Synthesis of 1,3,3-Trinitroazetidine via the Oxidative Nitrolysis of *N*-*p*-Tosyl-3-azetidinone Oxime

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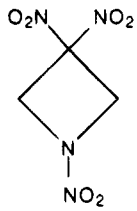
The *tert*-butyldimethylsilyl ether of 1,3-dibromo-2-propanol reacted with *p*-toluenesulfonamide in the presence of K_2CO_3 to give the corresponding *N*-*p*-tosyl-3-azetidinol. The same azetidinol was obtained when the similarly silyl-protected 3-(*p*-toluenesulfonamido)propan-2-ol 1-(*p*-toluenesulfonate) was treated with LiH. Desilylation and oxidation of the *N*-*p*-tosyl-3-azetidinol followed by oxidation readily afforded *N*-*p*-tosyl-3-azetidinone oxime. Oxidative nitrolysis of the latter intermediate delivered 1,3,3-trinitroazetidine through a new sequence of reactions.

Introduction

Strained polynitro cyclic compounds are at the forefront of the search for more powerful and less sensitive energetic materials.[1] Examples in this regard are polynitrobicyclooctanes,[2] polynitrocubanes,[3] polynitropolycyclododecane,[4] and various polynitromono- and polycyclicpolyazanitramines.[1b,5,6] Such materials are potentially useful as explosives, propellants, fuels, and binders in applications requiring substances which combine high-energy, high-density, and reduced sensitivity properties. An important new member of this class of energetic materials is 1,3,3-trinitroazetidine (**1**). Among



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its favorable properties are a low melting point (mp 101 °C), moderate density (1.84 g cm^{-3}), good thermal stability (>240 °C), and low sensitivity.[7] Infrared[8] and thermolysis[9] studies have been reported for this material as well as the experimental[10] and theoretical[11] examination of the energetics of its initial dissociation processes.

The principal source of 1,3,3-trinitroazetidine (**1**) remains the original preparative method starting from *tert*-butylamine and epichlorohydrin, despite the poor overall yield[12] and the intense effort aimed at developing an alternate synthesis.[13] The present report describes the results of the full investigation and experimental details of an alternate route to 1,3,3-trinitroazetidine (**1**) that we recently presented in communication form.[14] In our synthesis, key roles are played by protection of a secondary hydroxyl group to effect azetidine ring closure and oxidative nitrolysis for the simultaneous introduction of the NNO_2 and $C(NO_2)_2$ groups.

Results and Discussion

The strategy adopted in our approach to develop an alternate synthesis of 1,3,3-trinitroazetidine (**1**) centered on the introduction of the geminal dinitro function by the oxidative nitrolysis of an oxime moiety according to the generalized sequence outlined in Scheme 1. This methodology had been successfully employed for similar transformations in related systems.[15] An attractive feature of this route is that the HNO_3 oxidation leading to the formation of the $C(NO_2)_2$ group is combined, in one step, with the nitrolysis of the N-substiuent to produce the NNO_2 function.[16] An added benefit of this approach is that all energetic nitro groups would be introduced only

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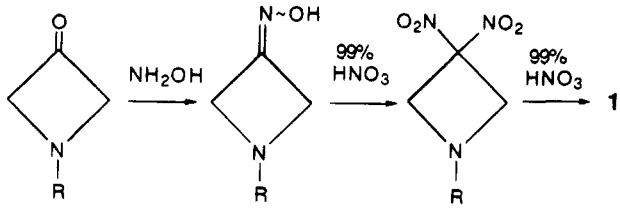
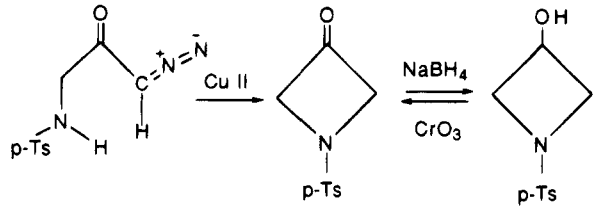
Scheme 1



Scheme 2



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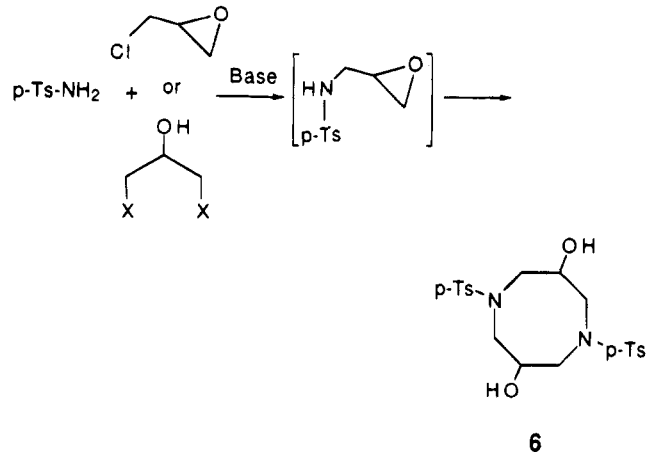
in the final step of the synthesis which is desirable from a safety viewpoint.

