A Novel Approach to the Synthesis of 1,3,3-Trinitroazetidine

Alan P. Marchand,* D. Rajagopal, and Simon G. Bott*

Department of Chemistry, University of North Texas, Denton, Texas 76203-0068

Thomas G. Archibald*

Aerojet, Propulsion Division, P. O. Box 13222, Sacramento, California 95813-6000

Received March 10, 1995

Introduction

1,3,3-Trinitroazetidine (TNAZ, **1**) has received attention in recent years as a new energetic material that is of considerable interest to U. S. military agencies.[1-4] Previously reported routes for synthesizing **1** generally proceed via intermediate *N*,3-disubstituted azetidines, which in each case requires subsequent conversion of the various substituents to $C(NO_2)_2$ groups. We now report a novel approach to the synthesis of **1** which involves electrophilic addition of NO^+ NO_2^- across the highly strained C(3)–N σ-bond in 1-azabicyclo[1.1.0]butane and in 3-(bromomethyl)-1-azabicyclo[1.1.0]butane.

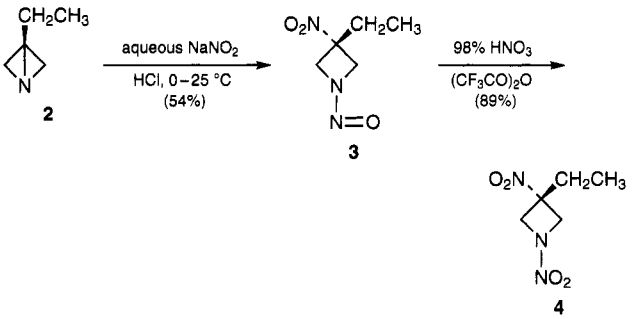
In 1969, Funke reported the synthesis of substituted 1-azabicyclo[1.1.0]butanes and some aspects of their chemistry.[5] Since that time, relatively little interest has been shown in this unusual ring system. Recently,[6] we investigated reactions of **2** with a variety of electrophiles, e.g., N_2O_4, $ClCO_2Et$, Tf_2O, and Ms_2O. In each case, the observed reaction product(s) resulted via addition of the reagent, X–Y, across the highly strained C(3)–N σ-bond in the substrate, thereby affording new *N*,3-disubstituted azetidines. In the present study, we have used this approach to synthesize *N*-NO- and *C*-NO_2-containing intermediates which serve as useful synthetic precursors to **1**.

Results and Discussion

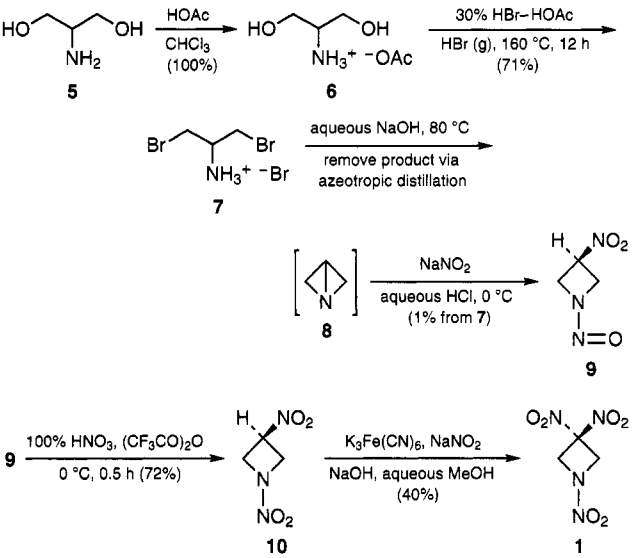
Compound **2**, synthesized by using a previously published modification[6] of a literature procedure,[5] was employed as substrate in a model study.[6b] In our hands, reaction of **2** with *in situ* generated aqueous HNO_2 resulted in addition of the elements of HNO_2 across the C(3)–N σ-bond with concomitant *N*-nitrosation of the resulting intermediate azetidine, thereby affording **3** (54% yield, Scheme 1). Subsequent oxidation of the *N*-NO functionality by using 98% HNO_3–$(CF_3CO)_2O$ afforded the corresponding *N*-nitramine (**4**, 89% yield).[6b]

Our success in achieving the synthesis of **4** via the route shown in Scheme 1 pointed the way toward a novel TNAZ synthesis. The key step in this synthesis, shown

