Chemistry of Sulfenic Acids. 5.[1] A Novel Rearrangement of 2,4,6-Trineopentylbenzenesulfenic Acid to 2-*tert*-Butyl-4,6-dineopentylbenzo[*b*]thiete and 3,3-Dimethyl-4,4-dihydro-6,8-dineopentylbenzo[*b*]thiapyran. Synthesis of Thiete Sulfoxides

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2,4,6-Trineopentylbenzenesulfenic acid (**4**), prepared by flash vacuum pyrolysis of the corresponding *n*-butyl sulfoxide, **5**, undergoes a novel rearrangement to give benzo[*b*]thiete **7** and benzo[*b*]thiapyran **8**. A mechanism involving a 1,4-dehydration of the sulfenic acid to afford an intermediate *o*-thioquinone methide **6a** is proposed. Oxidation of **7** gives the stable benzo[*b*]thiete sulfoxide **10** in good yield, whereas oxidation of thiete **11** gave dimeric sulfoxide **14**. The stability of sulfinyl radicals (RSO·) is the proposed reason for the high reactivity of thiete sulfoxides.

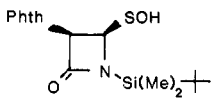
Sulfenic Acids (RSOH), transient intermediates in many organic and bioorganic sulfur reactions, display a spectrum of reactivity exhibited by few other functionalities.[2-4] Despite the importance of these compounds, they are seldom isolated or even detected. In the rare examples where sulfenic acids can be isolated their stability has often been attributed to intramolecular hydrogen bonding, steric, and polar effects.[2,5] To date, however, the reason for the high reactivity of these species remains elusive.

Steric inhibition of thiosulfinate (RS(O)SR) formation (eq 1), the primary reaction of sulfenic acids,[5] is probably

$$2RSOH \rightarrow RS(O)SR + H_2O \qquad (1)$$

responsible for the relative stability of 2-methyl-2-propanesulfenic acid (*t*-BuSOH) in solution.[5,6] The unusual thermal stability of a derivative of 2-oxoazetidine-4-sulfenic acid (**1**), reported by Bachi and Gross, has also been attributed to steric inhibition of reaction 1.[7] Our attempts to stabilize arenesulfenic acids by steric protection of the reactive site, however, have been unsuccessful. For example 2,4,6-triisopropylbenzenesulfenic acid (**2**), prepared by flash vacuum pyrolysis (FVP) of the corresponding *n*-butyl sulfoxide, affords only the thiosulfinate even in the presence of methyl propiolate, a sulfenic acid trapping reagent.[8] 2,4,6-*tert*-Butylbenzenesulfenic acid (**3**) is actually destabilized by the adjacent *tert*-butyl groups, giving products resulting from homolytic cleavage of the aryl–SOH bond.[5]

Dreiding and space-filling CPK models of 2,4,6-trineopentylbenzenesulfenic acid (**4**) suggest that the SOH group resides in a hydrophobic pocket where there is less interaction between the adjacent neopentyl groups than the *tert*-butyl groups in **3**. These models also imply that reaction 1 should be sterically inhibited. Although **3** was unstable, **4** may be stable enough to detect and/or isolate.



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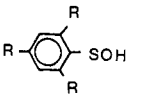
Phth = phthalimido



2, R =

3, R =

4, R =

Sulfoxide **5** was prepared in four steps from 2-bromo-1,3,5-trineopentylbenzene with an overall yield of 61%, using the methodology previously developed in the synthesis of **3**.[5] Although a satisfactory elemental analysis could not be realized for the oily sulfoxide **5**, its structure is consistent with spectral data. In addition to a reasonable ^1H NMR spectrum, the IR spectrum displays S–O absorption at 1060 cm^{-1} and a molecular ion at m/z 392 in the EI-MS.

Two major products and one minor product were obtained on FVP of sulfoxide **5** at 600 °C. The minor product, isolated in 7% yield by preparative TLC on silica gel, was identified as bis(2,4,6-trineopentylphenyl) disulfide by comparison with an authentic sample.