Clearly, 3-azetidinones are crucial to this method. A review of the literature, however, indicates that these compounds are relatively inaccessible. Moreover, of the 3-azetidinones that have been described, those that appear to exhibit the greatest stability have electron-withdrawing substituents, not alkyl groups, on the ring nitrogen.[17,18] Nonetheless, since 1-alkyl-3-azetidinols are easily prepared by the procedures of Gaertner[19] and Anderson and Lok,[20] we undertook the investigation of several oxidative procedures for converting 1-alkyl-3-azetidinols to the corresponding 3-azetidinones.[21,22] Both the Jones and Swern oxidation methods when applied to either 1-*tert*-butyl or 1-*tert*-octyl-3-azetidinol, in our hands, even at low temperatures, led to unstable ketone products.[22] NMR and MS analysis of these products indicated them to be dimeric and trimeric mixtures arising from the self-condensation of the initially formed 3-azetidinones.[22] Under similar oxidation conditions, 1-benzhydryl-3-azetidinol gave the corresponding 3-azetidinone as a stable crystalline solid which could readily be hydrogenolyzed to an unstable salt of 3-azetidinone[17,18] or converted to its oxime.[22] However, the inconvenience and economics of using benzhydrylamine in an eventual scale-up were deemed unfavorable, and this approach was abandoned.

On the other hand, *N*-*p*-tosyl-3-azetidinone (**2**), prepared by the Cu(II)-promoted decomposition of diazo ketone **3** (Scheme 2), has been shown to be an extremely stable material.[23] A series of preliminary experiments demonstrating that **2** was readily converted to its oxime **4**, which in turn could be nitrolyzed to 1,3,3-trinitroazetidine (**1**), prompted us to explore synthetic routes to *N*-*p*-tosyl-3-azetidinol (**5**). It was initially established that **5** was an inherently stable compound as it could be

Scheme 3



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easily prepared by $NaBH_4$ reduction of **2**. Transformation of *N*-*p*-tosyl-3-azetidinol (**5**) back to ketone **2** was effected without difficulty by oxidation with CrO_3/HOAc. Thus, we were encouraged to seek simpler methods of preparing **5** that were amenable to large-scale work.

The base-induced intramolecular cyclization of bulky *N*-alkylamino oxiranes[19] is an important synthetic route to the azetidine ring system. This methodology works well for the preparation of *N*-*p*-tosylazetidine-2-methanols and *N*-*p*-tosylpyrrolidin-3-ols depending on the substitution of the parent oxirane.[24] However, in the case of *N*-(2,3-epoxypropyl)-*p*-toluenesulfonamide cyclodimerization products are obtained instead of the anticipated *N*-*p*-tosyl-3-azetidinols.[25] For example, as outlined in Scheme 3, the base-mediated reaction of *p*-toluenesulfonamide with either epichlorohydrin or 1,3-dihalo-2-propanols also affords a mixture of the cyclodimerization products, *cis*- and *trans*-1,5-bis(*p*-toluenesulfonyl)-3,7-dihydroxyoctahydro-1,5-diazocines (**6**) and none of the desired *N*-*p*-tosyl-3-azetidinol (**5**). 1,3-Disubstituted propanes do, however, react with the *p*-toluenesulfonamide anion to give azetidines.[26,27]

Therefore, the failure of 1,3-dihalo-2-propanols to form azetidines implies an intermediate oxirane and cannot be attributed wholly to steric factors. In contrast, the neopentyl-like system with *gem*-dimethyl substitution at C-2, surprisingly, cyclizes smoothly to the azetidine.[28,29]

The importance of achieving optimum azetidine formation and avoiding cyclodimerization prompted us to investigate the reaction of sulfonamides with a number of base-stable ether derivatives of 1,3-disubstituted-2-propanols.[30] Two parallel routes, shown in Scheme 4, were used to obtain the necessary 2-propanol derivatives

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Scheme 4

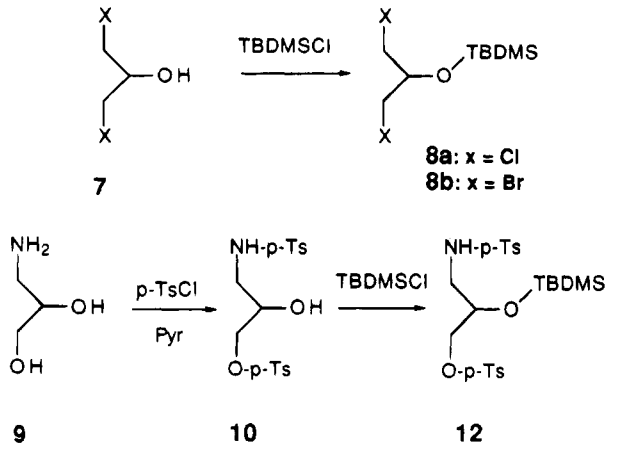
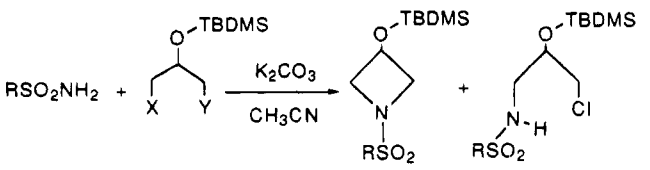


