chloride (0.90 g, 3.85 mmol) was added over a 0.5-h period. The resulting suspension was stirred at −35 °C for an additional half hour and then allowed to warm to room temperature and stirred for an additional 3 h. Hexane (50 mL) was added, the mixture cooled in ice and filtered. The solvents were evaporated under vacuum to leave 1.1 g of partially solid material, which was extracted with hexane, and the hexane was evaporated to leave 0.55 g of brown oil. Chromatography on neutral alumina (activity III) yielded hydrocarbon **1** (0.077 g, 0.38 mmol, 22%).

Reaction of 1 with Maleic Anhydride. A solution of hydrocarbon 1 (0.20 g, 0.97 mmol) and maleic anhydride (0.24 g, 2.4 mmol) in dry toluene was heated at reflux for 2.5 h. The solution was allowed to stand overnight at room temperature and the solvent evaporated under vacuum. The residue was heated at 105 °C at a pressure of 0.3 Torr until sublimation of excess maleic anhydride was complete. The dark brown oil remaining crystallized on standing in the refrigerator. Recrystallization from ether yielded adduct **12** (0.081 g, 0.27 mmol, 29%) as white needles: mp 178–180 °C; ^{1}H NMR δ 1.02 (s, 3 H), 3.23–3.50 (m, 2 H), 3.60–4.00 (m, 2 H), 5.30 (s, 1 H), 5.63 (s, 1 H), 6.32–6.50 (m, 3 H), 7.07–7.30 (m, 3 H), 7.40–7.65 (m, 1 H). Anal. Calcd for $C_{20}H_{16}O_3$: C, 78.93; H, 5.30. Found: C, 78.91; H, 5.29.

Photorearrangement of Hydrocarbon 1. A stream of argon was bubbled through a solution of 1 (0.224 g, 1.09 mmol) in 20 mL of benzene in a Pyrex flask for 10 min, and the solution was then irradiated by a GE 275-W sun lamp for 18 h. GLPC analysis by comparison with standard solutions on a 6-ft 3% SE-30 Chromosorb W column at 180 °C showed the solution to contain 0.15 mmol (14%) of 1,10-dimethylanthracene. Chromatography on alumina, eluting with petroleum ether, followed by recrystallization from benzene–hexane, yielded 7 mg (3.4 mmol, 3%) of pure 1,10-dimethylanthracene.

1,10-Dimethylanthracene. A solution of methyllithium in hexane (1.55 M, 5 mL, 7.75 mmol) was added to a stirred solution of 4-methylanthrone[12] (0.62 g, 3.0 mmol) in 25 mL of anhydrous ether. Water was added and the ether layer was washed with water and with brine and dried over magnesium sulfate. Evaporation of the solvent left a yellow powder, which was chromatographed on Florisil, eluting with 10% dichloromethane in petroleum ether, to yield 1,10-dimethylanthracene (0.405 g, 2.0 mmol, 67%) as yellow crystals: mp 127–128 °C; ^{1}H NMR δ 2.82 (s, 3 H), 3.05 (s, 3 H), 7.28–7.60 (m, 4 H), 7.95–8.44 (m, 3 H), 8.48 (s, 1 H); IR (mineral oil) 868, 831, 789, 722 cm^{-1}; UV (hexane) λ_{max} 342 (ϵ 4350), 358 (7550), 377 (12080), 398 (12090). Anal. Calcd for $C_{16}H_{14}$: C, 93.16; H, 6.84. Found: C, 92.95; H, 6.99.

Thermal Rearrangement of 1. a. In Diphenyl Ether Solution. Diphenyl ether (5 mL) was heated at 154–155 °C and degassed with a stream of argon. Hydrocarbon 1 (0.087 g, 0.42 mmol) was added and heating was continued under an argon atmosphere for 28 min. The solution was cooled in ice and analyzed by GLPC on a 6-ft, 3% OV 101 on Chromosorb W column at 170 °C. In addition to a peak for residual 1 (t_R 10.4 min), new peaks were present at retention times of 8.7 and 9.2 min. These components were identified by GC/MS as 9-methylanthracene and 9-ethylanthracene, respectively. Calibration aginst standard solutions showed that 9-methylanthracene and 9-ethylanthracene were obtained in 4% and 27% yields, respectively, together with 9% of recovered 1.