The major products, isolated in 55% and 25% yields by preparative gas chromatography (GLC), were identified as 2-*tert*-butyl-4,6-dineopentylbenzo[*b*]thiete (**7**) and 3,3-dimethyl-4,4-dihydrobenzo[*b*]thiapyran (**8**), respectively. The identities of **7** and **8** are based on satisfactory elemental analyses, IR, NMR, and EI-MS.

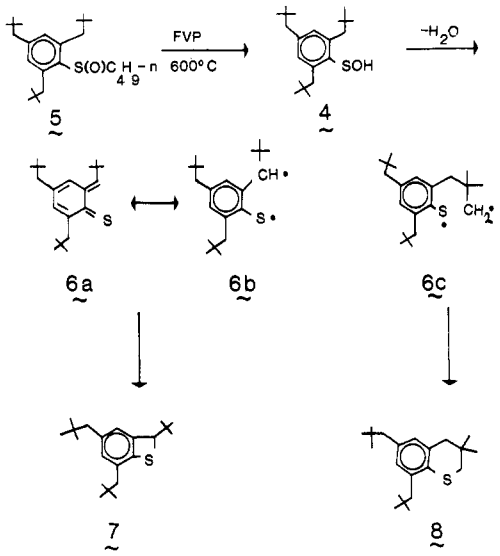
Consistent with their structures, both **7** and **8** have very similar mass spectra. Molecular ions were observed at m/z 318 and both compounds formed their base ions, m/z 261, by loss of a C_4H_9 fragment. Prominent ions at M – 1 and M – alkyl are observed in the EI-MS of alkyl substituted thietes.[9]

High-field ^1H NMR (250 MHz) of **7** clearly supports the proposed structural assignment. The two neopentyl *tert*-butyl groups are singlets centered at 0.87 and 0.94 ppm with the thiete ring *tert*-butyl group at 1.07 ppm. The most definitive evidence in support of the proposed structure is the absorption at 4.47 ppm assigned to the single thiete ring proton. The chemical shift position of

(1) Part 4: Davis, F. A.; Billmers, R. L. *J. Am. Chem. Soc.* **1981**, *103*, 7016.
(2) For reviews on the chemistry of sulfenic acids, see: Kice, J. L. *Adv. Phys. Org. Chem.* **1980**, *17*, 65. Hogg, D. R. *Compr. Org. Chem.* **1979**, *4*, 261.
(3) For leading references to the biological reactions of sulfenic acids, see ref 1.
(4) Davis, F. A.; Jenkins, R. H., Jr. *J. Am. Chem. Soc.* **1980**, *102*, 7967.
(5) Davis, F. A.; Jenkins, R. H., Jr.; Rizvi, S. Q. A.; Yocklovich, S. G. *J. Org. Chem.* **1981**, *46*, 3467.
(6) Davis, K. E.; Shelton, J. R. *Int. J. Sulfur Chem.* **1973**, *8*, 197. Block, E.; O'Conner, J. *J. Am. Chem. Soc.* **1974**, *96*, 3921, 3929.
(7) Bachi, M. D.; Gross, A. *J. Org. Chem.* **1982**, *47*, 897.
(8) A method we have proposed for estimating the influence of structural variations on the reactivity of sulfenic acids generated by FVP is measurement of the vinyl sulfoxide/thiosulfinate ratio. See ref 5.
(9) Dittmer, D. C.; Chang, P. L.-F.; Davis, F. A.; Iwanami, M.; Stamos, I. K.; Takahashi, K. *J. Org. Chem.* **1972**, *37*, 1111.

0022-3263/83/1948-3071$01.50/0

Scheme I



this proton is in excellent agreement with that reported for the thiete ring proton in the parent benzo[*b*]thiete (4.28–4.22 ppm).[10,11] The ^{13}C NMR of **7**, which is similar to that reported for 1,3,5-trineopentylbenzene,[12] also supports the proposed structure. The principal difference is that the chemical shift of C-2 at 64.3 ppm is at much lower field than this carbon in the parent benzo[*b*]thiete, which absorbs at 36.4 ppm.[10] A possible explanation is the attached *tert*-butyl group, which causes such a large downfield shift. Note that the 4- and 6-neopentylmethylene carbon atoms in **7** are observed at 45.4 and 50.5 ppm, respectively.