Table 1. Comparison of Yields and Reaction Times of *tert*-Butyldimethylsilyl Ethers of 1,3-Dihalo-2-propanols with Sulfonamides To Form Azetidines



R	X	Y	Reflux time, h	Yield, %	
H_3C-C$_6$H$_4$-	Br	Br	27	68	....
H_3C-C$_6$H$_4$-	Cl	Cl	90	50	50[a]
CH_3 —	Br	Br	27	66	....

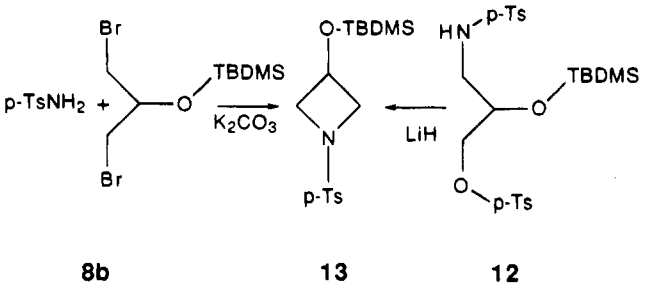
[a] Estimated from analysis of NMR spectrum.

which would serve as precursors to construct the azetidine ring system. In one case the reaction of *tert*-butyldimethylsilyl ether derivatives of 1,3-dihalo-2-propanols with methanesulfonamide and *p*-toluenesulfonamide in acetonitrile in the presence of potassium carbonate was studied under a variety of experimental conditions. These results are summarized in Table 1. The data confirm that when epoxide formation is prevented, the *tert*-butyldimethylsilyl ethers of either 1,3-dichloro-2-propanol (**8a**) or 1,3-dibromo-2-propanol (**8b**) cyclize to the azetidine, albeit under prolonged heating. The structures of the products were established by analysis of their ^{1}H and ^{13}C NMR spectra and analysis of their mass spectra.

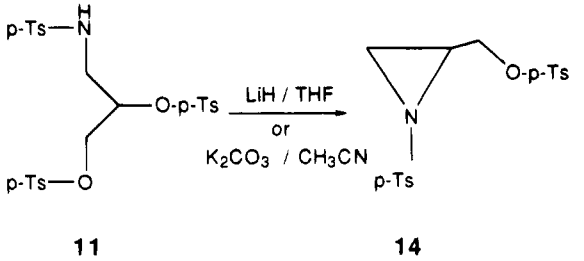
For example, ring closure of **8b** gave azetidine **13** in 68% yield after heating for 27 h. Under the same conditions **8a** fails to cyclize to **13.** On prolonged heating, **8a** can eventually be cyclized to **13**, but at a rate judged too slow to be synthetically useful. The addition of tetrabutylammonium iodide as a phase-transfer catalyst had no significant rate enhancing effect on these cyclization reactions. Azetidine ring closure in the reaction of amines with either the tetrahydropyranyl or trimethylsilyl ethers of 1,3-dichloro-2-propanol is also reported to require extensive reaction times.[31]

In the second approach, to investigate the possibility of shortening the reaction time, 3-amino-1,2-propanediol

Scheme 5



Scheme 6



(**9**) was converted to the ditosyl derivative **10** by reaction with *p*-toluenesulfonyl chloride in pyridine. This was accompanied by the formation of the tritosylated 3-amino-1,2-propanediol **11**. Compounds **10** and **11** were obtained in 66% and 26% yields, respectively, after separation by silica gel chromatography. Compound **10** was then converted in 88% yield to its *tert*-butyldimethylsilyl ether **12.** Cyclization of **12** using lithium hydride as the base gave **13** in 91% yield. These synthetically practical ring closures are shown in Scheme 5.

Also, consistent with earlier observations, where an intermediate epoxide may intervene, the treatment of **10** with LiH/THF failed to give the desired azetidinol, and only the cyclodimerization products, *cis*- and *trans*-1,5-bis(*p*-toluenesulfonyl)-3,7-dihydroxyoctahydro-1,5-diazocines (**6**) were obtained (Scheme 3). It should, however, be pointed out that Gaertner[32] observed varying amounts of azetidines and eight-membered ring products in the reaction of alkylamines with epoxides.

It is also interesting to note that the reaction of tritosylate **11** with either LiH or K_2CO_3 affords exclusively, and not unexpectedly,[33] the aziridine **14** shown in Scheme 6.