Reactions at higher temperatures or in tetralin solutions were carried out by the same procedure.

b. In *N,N*-Dimethylaniline Solution. A solution of hydrocarbon 1 (0.157 g, 0.76 mmol) in 5 mL of *N,N*-dimethylaniline was heated at reflux in the dark under an atmosphere of argon for 2.5 h. The solution was allowed to cool, and water and 1 M hydrochloric acid were added. The resulting mixture was extracted with ether and the ether layer was washed with water and with brine and dried over magnesium sulfate. Evaporation of the solvent left 0.150 g of a viscous red oil. GLPC analysis showed the absence of 1 and the presence of 9-methylanthracene (6%) and 9-ethylanthracene (31%).

c. In the Absence of Solvents. A Pyrex tube (15.0 × 0.8 cm) filled with Pyrex beads (ca. 0.4 cm in diameter) was heated to 375 °C by electrical heating tape. A stream of argon was passed through the tube and hydrocarbon 1 (0.20 g, 1.0 mmol) was dropped into the tube, which was then immediately cooled in dry ice. The reaction product was dissolved in dichloromethane and the solvent evaporated to give 0.2 g of a red oil, which was analyzed by GLPC.

Acknowledgment. We thank the donors of the Petroleum Research Fund, administered by the American Chemical Society, for a grant in support of this work.

Stereochemistry of Hydride Reductions of 4,8-Dihalo-2-thiaadamantanes and Related Thiabicyclo[3.3.1]nonanes

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Received November 24, 1986

$LiAlD_4$ reductions of *anti*-4,8-dihalo-2-thiaadamantanes and *anti*-2,6-dihalo-9-thiabicyclo[3.3.1]nonanes in ether and THF solution occur with complete retention of configuration. Participation by sulfur to form intermediate thiiranium ions is the most likely explanation for this behavior. Reaction of the thiabicyclononanes with $LiEt_3BD$ involves chiefly elimination; single-electron transfer is a significant (20–25%) pathway in the reaction of $LiEt_3BD$ with the thiaadamantane.

Introduction

A neighboring heteroatom might affect the hydride reduction of an alkyl halide in several ways: (a) by nucleophilic participation to form an intermediate onium ion, leading to reduction with retention of configuration; (b) by formation of a monodentate complex with the reagent, delivering hydride intramolecularly (retention or inversion); (c) by formation of a bidentate complex of halide, neighboring group, and reagent, to be attacked by a second molecule of reductant (inversion); (d) by altering the reduction potential of the C–X bond so as to make single-electron-transfer (SET) reduction more or less likely (no stereoselectivity); or (e) by a steric effect.

The possibility of effecting a choice among these mechanisms by appropriate selection of heteroatom and reagent, and thereby controlling the stereoselectivity of the reduction, seems to us a goal of some importance, given the widespread use of such reductions in synthesis. We therefore have begun to examine a number of systems suitable for the observation of each kind of behavior.

In this paper, we report our examinations of the stereochemical course of $LiAlD_4$ and $LiEt_3BD$ reductions of

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Table I. Yields and Deuterium Incorporation[a]

substr	reducing agent	solvent	yield, %	% d_1	% d_2
1	$LiAlD_4$	Et_2O	99	4.9	94.5
1	$LiAlD_4$	THF	36	5.2	94.3
2	$LiAlD_4$	THF	92	5.8	93.0
1	$LiEt_3BD$	THF	7	7.3	91.9
2	$LiEt_3BD$	THF	17	6.4	93.0
3	$LiAlD_4$	Et_2O	78	3.6	96.2
3	$LiAlD_4$	THF	53	7.8	92.0
3	$LiEt_3BD$	THF	27	55.8	43.0
3	$LiAlH_4$ (0.27 equiv of DCPD)	THF	75	10.4	5.1
3	$LiEt_3BH$ (0.30 equiv of DCPD)	THF	26	9.6	4.4

[a] Deuterium incorporations are regarded as accurate to ±1%.