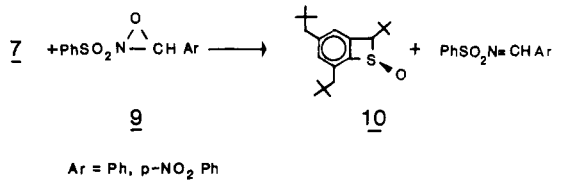
In **8**, the two neopentyl *tert*-butyl groups appear at 0.96 and 0.89 ppm, respectively. The fact that the methyl and methylene protons of the thiapyran ring are singlets at 1.07, 2.54, and 2.62 ppm, respectively, eliminate other positional isomers for this compound.

The formation of benzo[*b*]thiete **7** and benzo[*b*]thiapyran **8** is suggested to proceed as outlined in Scheme I. Dehydration of sulfenic acid **4** affords *o*-thioquinone methide **6a** and/or the diradical **6b** which collapse to **7**. Although *o*-thioquinone methide and related heteroatom analogues (**6a**, S = O, NR) are generally not considered to be diradicals,[11,15,16] vinyl sulfenes, intermediates in the pyrolytic rearrangement of thiete sulfones to sultines, are suggested to have diradical and/or dipolar character.[17] The gas-phase (700 °C) dehydration of *o*-mercaptobenzyl alcohol to give benzo[*b*]thiete has recently been described by Mao and Boekelheide.[11] While 1,4-dehydration of sulfenic acids (Scheme I) has not previously been observed, the gas-phase dehydration of methanesulfenic acid (MeSOH) to thioformaldehyde (CH_2=S) has been described.[13,14]

The most likely precursor of **8**, obtained in 25% yield, is diradical **6c**. This diradical is apparently not formed from **6a,b** since **8** was not detected on FVP of **7** at 600 °C. Homolytic cleavage of the S–OH bond to afford a hydroxyl radical that abstracts a hydrogen atom from one of the adjacent neopentyl methyl groups is suggested as the source of this radical. The 2,4,6-trineopentylphenyl radical is thought to rearrange to a radical analogous to **6c**.[18]

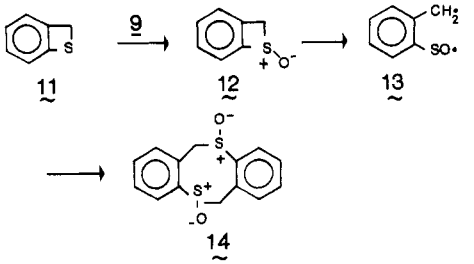
Although sulfones of thiete and benzo[*b*]thiete are well-known stable compounds,[19] the only example of a thiete sulfoxide is naphtho[1,8-*bc*]thiete 1-oxide, a special example.[20] All attempts to prepare other thiete sulfoxides by oxidation of thietes have been unsuccessful.[21]

Oxidation of **7** with 2-(phenylsulfonyl)-3-phenyloxaziridine (**9**), an aprotic and neutral oxidizing reagent,[22] gives benzo[*b*]thiete sulfoxide **10** in 79% isolated yield.



Sulfoxide **10** is a stable, white crystalline solid, melting at 109–110 °C without decomposition. The structure of **10** is supported by a satisfactory elemental analysis, IR absorption at 1055 cm^{-1} for the sulfoxide group, molecular ion at m/z 334 in the EI-MS, and a downfield shift of the thiete ring carbon from 64.3 in **7** to 85.9 ppm in **10**.

By contrast oxidation of benzo[*b*]thiete (**11**) gives only dimeric sulfoxide **14** as a 58:42 mixture of diastereomers, isolated in 68% yield. Benzo[*b*]thiete sulfoxide (**12**) is not detected by NMR. The structure of **14** is based on a satisfactory elemental analysis (as the hydrate), a molecular ion at m/z 276 in the mass spectrum, IR absorption at 1050 cm^{-1} for the sulfoxide group, and an AB quartet (J = 14.8 Hz) for the diastereotopic benzyl protons. Compound **14**, 70:30 mixture of diastereomers, was prepared independently by oxidation of 6*H*,12*H*-dibenzo[*b*,*f*]-1,5-dithiocin (the dimer of **11**) in 96% yield.