The synthesis of 1,3,3-trinitroazetidine **1** was ultimately achieved by the sequence of steps outlined in Scheme 7. Deprotection of **13** afforded the *N*-*p*-tosyl-3-azetidinol (**5**) in near-quantitative yield. Transformation of *N*-tosyl-3-azetidinol (**5**) to ketone **2** was effected in 74% yield by oxidation with CrO_3/HOAc, and the latter ketone on treatment with hydroxylamine afforded the *N*-*p*-tosyl-3-azetidinone oxime (**4**) in nearly quantitative yield.[34] In the final step this oxime was treated with 99% HNO_3 in refluxing methylene chloride to simultaneously nitrolyze the *p*-tosyl group[35] and oxidize the oxime function to

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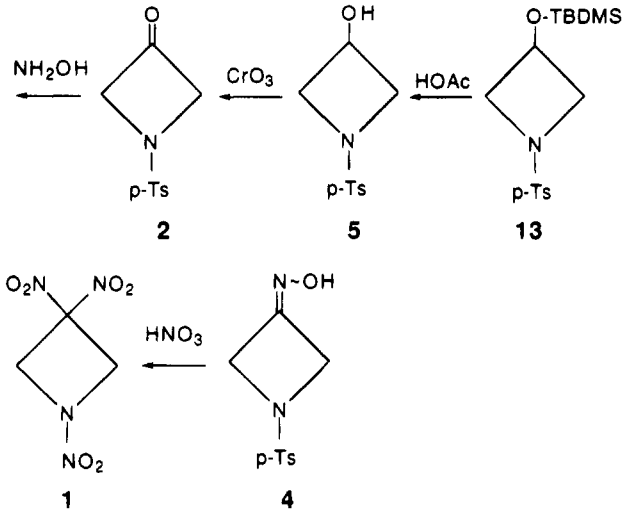
Scheme 7



produce in 30–50% yields the desired 1,3,3-trinitroazetidine (**1**).

In conclusion, a new synthesis of 1,3,3-trinitroazetidine **1** has been developed which uses *p*-toluenesulfonamide and 2-propanol derivatives as starting materials. In this synthetic route key steps involve the protection of a secondary hydroxyl group to effect azetidine ring closure and oxidative nitrolysis methods employed for the simultaneous introduction of the NNO_2 and $C(NO_2)_2$ groups. Significantly, all the energetic nitro groups are introduced in the final step of the sequence which is an important safety consideration.

Experimental Section

CAUTION. Reactions with 99% HNO_3 should be carried out behind a protective barrier as should the handling of nitroazetidines which are potentially heat and shock sensitive.

General. ^1H and ^{13}C NMR spectra were recorded on a Bruker 300 MHz spectrometer; the chemical shifts in $CDCl_3$, DMSO-d_6, and acetone-d_6 are reported in δ (ppm) relative to tetramethylsilane as internal standard. Low-resolution EI and CI (NH_3) mass spectra were recorded on a Finnigan-MAT Model SSQ 70 mass spectrometer. Samples were introduced via a direct inlet probe heated from 20–250 °C. Ionization was achieved at an energy of 70 eV. High-resolution mass spectra were measured on a JEOL HX110A mass spectrometer by FAB ionization mode using peak matching. Melting points are uncorrected.

Materials. All solvents were obtained from commercial sources and used without further purification unless otherwise noted. Tetrahydrofuran (THF) was distilled from Na/benzophenone prior to use.

3-(*p*-Toluenesulfonamido)-1,2-propane Bis(*p*-toluenesulfonate) (11) and 3-(*p*-Toluenesulfonamido)propan-2-ol 1-(*p*-Toluenesulfonate) (10). To a stirred solution of 3-amino-1,2-propanediol (**9**) (1.34 g, 14.68 mmol) in dry pyridine (20 mL) maintained at ice temperature was added a solution of *p*-toluenesulfonyl chloride (5.60 g, 29.4 mmol) in pyridine (10 mL) over a 2-h period. The resulting yellow suspension was refrigerated overnight, acidified with ice-cold 6 N HCl, and then extracted with methylene chloride (3 × 20 mL). The combined extracts were washed with 5% aqueous $NaHCO_3$ (2 × 10 mL), dried over $MgSO_4$, and concentrated in vacuo to give a syrupy residue. Silica gel chromatography (chloroform–methanol, 95:5) of this residue afforded **11** (2.1 g, 26%) as a white solid, mp 108–110 °C, after recrystallization from absolute ethanol: ^1H NMR ($CDCl_3$) δ 2.43 (s, 3H), 2.46 (s, 3H), 2.47 (s, 3H), 3.15 (m, 2H), 4.09 (dd, J = 3.7, 4.7 Hz, 2H), 4.65 (quintet, 1H, CH), 4.86 (t, 1H, NH), 7.30–7.35 (m, 4H), 7.57–7.68 (m, 4H); ^{13}C NMR (CD_2Cl_2) δ 21.63, 21.82, 43.11, 67.80, 77.05, 127.32, 128.30, 130.24, 130.42, 132.27, 132.73, 144.53, 146.08, 146.23; HRMS (FAB) calcd for $C_{24}H_{28}O_8S_3N$ $(M + 1)^+$ 554.0977, found m/z 554.0980.