Scheme 1



Scheme 2



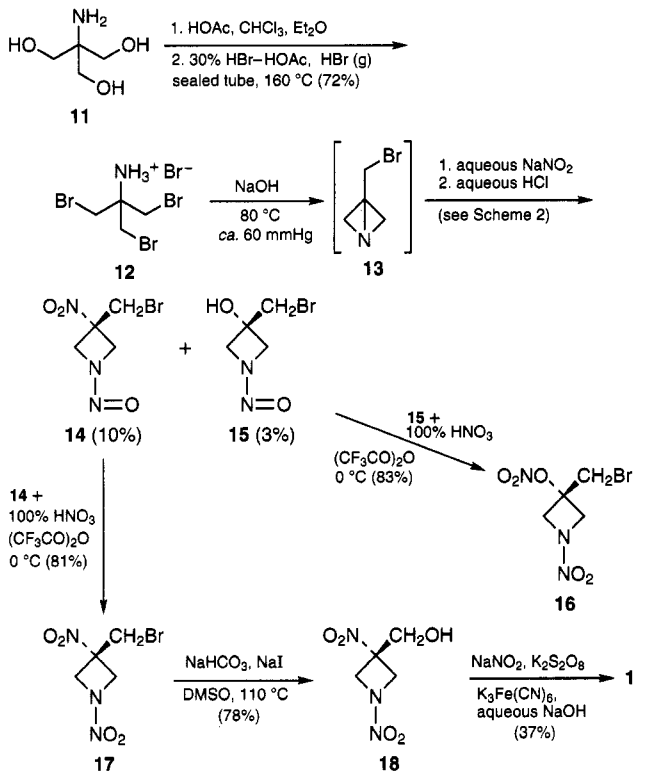
in Scheme 2, is the formation of 1-azabicyclo[1.1.0]-butane, **8**, which is removed rapidly from the reaction medium via azeotropic distillation and is trapped *in situ* in the distillation receiver via its reaction with aqueous $NaNO_2$–HCl, thereby affording *N*-nitroso-3-nitroazetidine (**9**) in low yield. The method by which **9** is converted subsequently into **1** is outlined in Scheme 2. The structure of 1,3-dinitroazetidine (**10**), an intermediate in the conversion of **9** to **1**, was established unequivocally via application of X-ray crystallographic methods. It should be noted that the formation and trapping of **8**, the key intermediate in the reaction sequence shown in Scheme 2, proceeds in poor yield (*ca.* 1%). In addition, the starting material, 2-amino-1,3-propanediol (**5**), although available commercially, nevertheless is very expensive.

In attempting to address these issues, we studied an alternative reaction sequence which like the method shown in Scheme 2 preserves the unique approach of formation and trapping of an intermediate 1-azabicyclo-[1.1.0]butane. Pertinent results in this regard are outlined in Scheme 3. Thus, 1-aza-3-(bromomethyl)bicyclo-[1.1.0]butane (**13**) is generated by the method shown in Scheme 3 and subsequently is trapped by *in situ* generated HNO_2. This results in the formation of two *N*-nitrosoazetidines, **14** and **15**, each of which was oxidized[6b,7] subsequently to the corresponding *N*-nitro derivative (i.e., **16** and **17**, respectively). The structures of **16** and **17** have been established unequivocally via application of

(1) Archibald, T. G.; Gilardi, R.; Baum, K.; George, C. *J. Org. Chem.* **1990**, *55*, 2920.
(2) (a) Axenrod, T.; Watnick, C.; Yazdehkasti, H.; Dave, P. R. *Tetrahedron Lett.* **1993**, *34*, 6677. (b) Axenrod, T.; Watnick, C.; Yazdehkasti, H.; Dave, P. R. *J. Org. Chem.* **1995**, *60*, 1959.
(3) Katritzky, A. R.; Cundy, D. J.; Chen, J. *J. Heterocycl. Chem.* **1994**, *31*, 271.
(4) Hiskey, M. A.; Coburn, M. D. U. S. Patent 5,336,784; *Chem. Abstr.* **1994**, *121*, 300750s.
(5) (a) Funke, W. *Chem. Ber.* **1969**, *102*, 3148. (b) Funke, W. *Angew. Chem., Int. Ed. Engl.* **1969**, *8*, 70.
(6) (a) Marchand, A. P.; Rajagopal, D.; Bott, S. G.; Archibald, T. G. *J. Org. Chem.* **1994**, *59*, 1608. (b) Marchand, A. P.; Rajagopal, D.; Bott, S. G.; Archibald, T. G. *J. Org. Chem.* **1994**, *59*, 5499.
(7) Bull, J. R.; Jones, E. R. H.; Meakins, G. D. *J. Chem. Soc.* **1965**, 2601.