Table II. Deuterium Chemical Shifts of Reduction Products[a]

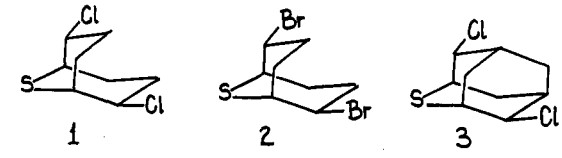
sulfide	chem shift	$Pr(fod)_3$ shift
thiabicyclononane (5)	1.93	5.37
thiaadamantane (6)	2.09	5.63
authentic *syn*-bicyclononane (9)	2.14	13.78

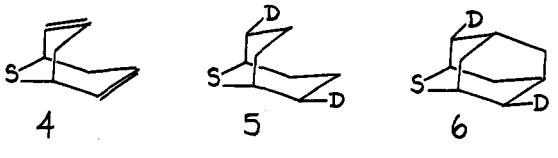
[a] Chemical shifts are referenced to $CDCl_3$ = 7.27 ppm; $Pr(fod)_3$ shift refers to the change in chemical shift calculated for a 1:1 mole ratio of shift reagent and sulfone.

some thiaadamantanes and thiabicyclononanes. These substrates were chosen because earlier work in several laboratories had indicated them to form thiiranium ions with ease[2,4b,7] and because the reduction of one of them with $LiAlD_4$ has previously been reported[4] to occur with retention of configuration.

Results and Discussion

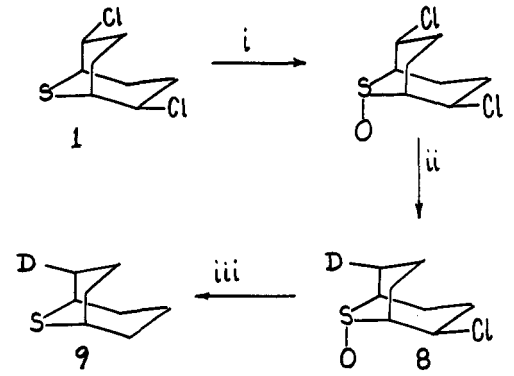
The necessary starting materials, compounds **1–3**, were prepared by literature methods[3,4] and subjected to reduction with $LiAlD_4$ or $LiEt_3BD$ to yield sulfides **5** and **6**. The results are shown in Table I.





The stereochemistry of the deuterium in the sulfides **5** and **6** was determined by ^2H NMR spectroscopy, demonstrated by Nordlander[5] to be a particularly effective method.[6] As shown in Table II, each sulfide gave a single deuterium resonance, thus indicating that both deuterium atoms have the same stereochemistry. That the stereochemistry is anti,anti rather than syn,syn is demonstrable in two ways.

Scheme I. Synthesis of Authentic Syn Deuteriated 9[a]



[a] i = $VaSO_4$, H_2O_2; ii = $LiEt_3BD$, THF; iii = $LiAlH_4$, Et_2O.

First, we prepared a compound having the deuterium authentically syn to the sulfur (Scheme I). Oxidation[7] of **1** with hydrogen peroxide and vanadyl sulfate gives the sulfoxide **7** in which the oxygen both prevents nucleophilic participation by sulfur and blocks S_N2 displacement of the halogen on the same face of the sulfur. Reduction of **7** with $LiEt_3BD$ proceeds with inversion of configuration at the unblocked site to form syn-deuteriated monohalosulfoxide **8** (59%). Reduction with $LiAlH_4$ now removes both the oxygen and the remaining halogen, producing **9** (59%), which has a distinctly different ^2H chemical shift from the sulfide produced by direct reduction.

However, attempts to prepare a similarly authentic sample of a *syn*-deuteriothiaadamantane were thwarted when the thiaadamantane sulfoxide failed to react with $LiEt_3BD$, even under forcing conditions. Consequently, we turned to the use of a shift reagent, $Pr(fod)_3$, to demonstrate the spatial relationship of the S and D atoms.

$Pr(fod)_3$ does not complex strongly enough with sulfides to provide significant shifts of the deuterium resonances. However, conversion of the sulfides to the sulfones (H_2O_2 + $VaSO_4$), which do form strong complexes with $Pr(fod)_3$, allowed the observation of substantial shifts (Table II).

As the concentration of the shift reagent is increased, the deuterium resonances of the sulfones from **5** and **6** move steadily upfield. Extrapolation to a 1:1 mole ratio of shift reagent and sulfone yields a value for the chemical shift change in the complex of 5.63 ppm for **5** and 5.37 ppm for **6**. These compounds clearly have the same stereochemistry for their deuteriums.

The sulfone from sulfide **9** likewise experiences an upfield shift of the deuterium resonance; however, in this case, the chemical shift change for the 1:1 complex is 13.78 ppm. The deuterium in this sulfone must lie distinctly closer to the Pr than the deuteriums in the other compounds. The deuterium in **9** is thus demonstrated to be syn, as expected from the mode of preparation of **9**, and the distinctly different deuteriums in **5** and **6** are anti.