The formation of benzothiete sulfoxide dimer **14** is believed to occur by dimerization of diradical **13** resulting from rupture of the C–S(O) bond in **12**. A similar transformation would be sterically unfavorable for thiete sulfoxide **10** and is suggested as the reason for the stability of this sulfoxide. The much greater stability of sulfinyl (RSO·) vs. thiyl (RS·) and sulfonyl (RSO_2·) radicals is

(10) van Tilborg, W. J. M.; Plomp, R. *J. Chem. Soc., Chem. Commun.* **1977**, 130.
(11) Mao, Y-L.; Boekelheide, V. *Proc. Natl. Acad. Sci. U.S.A.* **1980**, *77*, 1732.
(12) Nilsson, B.; Drankenberg, T. *Org. Magn. Reson.* **1974**, *6*, 155.
(13) Penn, R. E.; Block, E.; Revelle, L. K. *J. Am. Chem. Soc.* **1978**, *100*, 3622.
(14) Davis, F. A.; Yocklovich, S. G.; Baker, G. S. *Tetrahedron Lett.* **1978**, 97.
(15) de Mayo, P.; Weedon, A. C.; Wong, G. S. K. *J. Org. Chem.* **1979**, *44*, 1977.
(16) Mao, Y-L.; Boekelheide, V. *J. Org. Chem.* **1980**, *45*, 1547.
(17) Dittmer, D. C.; Henion, R. S.; Takashina, N. *J. Org. Chem.* **1969**, *34*, 1310.
(18) Brunton, G.; Griller, D.; Barclay, L. R. C.; Ingold, K. U. *J. Am. Chem. Soc.* **1976**, *98*, 6803.
(19) For leading references on the chemistry of thietes and benzo[*b*]-thietes, see: Dittmer, D. C. In "New Trends in Heterocyclic Chemistry"; Elsevier: Amsterdam, 1979; p 130 ff. Patwardhan, B. H.; Parker, E. J.; Dittmer, D. C. *Phosphorus Sulfur* **1979**, *7*, 5.
(20) Meinwald, J.; Knapp, S.; Obendorf, S. K.; Hughes, R. E. *J. Am. Chem. Soc.* **1976**, *98*, 6643.
(21) Dittmer, D. C.; Davis, F. A. *J. Am. Chem. Soc.* **1965**, *87*, 2064. Tsai, A. Ph.D. Thesis, Syracuse University, Syracuse, NY, 1973.
(22) For references to the oxidation chemistry of 2-sulfonyloxaziridines, see: Davis, F. A.; Stringer, O. D. *J. Org. Chem.* **1982**, *47*, 1744. Davis, F. A.; Jenkins, R. H., Jr.; Awad, S. B.; Stringer, O. D.; Watson, W. H.; Galloy, J. *J. Am. Chem. Soc.* **1982**, *104*, 5412. Davis, F. A.; Stringer, O. D.; Billmers, J. M. *Tetrahedron Lett.* **1983**, *24*, 1213.

apparently responsible for the high reactivity of thiete sulfoxides[21] in comparison to the corresponding thiete and thiete sulfone derivatives.[24]

In summary, steric effects do not appear to be significant contributors to the stability of arenesulfenic acids (ArSOH) prepared by the FVP method. Studies are underway to ascertain the influence of intramolecular hydrogen bonding and polar effects on sulfenic acid reactivity.

The stability of sulfinyl radicals is proposed as responsible for the high general reactivity of thiete sulfoxides and derivatives.