Compound **10** (3.88 g, 66%) was obtained from silica gel chromatography as a viscous oil which crystallized from ethyl acetate–hexane to give a colorless solid: mp 96.5–98 °C; ^1H NMR ($CDCl_3$) δ 2.41 (s, 3H), 2.43 (s, 3H), 2.93–3.01 (m, 4H), 3.94–4.03 (m, 1H), 4.00 (s,1H, OH), 7.31–7.39 (m, 4H), 7.70–7.79 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 21.52, 21.66, 44.81, 68.02, 70.78, 127.05, 127.96, 129.86, 130.05, 132.08, 136.15, 143.82, 145.37; HRMS (FAB) calcd for $C_{17}H_{22}O_6S_2N$ $(M + 1)^+$ 400.0889, found m/z 400.0901.

3-(*p*-Toluenesulfonamido)-2-(*tert*-butyldimethylsiloxy)propane-1-(*p*-Toluenesulfonate) (12). To a solution of *tert*-butyldimethylsilyl chloride (380 mg, 2.52 mmol) and imidazole (315 mg, 4.63 mmol) in DMF (5 mL) was added a solution of 3-(*p*-toluenesulfonamido)propan-2-ol 1-(*p*-toluenesulfonate) (**10**) (820 mg, 2.1 mmol) in 5 mL of DMF at 25 °C. The reaction mixture was stirred for 24 h at ambient temperature and then concentrated under reduced pressure. Methylene chloride (10 mL) was added, and the solution was washed with water (4 × 5 mL). The organic layer was dried over $MgSO_4$ and concentrated under vacuum to give **12** as a white oil (951 mg, 88%): ^1H NMR ($CDCl_3$) δ 0.01 (s, 6H), 0.77 (s, 9H), 2.39 (s, 3H), 2.42 (s, 3H), 2.84–2.99 (m, 4H), 3.82-3.96 (m, 1H), 4.71 (t, 1H, NH), 7.26–7.33 (m, 4H), 7.65–7.74 (m, 4H); ^{13}C NMR ($CDCl_3$) δ −4.91, 17.81, 21.45, 21.59, 25.53, 43.32, 68.63, 70.32, 126.99, 127.89, 129.76, 129.92, 132.39, 136.21, 143.66, 145.08; HRMS (FAB) calcd for $C_{23}H_{36}SiO_6S_2N$ $(M + 1)^+$ 514.1753, found m/z 514.1758.

1-(*p*-Toluenesulfonyl)-3-(*tert*-butyldimethylsiloxy)-azetidine (13). This compound was prepared by (A) the cyclization of **12** with LiH in THF or (B) treatment of 1,3-dibromo-2-(*tert*-butyldimethylsiloxy)propane (**8b**) with K_2CO_3 in acetonitrile.

Method A. To a suspension of LiH (13.4 mg, 1.7 mmol) in dry THF (50 mL) under a nitrogen atmosphere was added a solution of **12** (710 mg, 1.4 mmol) in THF (20 mL) all at once. The resulting mixture was heated under reflux for 12 h and cooled to room temperature, and ice cold water (1 mL) was added cautiously to destroy the excess LiH. The solvent was removed under reduced pressure and the residue partitioned between water (10 mL) and methylene chloride (10 mL). The organic phase was separated, dried ($MgSO_4$), and concentrated in vacuo to give (448 mg, 91%) of **13** as a white solid: mp 100–102 °C; ^1H NMR ($CDCl_3$) δ −0.083 (s, 6H), 0.737 (s, 9H), 3.46 (t, 2H), 3.91 (t, 2H), δ 4.37 (quintet, 1H), 7.34 (d, J = 8.1, 2H), 7.67 (d, J = 8.3 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ −5.14, 17.65, 21.52, 25.44, 60.40, 60.70, 128.37, 129.63, 131.53, 143.99; HRMS (FAB) calcd for $C_{16}H_{27}SiSO_3N$ $(M + 1)^+$ 342.1559, found m/z 342.1552.