0022-3263/95/1960-4943$09.00/0

Scheme 3



X-ray crystallographic methods. Hydrolysis[8] of **17** produced the corresponding alcohol, **18**, in good yield. Finally, under the reaction conditions shown in Scheme 3,[1] **18** undergoes retro-Henry reaction,[9] and the resulting α-nitro anion subsequently suffers oxidative nitration *in situ*, thereby affording **1** (37% yield from **18**).

Some important features of the reaction sequence shown in Scheme 3 should be noted. Thus, formation and trapping of the key intermediate in this reaction sequence, i.e., **13**, proceeds in *ca.* 7% overall yield from the starting material, a significant improvement in yield *vis-à-vis* that of the corresponding reaction sequence shown in Scheme 2. In addition, the route shown in Scheme 3 offers the distinct advantage that the 3-bromomethyl functionality in **17** can easily be replaced by NO_2 via a two-step reaction sequence that employs the retro-Henry reaction with concomitant oxidative nitration of a carbanionic intermediate. Finally, in contrast to the prohibitively high cost of **5** (Scheme 2), the starting material for the reaction sequence shown in Scheme 3 [i.e., tris(hydroxymethyl)aminomethane, **11**] is relatively inexpensive. We are continuing to pursue new high-yield routes to appropriately functionalized 1-azabicyclo[1.1.0]-butanes and to study the chemistry of these new systems as a potentially important class of alkylating agents.

Experimental Section

Melting points are uncorrected. Elemental microanalyses were performed by M-H-W Laboratories, Phoenix, AZ. Compounds **5** and **11** were purchased from the Aldrich Chemical Co. and used as obtained, without further purification.

1,3-Dibromo-2-ammonium Bromide (7). To a solution of 2-amino-1,3-propanediol (**5**, 20.0 g, 0.219 mol) in warm $CHCl_3$ (400 mL) was added dropwise with stirring glacial HOAc (60.0 g, 1.0 mol), and the resulting mixture was stirred at ambient temperature for 1 h. The reaction mixture was diluted with Et_2O (500 mL), and the resulting mixture was cooled to 5 °C by application of an external ice–water bath for 2 h. During this time, a colorless solid slowly precipitated from solution. This solid was collected by filtration, and the residue was washed with Et_2O (3 × 100 mL). The residue was dried thoroughly *in vacuo*, thereby affording 1,3-dihydroxypropyl-2-ammonium acetate (**6**, 33.0 g, 100%): mp 64–66 °C. This material was used as obtained in the next step without further purification.

Compound **6** (10.0 g, 11.2 mmol) was dissolved in a solution of 30% HBr–HOAc (50 mL), and the resulting solution was cooled to 5 °C via application of an external ice–water bath. Dry HBr gas was passed into this cooled solution until the reaction mixture had become saturated with HBr. The resulting thick syrup was heated in a sealed tube at 160 °C for 12 h. The reaction mixture was allowed to cool slowly to room temperature and then was diluted with MeOH (200 mL). The resulting solution was concentrated *in vacuo*. The residue was dissolved in MeOH (100 mL), and the resulting solution was clarified with Norite and then filtered. The filtrate was concentrated *in vacuo*, thereby affording a thick syrup which solidified upon prolonged drying under high vacuum. Compound **7** (13.4 g, 71%) was thereby obtained as a colorless microcrystalline solid: mp 157–159 °C (lit.[5b] mp 158–159 °C).