Experimental Section

Melting points were determined on a Mel-Temp apparatus and are uncorrected. ^{1}H NMR spectra were measured on a Varian A-60A (60 MHz), JEOL FX 90Q (90 MHz), and Bruker WM-250 (250 MHz) NMR spectrometers. ^{13}C NMR spectra were measured at 22.49 MHz on the JEOL FX 90Q NMR spectrometer using Me_4Si as the internal reference. GC/MS data were obtained on a Finnigan 4000 GC/MS instrument using a 6 ft × $^1/_4$ in., 3% OV-17 on Anakorm Q (90/100 mesh), glass column. Gas chromatography was performed on a Varian 3700 gas chromatograph equipped with an FID and Columbia Scientific electronic integrator and on an HP F&M 5750 gas chromatograph equipped with TCD. Liquid chromatographs were obtained with use of a MCH-5 reverse phase column (70:30 acetonitrile–methanol) on a Varian 5060 HP liquid chromatograph; UV detector (260 nm).

Bis(2,4,6-trineopentylphenyl) Disulfide. In a 250-mL three-necked flask equipped with nitrogen inlet, reflux condenser, dropping funnel, and magnetic stir bar was placed 0.72 g (0.03 mol) of magnesium turnings in 15 mL of dry THF. 2-Bromo-1,3,5-trineopentylbenzene,[23] 10.9 g (0.030 mol) in 60 mL of THF, was added to the reaction mixture under nitrogen. The Grignard reaction was initiated by adding several drops of iodomethane and by crushing the magnesium turnings. After addition was complete the reaction mixture was heated at reflux until almost all of the magnesium had dissolved, approximately 2 h. Freshly sublimed sulfur (1.05 g, 0.033 mol) was slowly added and the solution refluxed under nitrogen for 12 h. The reaction mixture was carefully hydrolyzed by dropwise addition of a saturated solution of NH_4Cl and extracted with ether (3 × 50 mL). After being dried over anhydrous $MgSO_4$, the ether solution was evaporated to give the crude product as a mixture of the thiol and disulfide by GLC. The crude thiol/disulfide mixture was oxidized to the disulfide with use of triethylamine–I_2 in methanol,[5] to give 6.9 g (72%) of the crude disulfide, mp 153–158 °C.

An analytical sample was obtained by crystallization from methanol–ether: mp 155–157 °C; ^{1}H NMR ($CDCl_3$) δ 0.8 (s, 18 H), 0.91 (s, 9 H), 1.54 (s, 2 H), 2.41 (s, 2 H), 6.7 (s, 2 H).

Anal. Calcd for $C_{42}H_{70}S_2$: C, 79.00; H, 10.97. Found: C, 78.74; H, 10.68.

2,4,6-Trineopentylbenzenethiol. In a 100-mL three-necked flask equipped with reflux condenser, nitrogen inlet, and magnetic stir bar was placed 2.38 g (0.063 mol) of lithium aluminum hydride (Aldrich) in 50 mL of dry THF. Crude bis(2,4,6-trineopentylbenzene) disulfide (4.0 g, 0.0063 mol) was added, and the reaction mixture was refluxed for 1 h and hydrolyzed by cautious addition of 10% HCl solution. The reaction mixture was extracted with ether (3 × 50 mL) and dried over anhydrous $MgSO_4$. A colorless oil (3.8 g, 94%) was obtained on removal of the ether solution under vacuum. A solid, mp 41–43 °C, was obtained on washing with methanol–ether: ^{1}H NMR ($CDCl_3$) δ 0.92 (s, 9 H), 0.98 (s, 18 H), 2.4 (s, 2 H), 2.8 (s, 4 H), 3.2 (s, 1 H, SH), 6.8 (s, 2 H, Ar).