Method B. To a solution of *p*-toluenesulfonamide (103.4 mg, 0.602 mmol) in 7 mL of acetonitrile containing suspended anhydrous potassium carbonate (183 mg, 1.32 mmol) was added a solution of 1,3-dibromo-2-(*tert*-butyldimethylsiloxy)-propane (**8b**) (200 mg, 0.602 mmol) in CH_3CN (2 mL) all at once. The resulting mixture was heated under reflux for 27 h. The mixture was cooled to room temperature, and the solvent was removed under reduced pressure. The residue was partitioned between water (10 mL) and methylene chloride (10 mL), and the organic phase was washed with 5% NaOH (5 mL) followed by water (5 mL), dried over $MgSO_4$, and concentrated in vacuum to give 139 mg (68%) of a white solid: mp 101–103 °C; ^1H NMR ($CDCl_3$) δ −0.083 (s, 6H), 0.737 (s, 9H), 3.46 (t, 2H), 3.91 (t, 2H), 4.37 (quintet, 1H), 7.34 (d, J = 8.1 Hz, 2H), 7.67 (d, J = 8.3 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ −5.14, 17.65, 21.52, 25.44, 60.40, 60.70, 128.37, 129.63, 131.53, 143.99; HRMS (FAB) calcd for $C_{16}H_{27}SiSO_3N$ $(M + 1)^+$ 342.1559, found m/z 342.1552.

1-(*p*-Toluenesulfonyl)azetidin-3-ol (5). This compound was prepared by two independent routes: (A) by the $NaBH_4$ reduction of **2** obtained from the cyclization of the corresponding diazo ketone[23] and (B) by deprotection of **13**.

Method A. $NaBH_4$ Reduction of 2. A solution of 1-(*p*-toluenesulfonyl)azetidin-3-one (**2**) (101 mg, 0.449 mmol) in MeOH (10 mL) was prepared by slight warming. To this

solution at room temperature was added all at once with swirling 40 mg of solid $NaBH_4$. Swirling was continued at room temperature for an additional 10 min during which time hydrogen evolution ceased. The reaction mixture was poured onto crushed ice (ca. 20 g), and the mixture was extracted with CH_2Cl_2 (2 × 15 mL). The CH_2Cl_2 solution was washed with H_2O (15mL), dried over Na_2SO_4, and concentrated on a rotary evaporator to give an oil (94 mg, 92%), which crystallized on standing: mp 106–107 °C; ^1H NMR ($CDCl_3$) δ 2.45 (s, 3H) 2.56 (s, 1 H), 3.55 (m, 2H), 3.95 (m, 2H), 4.44 (m, 1H); ^{13}C NMR ($CDCl_3$): δ 21.5, 60.1, 60.4, 128.3, 129.8, 131.6, 144.2; HRMS (FAB) calcd for $C_{10}H_{14}SO_3N$ (M + 1)$^+$ 228.0694, found *m/z* 228.0695.

Method B. Deprotection of 13. A mixture of 1-(*p*-toluenesulfonyl)-3-(*tert*-butyldimethylsiloxy)azetidine (**13**) (40 mg, 0.117 mmol) and acetic acid–water–THF 3:1:1 (1 mL) was stirred at ambient temperature for 36 h. The mixture was concentrated in vacuum, and THF (5 mL) was added to the resulting residue. Removal of the THF under vacuum gave **5** (26 mg, 98%) as a white solid: mp 104–105 °C; ^1H NMR ($CDCl_3$) δ 2.42 (s, 3H), 2.56 (br, s, 1H), 3.52 (t, 2H), δ 3.93 (t, 2H), 4.41 (m, 1H), δ 7.33 (d, J = 8.1 Hz, 2H), δ 7.67 (d, J = 8.1 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 21.50, 60.10, δ 60.40, 128.31, 129.73, 131.13, 144.28.

1-(*p*-Toluenesulfonyl)azetidin-3-one (2). This compound was prepared by either (A) the oxidation of **5** or by (B) the bis(hexafluoroacetylacetonato)copper(II)-catalyzed cyclization of the *N*-*p*-tosyldiazomethyl ketone **3** derived from glycine.[23]

Method A. Oxidation of 5. The method of Chaterjee and Shoeb[21] was used. A mixture of **5** (30 mg, 0.132 mmol), concentrated H_2SO_4 (50 mg), CrO_3 (15 mg), and HOAc (50 mg) in 0.5 mL of 15% aqueous acetone was maintained between −5 and 0 °C for 2 h. The cold solution was then treated with 2 mL of water containing 2 drops of concd NH_3, and the mixture was extracted with ether (2 × 3 mL). The ether was washed with water, dried over Na_2SO_4, and evaporated to give an oil (22 mg, 74%) which crystallized on standing: mp 149 °C; ^1H NMR ($CDCl_3$) δ 2.43 (s, 3H), 4.59 (s, 4H), 7.35 (d, J = 9 Hz, 2H), 7.76 (d, J = 9 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 21.5, 72.4, 128.4, 130.0, 131.8, 145.0, 192.4. This material was identical with **2** prepared from the α-diazo ketone.[23]