***N*-Nitroso-3-nitroazetidine (9).** A 1000 mL round-bottom flask was fitted with an addition funnel, a distillation condenser, and a receiver. The reaction vessel was charged with a solution of NaOH (80.0 g, 2.0 mol) in water (400 mL), and the resulting solution was heated to 80 °C (internal reaction temperature). To this hot solution was added a solution of **7** (40.0 g, 0.13 mol) in water (80 mL) dropwise during 45 min. The reaction product was removed continuously during this period via azeotropic distillation with water at reduced pressure (60 mmHg, water aspirator). An aqueous solution of **8** distilled over continuously and was collected in a receiver that was maintained at −78 °C by application of an external dry ice–acetone bath. The water distillation process was continued for 30 min after the addition of **7** had been completed. A total of 3 mL of distillate was thereby collected. Water (5 mL) was added to the distillate followed by addition of $NaNO_2$ (2.07 g, 30.0 mmol). The resulting mixture was cooled to 0 °C via application of an external ice–water bath. Concentrated aqueous HCl (3 mL) was added dropwise with stirring to the cold reaction mixture, and the resulting mixture was stirred at 0 °C for 10 min. An additional quantity (5 mL) of concentrated aqueous HCl was added dropwise, and the resulting mixture was stirred at 0 °C for 30 min. Water (25 mL) was added, and the resulting suspension was extracted with EtOAc (3 × 15 mL). The organic layer was washed sequentially with 10% aqueous $NaHCO_3$ (25 mL), water (25 mL), and brine (25 mL). The organic layer was dried (Na_2SO_4) and filtered, and the filtrate was concentrated *in vacuo*. The residue, a pale yellow oil, was purified by column chromatography on silica gel by elution with 10% EtOAc–hexane. Pure **9** (168 mg, 0.96%) was obtained as a pale yellow microcrystalline solid: mp 77–78 °C; IR (KBr) 2992 (w), 2902 (w), 1555 (s), 1370 (vs), 1301 (vs), 1159 (sh, m), 831 cm^{-1} (w); ^1H NMR ($CDCl_3$) δ 4.56 (d, J = 4.0 Hz, 2 H), 5.30–5.42 (m. 3 H); ^{13}C NMR ($CDCl_3$) δ 57.35 (t), 59.25 (t), 70.93 (d). Anal. Calcd for $C_3H_5N_3O_3$: C, 27.49; H, 3.84. Found: C, 27.25; H, 4.00.

1,3-Dinitroazetidine (10). A mixture of trifluoroacetic anhydride (500 mg, 2.4 mmol) and 100% HNO_3 (500 mg, 7.9 mmol, freshly prepared[7] via distillation from a 1:1 mixture of concentrated H_2SO_4 and fuming HNO_3) was cooled to 0 °C via application of an external ice–water bath. To this cooled solution was added **9** (50 mg, 0.38 mmol) in one portion with stirring. The resulting mixture was stirred at 0 °C for 30 min. The reaction mixture then was poured over crushed ice (20 g), and the resulting aqueous suspension was extracted with EtOAc (3 × 15 mL). The combined extracts were washed sequentially with water (30 mL), 10% aqueous $NaHCO_3$ (25 mL), and brine (25 mL). The organic layer was dried (Na_2SO_4) and filtered, and the filtrate was concentrated *in vacuo*. The residue, a pale yellow oil, was purified via column chromatography on silica gel by elution with 10% EtOAc–hexane. Pure **10** (40 mg, 72%) was

(8) Dave, P.; Byun, H.-S.; Engel, R. *Synth. Commun.* **1986**, *16*, 1343. This paper reports the use of NaI–DMSO–$NaHCO_3$ to oxidize primary alkyl halides to aldehydes. In our hands, application of this regimen to **17** resulted simply in hydrolysis to afford the corresponding primary alcohol (**18**) without concomitant oxidation.

(9) For a review of the Henry reaction, see: Baer, H. H.; Urbas, L. In *The Chemistry of the Nitro and Nitroso Groups*; Feuer, H., Ed.; Wiley-Interscience: New York, 1970; Part 2, pp 76–117.

thereby obtained as a colorless microcrystalline solid: mp 62–63 °C; IR (KBr) 1631 (sh, m), 1558 (vs), 1372 (s), 1323 (s), 1264 (s), 1216 (m), 1157 (m), 991 (w), 854 cm^{-1} (w) cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.70 (m, 4 H), 5.08–5.24 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 60.56 (t), 68.70 (d). Anal. Calcd for $C_3H_5N_3O_4$: C, 24.50; H, 3.43. Found: C, 24.43; H, 3.25. The structure of **10** was established unequivocally via single crystal X-ray structural analysis (*vide infra*).

Oxidative Nitration of 10.[10] To a stirred solution of NaOH (16 mg, 0.34 mmol) in 40% aqueous MeOH (4.5 mL) was added **10** (50 mg, 0.32 mmol), and the resulting solution was stirred at ambient temperature for 30 min. This solution was added rapidly with stirring to a mixture of $K_3Fe(CN)_6$ (520 mg, 0.32 mmol), $NaNO_2$ (220 mg, 3.2 mmol), water (5 mL), and Et_2O (25 mL). Stirring was continued for 30 min after the addition of these reagents had been completed. The layers then were separated, and the aqueous layer was extracted with CH_2Cl_2 (3 × 10 mL). The combined extracts were washed sequentially with water (25 mL) and brine (25 mL). The organic layer was dried (Na_2SO_4) and filtered, and the filtrate was concentrated *in vacuo*. The residue thereby obtained was placed onto a small pad of silica gel and eluted with 25% EtOAc–hexane, thereby affording **1** (25 mg, 40%) as a colorless waxy solid: mp 97–100 °C (lit.[1] mp 103–104 °C); ^1H NMR ($CDCl_3$) δ 5.20 (s, 4 H).

