, 2847 (1985).

[6] R. Mello, M. Fiorentino, O. Sciacovelli and R. Curci, *J. Org. Chem.*, **53**, 3890 (1988).

[7] The ring nitrogens, which would be expected to appear between −50 ppm and −100 ppm, failed to come up even when chromium(III) acetylacetonate was added and very long pulse delays were employed.