***n*-Butyl 2,4,6-Trineopentylphenyl Sulfide.** In a 100-mL three-necked flask equipped with a magnetic stir bar, reflux condenser, dropping funnel, and nitrogen inlet was placed 3.28 g (57% in mineral oil) of sodium hydride (Aldrich) in 25 mL of dry THF. The sodium hydride was washed with *n*-pentane (3 × 10 mL) to remove the mineral oil, 25 mL of dry THF was added, and the solution was cooled to 0 °C in an ice bath. The crude thiol, obtained as described above (2.5 g, 0.0078 mol), was added dropwise in 25 mL of THF to the sodium hydride solution. After this mixture was stirred at room temperature for 30 min, 5.0 mL of *n*-butyl bromide was added dropwise and stirring continued for 8 h at room temperature under an atmosphere of nitrogen. Water (100 mL) was added slowly, the solution was extracted with ether (3 × 50 mL), and the ether extracts were dried over anhydrous $MgSO_4$. Removal of the solvent under vacuum gave an oil, which was purified by chromatography on silica gel (elution with *n*-pentane–ether) to give 2.8 g (95%) of an oil: ^{1}H NMR ($CDCl_3$) δ 0.85 (s, 27 H), 1.2–1.6 (m, 7 H), 2.4 (m, 4 H), 2.9 (s, 4 H), 6.8 (s, 2 H).

Anal. Calcd for $C_{25}H_{44}S$: C, 79.78; H, 11.70. Found: C, 79.91; H, 11.85.

***n*-Butyl 2,4,6-Trineopentylphenyl Sulfoxide (5).** In a 100-mL single-necked flask equipped with magnetic stir bar and drying tube was placed 1.5 g (0.0040 mol) of *n*-butyl 2,4,6-trineopentylphenyl sulfide in 25 mL of chloroform. To the reaction mixture, in 15 mL of chloroform, was added 0.81 g (0.0040 mol) of 85% *m*-chloroperbenzoic acid (Aldrich). After the mixture was stirred for 30 min, the precipitated chlorobenzoic acid was removed by filtration; the solvent was removed under vacuum to afford an oil, which was purified by chromatography on silica gel G (elution with *n*-pentane/ether, 2:1) to give 0.94 g (60%) of an oil. The sulfoxide had the following properties: IR (thin film) 1055 cm^{-1} (SO); ^{1}H NMR ($CDCl_3$) δ 0.88 (s, 9 H), 0.93 (s, 18 H), 1.2–1.8 (m, 5 H), 2.4 (s, 2 H), 2.5–3.2 (m, 8 H), 6.83 (s, 2 H); EI-MS, *m/z* (relative intensity) 392 (13, M), 374 (30), 71 (19), 57 (100). A satisfactory elemental analysis could not be obtained.

Flash Vacuum Pyrolysis of Sulfoxide 5. Flash vacuum pyrolysis of sulfoxide **5** (0.15 g, 0.00038 mol), by procedures previously described,[5] at 600 °C afforded an oil that was first purified by preparative TLC (silica gel G, developed with *n*-pentane) to give two fractions. The second fraction, 0.01 g (7%), was identified by its spectral properties as bis(2,4,6-trineopentylbenzene) disulfide (vide supra). The first fraction, obtained as an oil (0.097 g, 80%), consisted of two products in the ratio of 2:1. Analytical samples of these compounds were obtained by preparative gas chromatography, using a 6 ft × $^1/_4$ in. OV-17 on Supelcoport (80/100 mesh) column.

The first compound, 54%, **2-*tert*-butyl-4,6-dineopentylbenzo[*b*]thiete (7),** had the following properties: 250-MHz ^{1}H NMR ($CDCl_3$) δ 0.87 (s, 9 H), 0.94 (s, 9 H), 1.07 (s, 9 H), 2.3 (s, 2 H), 2.4 (s, 2 H), 4.47 (s, 1 H), 6.48 (s, 1 H), 6.72 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 26.6 and 31.8 (Me and C of 4-*t*-Bu), 29.4 and 33.4 (Me and C of 6-*t*-Bu), 29.6 and 31.8 (Me and C of 2-*t*-Bu), 45.4 and 50.5 (CH_2 of 4- and 6-neopentyl groups), 64.3 (C-2), 122.4 and 133.0 (C-3 and C-5); EI-MS, *m/z* (relative abundance) 318 (19, M), 303 (4), 261 (100), 205 (17).

Anal. Calcd for $C_{21}H_{34}S$: C, 79.25; H, 10.69. Found: C, 79.00; H, 11.06.