Tris(bromomethyl)aminomethane Hydrobromide (12). A solution of tris(hydroxymethyl)aminomethane (**11**, 60.5 g, 0.5 mol) in $CHCl_3$ (500 mL) was cooled to 5 °C by application of an external ice–water bath. To this cooled solution was added portionwise with stirring glacial HOAc (120 g, 2.0 mmol). After the addition of HOAc had been completed, the external cold bath was removed, and the stirred reaction mixture was allowed to warm gradually to room temperature during 2.5 h. Diethyl ether (300 mL) was added, and the resuting mixture was filtered. The residue was washed with Et_2O (3 × 100 mL) and then dried *in vacuo*. The product, $(HOCH_2)_3C-NH_3^+ \ ^-OAc$ (90.5 g, 100%), was thereby obtained as a colorless microcrystalline solid: mp 117–118 °C. This material was used as obtained in the next synthetic step.

A suspension of this salt (40 g, 0.22 mol) in 30% HBr–HOAc (175 mL, excess) was cooled to 10 °C by application of an external ice–water bath. Dry HBr gas was passed into this cooled suspension until the reaction mixture had become saturated with HBr. The resulting thick, syrupy suspension was divided into two equal portions, and each portion (*ca.* 90 mL) was placed in a sealed tube (capacity 180 mL) and heated at 160 °C for 12 h. The reaction vessels were cooled to room temperature and then opened. The contents of the two reaction vessels were poured into EtOAc (300 mL). The resulting suspension was filtered, and the residue was washed sequentially with EtOAc (100 mL) and Et_2O (2 × 100 mL) and then dried *in vacuo*. Compound **12** (62.3 g, 72%) was thereby obtained as a colorless microcrystalline solid: mp 256–257 °C; IR (KBr) 3226–2477 (br, s), 1567 (m), 1508 (m), 1420 (m), 1274 cm^{-1} (m); ^1H NMR (DMSO-d_6) δ 3.85 (s, 6 H), 4.62 (br s, 3 H); ^{13}C NMR (DMSO-d_6) δ 33.43 (t), 57.53 (s). Anal. Calcd for $C_4H_9NBr_4$: C, 12.30; H, 2.32. Found: C, 12.24; H, 2.34.

Generation and Trapping of 3-(Bromomethyl)-1-azabicyclo[1.1.0]butane (13).[6b] A solution of NaOH (80.0 g, 2.0 mol) in water (400 mL) was placed in a 1000 mL three-neck round-bottom flask. The reaction vessel was fitted with a pressure-equalized dropping funnel and a distillation condenser, and the reaction vessel was connected to a water aspirator. A solution of **12** (39.0 g, 0.10 mol) in 1% aqueous $NaHCO_3$ (100 mL) was placed in the dropping funnel, and the reaction vessel was evacuated to *ca.* 60 mmHg. The reaction vessel then was heated to 80 °C. The contents of the dropping funnel were added dropwise to the reaction mixture during 45 min. During this time, the product which distilled from the reaction mixture was collected in a receiving flask that was cooled externally to −78 °C. After the addition of **12** had been completed, the distillation was continued for an additional 2 h. The flask which contained the distillate (250 mL) was removed from the cold bath and allowed to warm gradually to room temperature. Solid $NaNO_2$ (69.0 g, 1.0 mol) was added to the distillate, and the resulting aqueous mixture was cooled in an external ice–water bath. To this cooled mixture was added dropwise with stirring 50% aqueous HCl. After the addition of aqueous HCl had been completed, the resulting mixture was stirred for an additional 30 min. The reaction mixture then was poured over crushed ice (250 g), and the resulting slurry was extracted with EtOAc (3 × 50 mL). The combined organic extracts were washed sequentially with water (100 mL) and brine (100 mL), dried (Na_2SO_4), and filtered, and the filtrate was concentrated *in vacuo*. The residue thereby obtained, a yellow-green oil, was purified via column chromatography on silica gel by elution with 20% EtOAc–hexane. Workup of the inital chromatography fractions afforded *N*-nitroso-3-(bromomethyl)-3-nitroazetidine (**14**, 2.26 g, 10% yield based on **12**): mp 74–75 °C; IR (KBr) 3013 (w), 1549 (m), 1396 (s), 1333 (vs), 1285 (vs), 1243 (s), 1169 (m), 857 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 4.05 (s, 2 H), 4.37 (dd, J = 13.5, 2.1 Hz, 1 H), 4.63 (dd, J = 13.5, 2.1 Hz, 1 H), 5.12 (dd, J = 11.9, 2.0 Hz, 1 H), 5.45 (dd, J = 11.9, 2.0 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 31.11 (t), 60.61 (t), 62.42 (t), 81.94 (s). Anal. Calcd for $C_4H_6N_3O_3Br$: C, 21.45; H, 2.70. Found: C, 21.55; H, 3.00.