1-(*p*-Toluenesulfonyl)-2-[[(*p*-toluenesulfonyl)oxy]-methyl]aziridine (14). To a suspension of LiH (10.5 mg, 1.32 mmol) in dry THF (55 mL) under a nitrogen atmosphere was added a solution of **11** (610 mg, 1.1 mmol) in THF (15 mL), and the resulting mixture was heated under reflux for 12 h. The reaction mixture was cooled to room temperature, and ice–water (1 mL) was added cautiously to destroy any excess LiH. The solvent was removed under reduced pressure and the residue partitioned between water (10 mL) and methylene chloride (10 mL). The organic phase was separated, dried over $MgSO_4$, and concentrated in vacuum to give **14** as a colorless oil (335 mg, 80%): ^1H NMR ($CDCl_3$) δ 2.18 (d, J = 4.3 Hz, 2H), 2.46 (s, 6H), 2.68 (d, J = 7.0 Hz, 2H), 3.00 (m, 1H), 4.00 (dd, J = 5.1 Hz, 1H), 7.31–7.36 (d, J = 6.0 Hz, 4H), 7.70–7.85 (d, J = 8.3 Hz, 4H); ^{13}C NMR ($CDCl_3$) δ 21.35, 21.50, 30.63, 36.56, 68.33, 127.59, 127.72, 129.53, 129.53, 129.70, 132.15, 133.96, 144.76, 144.99; HRMS (FAB) calcd for $C_{17}H_{20}S_2O_5N$ (M + 1)$^+$ 382.0783, found *m/z* 382.0786.

Compound **14** was also prepared by the reaction of **11** with K_2CO_3 in acetonitrile. The oil, obtained in 95% yield, had spectral properties identical with the material from the LiH reaction.

***cis*- and *trans*-1,5-Bis(*p*-toluenesulfonyl)-3,7-dihydroxyoctahydro-1,5-diazocines (6).** To a suspension of LiH (19.2 mg, 2.40 mmol) in dry THF (40 mL) under a nitrogen atmosphere was added a solution of **10** (810 mg, 2.00 mmol) in THF (25 mL), and the resulting mixture was heated under reflux for 12 h. The yellow mixture was cooled to room temperature, and ice–water (2 mL) was added cautiously to destroy any excess LiH. The solvent was removed under reduced pressure and the residue partitioned between water (5 mL) and methylene chloride (5 mL). The organic phase was separated, dried ($MgSO_4$), and concentrated in vacuum to give **6** as an oil (203 mg, 45%): ^1H NMR ($CDCl_3$) δ 2.41 (s, 3H), 2.43 (s, 3H), 3.20–3.70 (m, 8H), 4.1–4.3 (m, 2H), 7.32 (m, 2H), 7.68 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 21.5, 53.9, 54.1, 69.6, 127.3, 130.0, 134.4, 144.2.

The product obtained from this reaction was identical with the stereoisomeric mixture of diazocines, mp 198–212 °C, obtained from the reaction of *p*-toluenesulfonamide with epichlorohydrin: LRMS (CI, NH_3) calcd for $C_{20}H_{26}S_2O_6N_2$ (M + 18)$^+$ 472, found *m/z* 472.

3-Oximido-1-(*p*-toluenesulfonyl)azetidine (4). 1-(*p*-Toluenesulfonyl)azetidin-3-one (**2**) was converted to the corresponding oxime using the method of Corey, Melvin, and Haslanger.[34] To a solution of **2** (30 mg, 0.133 mmol) and NaOAc trihydrate (72 mg, 0.53 mmol) in methanol was added portionwise with stirring solid NH_2OH·HCl (17.7 mg, 0.27 mmol), and the resulting mixture was heated under reflux for 2 h. The reaction mixture was filtered, and the cooled filtrate was concentrated under reduced pressure. The residue was partitioned between water and methylene chloride. The organic phase was washed with saturated sodium bicarbonate solution and brine, dried (Na_2SO_4), and filtered. The filtrate was concentrated in vacuo to give the oxime **4** (29 mg, 90%), mp 171–3 °C, after recrystallization from CH_2Cl_2/hexane: ^1H NMR ($CDCl_3$) δ 2.44 (s, 3H), 4.52 (m, 4H), 7.36 (d, J = 9 Hz, 2H), 7.73 (d, J = 9 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 21.6, 59.0, 59.2, 128.3, 130.0, 131.8, 144.7, 146.1; IR (KBr) 3295 (br, s), 1600 cm^{-1} (w); LRMS (EI) calcd for $C_{10}H_{12}O_3SN_2$ (M)$^+$ 240.0, found *m/z* 239.9.

1,3,3-Trinitroazetidine (1). To a refluxing solution of **4** (24 mg, 0.1 mmol) in methylene chloride (20 mL) was added a solution of 99% HNO_3 (2 mL), urea (20 mg), and ammonium nitrate (20 mg) in methylene chloride (20 mL). After the addition was complete the mixture was heated under reflux for an additional 30 min and then cooled to room temperature. The mixture was then poured over ice and the layers were separated. The organic phase was dried (Na_2SO_4), filtered, and concentrated under reduced pressure to yield 1,3,3-trinitroazetidine (8 mg, 40%) which was identified and characterized by comparison of its physical and spectroscopic properties with an authentic sample: ^1H NMR (CD_3COCD_3) δ 5.45(s); ^{13}C NMR (CD_3COCD_3) δ 64.7, 104.9.