The second compound, 25%, **3,3-dimethyl-4,4-dihydro-6,8-dineopentylbenzo[*b*]thiapyran (8)** had the following properties: 250-MHz ^{1}H NMR ($CDCl_3$) δ 0.89 (s, 9 H), 0.96 (s, 9 H), 1.07 (s, 6 H), 2.39 (s, 2 H), 2.54 (s, 2 H), 2.6 (s, 4 H), 6.67 (s, 1 H), 6.73 (s, 1 H); EI-MS, *m/z* (relative abundance) 318 (24, M), 261 (100), 205 (26), 189 (5), 148 (10).

Anal. Calcd for $C_{21}H_{34}S$: C, 79.25; H, 10.69. Found: C, 79.10; H, 10.76.

2-*tert*-Butyl-4,6-dineopentylbenzo[*b*]thiete Sulfoxide (10). In a 5-mL single-necked flask equipped with magnetic stir bar and drying tube was placed 0.06 g (0.000 19 mol) of a mixture of **7** and **8** (2:1) in 1 mL of $CDCl_3$. To the reaction mixture was added 2-(phenylsulfonyl)-3-phenyloxaziridine (**9**, Ar = Ph)[22] and the disappearance of the oxaziridine 3-H monitored at 5.4 ppm. When the oxidation was complete, after approximately 30 min, the solvent was removed under vacuum and the resulting oil washed with *n*-pentane. The pentane washings were combined, and the solvent evaporated and the oily solid purified by preparative TLC on silica gel G. Development with *n*-pentane/ether (1:1) afforded a major fraction, 0.031 g (79% based on **7**), of sulfoxide **10**: mp 109–110 °C; IR (KBr) 1055 cm^{-1} (SO); ^{1}H NMR ($CDCl_3$) δ 0.91 (s, 9 H), 0.99 (s, 9 H), 1.18 (s, 9 H), 2.58 (s, 4 H), 3.99 (s, 1 H), 6.86 (s, 1 H), 6.92 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 27.7 and 29.4 (4,6-Me, *t*-Bu), 31.9 and 32.3 (4,6-C, *t*-Bu), 29.6 and 33.7 (2-*t*-Bu),

(23) Olsson, K. *Acta Chem. Scand.* **1972**, *26*, 3555.

(24) For a discussion of RSO_x· radicals, see: Block, E. "Reactions of Organosulfur Compounds"; Academic Press: New York, 1978; Chapter 5.

45.2 and 50.8 (4,6-CH_2, *t*-Bu), 85.9 (C-2), 125.2 and 133.9 (C-3, C-5); EI-MS, *m/z* (relative intensity) 334 (2, M), 278 (11), 277 (55), 71 (36), 57 (77), 43 (100).

Anal. Calcd for $C_{21}H_{34}SO$: C, 75.45; H, 10.18. Found: C, 75.14; H, 10.11.

Oxidation of Benzo[*b*]thiete (11). In a 25-mL round-bottom flask equipped with a magnetic stir bar and argon atmosphere was placed 0.14 g (0.001 14 mol) of benzo[*b*]thiete (11)[11] in 5 mL of dry methylene chloride. After the mixture was cooled to 0 °C in an ice bath, 0.35 g (0.001 14 mol) of 2-(phenylsulfonyl)-3-(*p*-nitrophenyl)oxaziridine (9, Ar = *p*-NO_2Ph)[22] was added dropwise and the reaction mixture allowed to warm to room temperature. After the mixture was stirred for 0.5 h, the solvent was removed under vacuum to afford a yellow-green solid. This material was purified by preparative TLC (silica gel), eluting first with methylene chloride followed by ether, to give 0.095 g (68%) of a white solid, mp 171–180 °C, identified as 6*H*,12*H*-dibenzo[*b*,*f*]-1,5-dithiocin disulfoxide (14), 58:42 mixture of diastereomers by HPLC, identical in properties with an authentic sample prepared as described below.