Continued elution of the chromatography column with 30% EtOAc–hexane afforded *N*-nitroso-3-(bromomethyl)-3-hydroxyazetidine (**15**, 630 mg, 3% yield based on **12**) as a pale yellow oil: IR (neat) 3336 (s), 2948 (w), 1639 (w), 1395 (m, sh), 1338 (s), 1282 (m, sh), 1238 (m), 1169 (m), 1056 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 3.00 (bs, 1 H), 3.71 (s, 2 H), 4.05–4.25 (m, 2 H), 4.77–4.92 (m, 2 H); ^{13}C NMR ($CDCl_3$) δ 39.47 (t), 62.93 (t), 65.34 (t), 70.09 (s). Compound **15** was further characterized via the corresponding *N*-nitro-*O*-nitrato derivative (i.e., **16**; *vide infra*).

1-Nitro-3-(bromomethyl)-3-nitratoazetidine (16). A mixture of 100% HNO_3 (freshly distilled from a 1:1 mixture of H_2SO_4 and fuming HNO_3,[7] 1.00 g, 15.8 mmol) and $(CF_3CO)_2O$ (TFAA, 1.0 g, 4.8 mmol) was cooled to 0 °C via external application of an ice bath. To the cooled reaction mixture was added with stirring **15** (80 mg, 0.41 mmol). After the addition had been completed, the reaction mixture was stirred for an additional 30 min. The reaction mixture then was poured over crushed ice (50 g), and the resulting slurry was extracted with EtOAc (3 × 10 mL). The combined organic layers were washed sequentially with water (25 mL) and brine (25 mL), dried (Na_2SO_4) and filtered, and the filtrate was concentrated in vacuo. The residue, a pale yellow oil, was purified by column chromatography on silica gel by elution with 40% EtOAc–hexane. Pure **16** (87 mg, 83%) was thereby obtained as a colorless microcrystalline solid: mp 91–92 °C; IR (KBr) 3039 (w), 2965 (w), 1650 (vs) 1507 (s), 1343 (s), 1296 (s), 1285 (s), 1217(s), 1021 (w), 831 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 3.91 (s, 3 H), 4.57 (*AB*, J_{AB} = 12.0 Hz, 2 H), 4.64 (*AB*, J_{AB} = 12.0 Hz, 2 H); ^{13}C NMR (C_6D_6) δ 31.01 (t), 62.89 (t), 75.31 (s). Anal. Calcd for $C_4H_6N_3O_5Br$: C, 18.77; H, 2.36. Found: C, 19.00; H, 2.41. The structure of **16** was established unequivocally via X-ray crystallographic methods.