Thus, all of the deuterium introduced into **1–3**, regardless of substrate or reducing agent, has entered with retention of configuration. The clear implication is that the thiiranium ions, **10** and **11**, are easily accessible, even under the mild conditions of the reductions.

The $LiAlD_4$ reductions proceed cleanly, to give high yields of reduced material with high deuterium incorporation. The $LiEt_3BD$ reductions, on the other hand, give

(1) To whom inquiries should be directed at the University of Maine.
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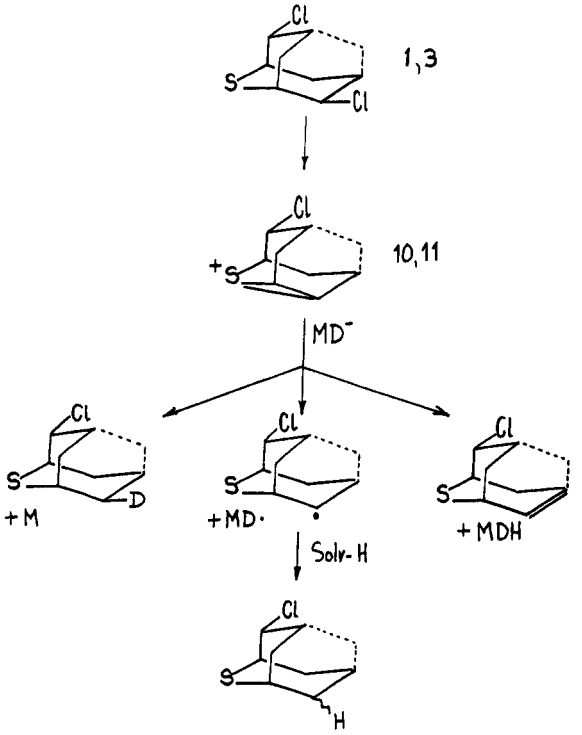
(6) The usual method of determining deuterium stereochemistry is observation of the C–D stretch in the infrared, which allows assignment of axial or equatorial ligature; in the thiaadamantane, a D that is axial to one ring is equatorial to the other. We observed a peak at 2135 cm^{-1} in the IR spectrum of **5** and one at 2130 cm^{-1} in the IR spectrum of **6**, both of which we assign to the C–D stretch.
(7) Weil, E. D.; Smith, K. J.; Gruber, R. J. *J. Org. Chem.* **1966**, *31*, 1669.

Scheme II. Mechanism of Reductions



low yields of reduction product and variable deuterium incorporation. The major product when compounds **1** and **2** are reduced with $LiEt_3BD$ appears to be the diene **4**, resulting from double dehydrohalogenation. Proton abstraction is not unknown behavior for $LiEt_3BD$; Brown[8] has reported formation of alkenes from halides such as 2-bromo-2-methylpentane and bromocyclohexane. Compound **3**, which cannot undergo elimination, is nearly inert to $LiEt_3BD$, and evidence appears of a new mode of reduction.

The alternate mode of reaction is signaled by the observation that of the small amount of reduction product obtained from **3** and $LiEt_3BD$, about half contains only one deuterium. As Ashby has shown,[9] the incorporation of protium during reductions with deuteride reagents is a signal of the reaction's taking an SET pathway, at least in part. We sought confirmation of this mechanism by conducting the reaction of **3** and $LiEt_3BH$ in the presence of $(C_6H_{11})2PD$ (DCPD), a well-known[9] radical scavenger. In this case, the introduction of deuterium would confirm the intervention of SET.

In the event, a 27% yield of reduction product was obtained, 14% of which contained at least one deuterium. SET clearly is operating in this reduction. Repetition of this experiment with $LiAlH_4$ and DCPD also gave significant incorporation of deuterium, indicating that in these cases as well, some SET is occurring, accounting for the undeuterated reduction product. In order to reconcile these observations with the completely retained stereochemistry of the deuterated reduction product, we suggest that SET and deuteride (hydride) transfer both involve the thiiranium ion; that is, no S_N2 displacement at all occurs in these reductions. Although both SET and elimination could occur from neutral substrate, the thiiranium ions are expected to be more reactive in both processes, and so are written as the sole reacting species.