6*H*,12*H*-Dibenzo[*b*,*f*]-1,5-dithiocin Disulfoxide (14). In a 25-mL round-bottom flask equipped with magnetic stir bar, dropping funnel, and argon atmosphere was placed 0.15 g (0.000 61 mol) of 6*H*,12*H*-dibenzo[*b*,*f*]-1,5-dithiocin[11] in 5 mL of methylene chloride. At room temperature 2-(phenylsulfonyl)-3-(p-nitrophenyl)oxaziridine (9, Ph = *p*-NO_2Ph;[22] 0.19 g, 0.000 61 mol) in 10 mL of methylene chloride was added dropwise and the solvent removed under vacuum to afford a solid that was purified by preparative TLC (silica gel) as described above to give 0.17 g (98%) of disulfoxide 14, as a 70:30 mixture of diastereomers by HPLC. Compound 14 had the following properties: mp 170–180 °C dec; IR (KBR) 1055 cm^{-1} (sulfoxide); ^1H NMR ($CDCl_3$) δ 3.8–4.4 (AB q, *J* = 14.8 Hz, 4 H), 7.0–7.5 (m, 8 H); ^{13}C NMR ($CDCl_3$) δ 58.86 (CH_2); EI-MS, *m/z* (relative intensity) 276 (4.2, molecular ion), 138 (96), 137 (100), 109 (31).

Anal. Calcd for $C_{14}H_{12}O_2S_2 \cdot H_2O$: C, 57.14; H, 4.76. Found: C, 57.14; H, 4.59.

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Reductions of Esters, Acyl Halides, Alkyl Halides, and Sulfonate Esters with Sodium Borohydride in Polyethylene Glycols: Scope and Limitation of the Reaction[1]

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Sodium borohydride in ethylene glycol oligomers (PEGs) has been explored as a novel reducing system for esters, acyl chlorides, alkyl halides, and sulfonate esters. The selectivity of the system is exemplified by its inertness toward nitrogen-containing functional groups such as amides, azides, nitriles, and nitroalkanes. Both hydroxy groups of the oligomeric diols have been established to be necessary for the above reducing system. The nature of the reductant formed by $NaBH_4$ in excess PEG 400 is discussed. Furthermore, an alkoxyborohydride, $Na[(PEG)_2BH_2]$, can be prepared by reaction of 1 mol of $NaBH_4$ and 2 mol of PEG 400. In THF the reagent reduces halides and tosylates rapidly to hydrocarbons in good yields.

Polyethylene glycols (PEGs) are oligomeric diols of general formula $HO(CH_2CH_2O)_nH$ in which the two terminal hydroxy groups are separated by several oxyethylene units (CH_2CH_2O). An average molecular weight $\bar{M}$ indicates approximately the numbers of such oxyethylene units. PEGs can be regarded as open-chain crown ethers as they are able to form complexes with alkaline and alkaline-earth cations in protic and aprotic solvents.[3] From preliminary studies, PEG 400 seems to most successful candidate for applications to organic synthesis.[4]

Sodium borohydride in PEG 400 exhibits a reactivity completely different from that shown by the borohydride in the presence of crown ethers in similar systems such as PEG ethers.[5] In fact, sodium borohydride in PEG 400 smoothly reduces carbonyl compounds at room temperature,[4] in this respect behaving similarly to $NaBH_4$ in hydroxylic solvents. Under the same conditions as above esters were unaffected, but when the temperature was

Table I. Reduction of 1 by 0.6 M $NaBH_4$ in Various PEGs at 80 °C[a]

solvent	time, h	yield,[b] %
PEG 200	3	85
PEG 300	5	80
PEG 400	8	90
PEG 600	5	85
PEG methyl ether[c]	16	

[a] Molar ratio of $NaBH_4$/1 of 3:1. [b] Yield of isolated benzyl alcohol. [c] From Aldrich.

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(3) Yanagida, S.; Takahashi, K.; Okahama, M. *Bull. Chem. Soc. Jpn.* **1978**, *51*, 1294 and 3111.
(4) Santaniello, E.; Manzocchi, A.; Sozzani, P. *Tetrahedron Lett.* **1978**, 4581.
(5) Hirao, A.; Nakahama, S.; Nakahashi, M.; Yamasaki, N. *Makromol. Chem.* **1978**, *179*, 2343.

0022-3263/83/1948-3074$01.50/0