1,3-Dinitro-3-(bromomethyl)azetidine (17). ***WARNING:*** *Solutions of 100% HNO_3 and TFAA, which contain* in situ *generated trifluoroacetyl nitrate, are extremely hazardous and potentially explosive. Such solutions should be handled with extreme caution, and appropriate safeguards (e.g., explosion shield, protective clothing and protective eyewear) should be employed by persons who work with this material.* A solution of TFAA (1.05 g, 5.0 mmol) was cooled externally to 0 °C. To the cooled TFAA was added with stirring 100% HNO_3 (freshly distilled from a 1:1 mixture of H_2SO_4 and fuming HNO_3,[7] 315 mg, 5.0 mmol), and the resulting mixture was stirred for 5 min at 0 °C. Compound **14** (100 mg, 0.44 mmol) then was added in one portion. The reaction mixture was stirred for 30 min and then was poured over crushed ice (50 g). The resulting aqueous suspension was extracted with EtOAc (3 × 10 mL). The combined organic layers were washed sequentially with water (50 mL) and brine (50 mL), dried (Na_2SO_4), and filtered, and the filtrate was concentrated *in vacuo*. The residue, a yellow oil, was purified via column chromatography on silica gel by eluting with 20% EtOAc–hexane. Pure **17** (85 mg, 81%) was thereby obtained as a colorless microcrystalline solid: mp 96–97 °C; IR (KBr) 3034 (w), 2971 (w), 1650 (sh, m), 1544 (s), 1428 (s), 1343 (vs), 1280 (s), 1227 (s), 1132 (m), 857 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 4.01 (s, 2 H), 4.58 (dd, J = 11.2, 1.1 Hz, 2 H), 4.93 (d, J = 12.0 Hz, 2 H); ^{13}C NMR ($CDCl_3$) δ 30.99 (t), 63.57 (t), 79.26 (s). Anal. Calcd for $C_4H_6N_3O_4Br$: C, 20.02; H, 2.52. Found: C, 20.10; H, 2.25. The structure of **17** was established unequivocally via X-ray crystallographic methods.

(10) Kornblum, N.; Singh, H. K.; Kelly, W. J. *J. Org. Chem.* **1983**, *48*, 332.

1,3-Dinitro-3-(hydroxymethyl)azetidine (18).[8] A mixture of **17** (100 mg, 0.41 mmol), NaI (122 mg, 0.82 mmol), and $NaHCO_3$ (68 mg, 0.82 mmol) in DMSO (2 mL) was heated in an external oil bath at 110 °C. The reaction was monitored by thin layer chromatographic (TLC) analysis. After all of the starting material had reacted (*ca.* 0.5 h), the oil bath was removed and the reaction was allowed to cool gradually to room temperature. Water (25 mL) was added, and the resulting aqueous suspension was extracted with EtOAc (3 × 10 mL). The combined organic layers were washed sequentially with water (25 mL) and brine (25 mL), dried (Na_2SO_4), and filtered, and the filtrate was concentrated *in vacuo*. The residue, a dark yellow oil, was purified by column chromatography on silica gel by eluting with 30% EtOAc–hexane. Pure **18** (58 mg, 78%) was thereby obtained as a colorless oil; IR (neat) 3480 (m), 2966 (vw), 2895 (vw), 1542 (vs), 1445 (m), 1344 (s), 1282 (m), 1063 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 4.13 (s, 2 H), 4.63 (*AB*, J_{AB} = 12.0 Hz, 2 H), 4.81 (*AB*, J_{AB} = 12.0 Hz, 2 H), 4.86 (br s, 1 H, disappears upon addition of D_2O); ^{13}C NMR ($CDCl_3$) δ 61.90 (t), 63.41 (t), 80.21 (s). Anal. Calcd for $C_4H_7N_3O_5$: C, 27.13; H, 3.98. Found: C, 27.30; H, 4.16.

1,3,3-Trinitroazetidine (1).[1] To a suspension of **18** (100 mg, 0.56 mmol) in water (1 mL) was added crushed NaOH pellets (27 mg, 0.67 mmol), and the resulting mixture was stirred for 10 min. The reaction mixture then was cooled to 10 °C via application of an external ice–water bath. To the cooled reaction mixture were added sequentially (i) a chilled (10 °C) solution of $NaNO_2$ (380 mg, 5.6 mmol) in water (1mL), (ii) a chilled (10 °C) solution of $K_3Fe(CN)_6$ (184 mg, 0.56 mmol) in water (1 mL), and (iii) solid $K_2S_2O_8$ (210 mg, 0.78 mmol). The external cold bath was removed, and the reaction mixture was stirred at room temperature for 48 h. Water (25 mL) was added, and the resulting aqueous suspension was extracted with EtOAc (3 × 10 mL). The combined organic layers were washed sequentially with water (25 mL) and brine (25 mL), dried (Na_2SO_4) and filtered, and the filtrate was concentrated *in vacuo*. The residue thereby obtained, a yellow oil, was purified via column chromatography on silica gel by eluting with 15% EtOAc–hexane. Pure **1** (40 mg, 37%) was thereby obtained as a colorless microcrystalline solid: mp 98–99 °C (lit.[1] mp 103–104 °C); ^1H NMR ($CDCl_3$) δ 5.20 (s, 4 H). Further elution of the chromatography column with 25% EtOAc–hexane allowed for recovery of unreacted starting material (i.e., **18**, 20 mg, 20%).