1,3-Dichloro-2-(*tert*-butyldimethylsiloxy)propane (8a). To *tert*-butyldimethylsilyl chloride (5.00 g, 31 mmol) and imidazole (3.90g, 57 mmol) in dimethylformamide (10 mL) was added a solution of 1,3-dichloro-2-propanol (3.33 g, 26 mmol) in dimethylformamide (5 mL) at 25 °C. The reaction mixture was stirred at ambient temperature for 24 h and then concentrated under vacuum. Methylene chloride (20 mL) was added and the solution washed with water (4 × 10 mL). The organic layer was dried over $MgSO_4$ and concentrated under vacuum to give **8a** as a liquid (5.53 g, 88%): ^1H NMR ($CDCl_3$) δ 0.10 (s, 6H), 0.88 (s, 9H), 3.57 (dd, J = 1.9, 2.5 Hz, 4H), 3.97–4.04 (quintet, 1H); ^{13}C NMR ($CDCl_3$) δ −4.72, 18.05, 25.64, 45.85, 72.25; LRMS (CI, NH_3) calcd for $C_9H_{24}ONSiCl_2$ (M + 18)$^+$ 260, 262, 264, found *m/z* 260, 262, 264.

1,3-Dibromo-2-(*tert*-butyldimethylsiloxy)propane (8b). This compound was prepared by the procedure described for the dichloro isomer **8a**: ^1H NMR ($CDCl_3$) δ 0.98 (s, 6H), 0.88 (s, 9H), 3.45 (dd, J = 2.0, 2.5 Hz, 4H), 3.96 (quintet, 1H); ^{13}C NMR ($CDCl_3$) δ −4.71, 17.97, 25.60, 35.39, 71.12; LRMS (CI, NH_3) calcd for $C_9H_{24}ONSiBr_2$ (M + 18)$^+$ 348, 350, 352, found *m/z* 348, 350, 352.

Reaction of 1,3-Dichloro-2-(*tert*-butyldimethylsiloxy)-propane (8a) with *p*-Toluenesulfonamide. To a solution of *p*-toluenesulfonamide (105.4 mg, 0.613 mmol) in acetonitrile (10 mL) containing suspended anhydrous potassium carbonate (186 mg, 1.35 mmol) was added a solution of 1,3-dichloro-2-(*tert*-butyldimethylsiloxy)propane (**8a**) (149 mg, 0.613 mmol) in CH_3CN (3 mL) all at once. The resulting mixture was heated under reflux for 90 h. The mixture was cooled to room temperature, and the solvent was removed under reduced pressure. The residue was partitioned between water (8 mL) and methylene chloride (10 mL), and the organic phase was washed with water (5 mL) and 10% aqueous HCl (5 mL), dried over $MgSO_4$, and concentrated under vacuum to give 128 mg of crude product. Analysis of the ^1H NMR and mass spectra indicated this to be a 1:1 mixture of 1-(*p*-toluenesulfonamido)-

3-chloro-2-(*tert*-butyldimethylsiloxy)propane (**15**) and 1-(*p*-toluenesulfonyl)-3-(*tert*-butyldimethylsiloxyl)azetidine (**13**).

1-(Methanesulfonyl)-3-(*tert*-butyldimethylsiloxy)-azetidine (16). To a solution of methanesulfonamide (64.4 mg, 0.680 mmol) in acetonitrile (7 mL) containing suspended anhydrous potassium carbonate (210 mg, 1.50 mmol) was added a solution of 1,3-dibromo-2-(*tert*-butyldimethylsiloxy)-propane (**8b**) (200 mg, 0.603 mmol) in CH_3CN (3 mL) all at once. The resulting mixture was heated under reflux for 27 h. The mixture was cooled to room temperature, and the solvent was removed under reduced pressure. The residue was partitioned between water (10 mL) and ethyl acetate (10 mL), and the organic phase was washed with 5% NaOH (5 mL) and water (5 mL), dried over $MgSO_4$, and concentrated in vacuum to give 106 mg (66%) of a brown oil which after chromatography on silica gel and elution with pentane gave a white crystalline solid: mp 45 °C; ^{1}H NMR ($CDCl_3$) δ −0.068 (s, 6H), 0.819 (s, 9H), 3.71 (t, 2H), 3.98 (t, 2H), 4.50 (quint, 1H); ^{13}C NMR ($CDCl_3$) δ −5.18, 17.72, 25.49, 35.51, 60.16, 60.22; HRMS (FAB) calcd for $C_{10}H_{24}SO_3NSi$ $(M + 1)^+$ 266.1246, found m/z 266.1250.

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Supplementary Material Available: Copies of the ^{1}H NMR spectra of **5**, **8b**, **11**, **13**, and **16** as well as ^{13}C NMR spectra of **4**, **8a**, **10**, **12**, and **14** (10 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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