X-ray Structures of 10, 16, and 17.[11a] Data were collected on an Enraf-Nonius CAD-4 diffractometer by using the $\omega - 2\theta$ scan technique, Mo Kα radiation (λ = 0.710 73 Å) and a graphite monochromator. Standard procedures in our laboratory that have been described previously were used for this purpose.[11b] Pertinent details are presented in Table 1. Data for **10** were corrected for Lorentz and polarization effects but not for absorption. Data for **16** and **17** were corrected for Lorentz and polarization effects and also for absorption (DIFABS).[12] The structure of **10** was solved by direct methods (SIR[13]), and the model was refined by using full-matrix least-squares techniques. The structures of **16** and **17** were solved by using Patterson techniques, and the models were refined by using full-matrix least-squares techniques. The treatment of thermal parameters was based upon the number of observed data. All non-hydrogen atoms in **10** were treated with anisotropic thermal parameters. Anisotropic parameters were incorporated for the Br and nitro group oxygen atoms in **16** and all non-hydrogen atoms in **17**. For all three structures, hydrogen atoms were located on difference maps and then included in the model in idealized positions [U(H) = $1.3B_{eq}(C)$]. All computations other than those specified were performed by using MolEN.[14] Scattering factors were taken from the usual sources.[15] The various bond lengths in the X-ray crystal structures of all three compounds are consistent with those which have been reported previously for similar systems.[16]

Table 1. X-ray Structure Data for 10, 16, and 17

compd	10	16	17
formula	$C_3H_5N_3O_4$	$C_4H_6BrN_3O_5$	$C_4H_6BrN_3O_4$
size (mm)	0.11 × 0.13 × 0.44	0.22 × 0.42 × 0.44	0.40 × 0.51 × 0.61
space group	*Pnma*	$P2_1/n$	$P2_1$
a (Å)	9.2950 (8)	6.892 (1)	7.3333 (6)
b (Å)	6.8145 (5)	9.645 (2)	5.9374 (4)
c (Å)	9.5088 7)	13.130 (2)	9.3702 (5)
α (°)	90	90	90
β (°)	90	100.62 (1)	101.423 (6)
γ (°)	90	90	90
V ($Å^3$)	602.29 (8)	857.9 (8)	399.93 (5)
Z	4	4	2
D_c (g-cm^{-3})	1.622	1.982	1.994
μ (cm^{-1})	1.41	47.39	50.71
$(2\theta_{max})$	50	44	60
total reflns	2101	1230	1757
unique reflns	649	1134	1275
R_{int}	0.024	0.041	0.035
$I \geq 3\sigma(I)$	406	521	1096
params	55	78	108
R, wR	0.0431, 0.052	0.0485, 0.0507	0.0395, 0.0453
$(\Delta/\sigma)_{max}$	<0.01	<0.01	<0.01
ϱ_{min}; ϱ_{max}	0.25; −0.21	0.43; −0.32	0.58; −0.40

Acknowledgment. We thank the Department of the Air Force (Contract F29601-92-K-0018, to A.P.M.), the Office of Naval Research (Contract N00014-92-J-1999, to A.P.M.), the Robert A. Welch Foundation [Grants B-963 (A.P.M.) and B-1202 (S.G.B.)], and the University of North Texas Faculty Research Committee (S.G.B.) for financial support of this study.

JO9504732

(11) (a) The author has deposited atomic coordinates for these structures with the Cambridge Crystallographic Data Centre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK. (b) Mason, M. R.; Smith, J. M.; Bott, S. G.; Barron, A. R. *J. Am. Chem. Soc.* **1993**, *115*, 4971.

(12) Walker, N.; Stuart, D. *Acta Crystallogr., Sect. A* **1983**, *39*, 159.

(13) Burla, M. C.; Carnalli, M.; Cascarano, G.; Giacovazzo, C.; Polidori, G.; Spagna, R.; Viterbo, D. *J. Appl. Crystallogr.* **1989**, *22*, 389.

(14) *MolEN, An Interactive Structure Solution Program*; Enraf-Nonius: Delft, The Netherlands, 1990.

(15) Cromer, D. T.; Waber, J. T. *International Tables for X-ray Crystallography*; Kynoch Press: Birmingham, 1974; Vol. IV, Table 2.

(16) Allen, F. H.; Kennard, O.; Watson, D. G.; Brammer, L.; Orpen, A. G.; Taylor, R. *J. Chem. Soc., Perkin Trans. 2* **1987**, S1.