Shceme II summarizes these ideas. A thiiranium ion, once formed, has three possibilities for further reaction. It can accept a D from the reagent, forming deuteriated reduction product with retention of configuration. It can donate a proton to the reagent, producing alkene. It can accept a single electron from the reagent, yielding a radical that then abstracts H from the solvent to give reduced material not containing deuterium. When protio reagents and DCPD are present, H transfer competes with D abstraction from the DCPD.

With the small reagent, $LiAlD_4$, deuteride transfer predominates. When the reagent is bulkier ($LiEt_3BD$), transfer of D is hindered but still leads to some retained product. In the bicyclononanes, competition from elimination becomes effective. In the adamantane, which cannot eliminate, SET becomes the effective competitor.

Summary. Our results thus demonstrate that thiiranium ions can be derived from compounds **1–3** under mild conditions, and with an appropriate choice of reagent, can be used to favor retention of configuration in hydride reduction. Conversion of the sulfide to the sulfoxide prevents thiiranium ion formation and in unhindered systems leads to reduction with inversion. We are extending these investigations to other, synthetically more important systems.

Experimental Section

Materials. Reagent grade tetrahydrofuran (THF) was distilled from lithium aluminum hydride and used immediately. Reagent grade anhydrous diethyl ether was used as received from Fisher Scientific. Lithium aluminum deuteride (98 atom % D) and lithium triethylborodeuteride (98 atom % D; 1.0 M solution in THF) were obtained from Aldrich Chemical Company and used as received. Deuteriated dicyclohexylphosphine,[9] *anti,anti*-2,6-dichlorothiabibyclo[3.3.1]nonane,[4] *anti,anti*-2,6-dibromothiabicyclo[3.3.1]nonane,[7] and *anti,anti*-4,8-dichloro-2-thiaadamantane[4] were all prepared according to literature procedures. Shift reagents Eu(fod) and Pr(fod) were obtained 99% pure from Aldrich and used as received. Thin layer chromatography employed Kodak Chromatogram silica gel sheets, and flash chromatography was performed with Merck silica gel, grade 60, 230–400 mesh.

General Procedures. All reductions were performed under argon. Calibrated syringes equipped with stainless steel needles were used for transfer of reagents. Glassware and syringes were baked overnight at 110 °C, assembled while hot, and cooled while connected to a $CaCl_2$ drying tube. Melting and boiling points are uncorrected.

Reductions were conducted in round-bottom flasks equipped with condenser, argon inlet tube, and Teflon-coated magnetic stirring bar. Solvents and reagents were syringed into the flask as it was momentarily disconnected from the argon flow. After complete reaction, the argon was disconnected and the mixture was hydrolyzed with either water or saturated sodium sulfate solution. When DCPD was a reactant, it was mixed with the metal hydride, and the halide was added to the mixture.

NMR spectra were obtained at Kent State with a Varian FT-80 spectrometer, and at the University of Maine with a Varian XL-200 spectrometer. Deuteriochloroform was employed as solvent unless otherwise noted, with Me_4Si as the internal standard. Deuterium NMR spectra were obtained on $CHCl_3$ solutions with $CDCl_3$ at natural abundance as an internal reference. Proton-coupled ^2H spectra were obtained in the unlocked mode with the magnet shimmed on pure $CDCl_3$ prior to each spectrum. Assignments in ^{13}C spectra agree with the literature.[10] Infrared (IR) spectra were obtained with a Perkin-Elmer 283 infrared spectrophotometer. Mass spectral analysis and deter-

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mination of deuterium incorporation were performed with a Hewlett-Packard 5985 GC/MS system. Deuterium incorporations are not corrected for ^{13}C and ^{34}S contributions.

***anti,anti*-2,6-Dichloro-9-thiabicyclo[3.3.1]nonane 9-Oxide (7).** To a stirred solution of 2.0067 g (0.0095 mol) of *anti,anti*-2,6-dichloro-9-thiabicyclo[3.3.1]nonane (**I**) in 30 mL of acetone was added 1 mL of 30% H_2O_2 and a catalytic amount of $VaSO_4$. The solution was stirred 24 h at room temperature and diluted with enough water to cause precipitation of **7** as a white solid. Filtration yielded 2.1 g of **7** (97.3%): mp 119–120 °C (lit.[7] mp 121–122 °C); ^1H NMR 1.55–2.8 (m, 8 H), 3.3 (br s, 2 H), 4.3 (m, 1 H), 4.95 (m, 1 H); ^{13}C NMR 17.1 (C4), 20.9 (C8), 31.0 (C3, C7), 52.4 (C2), 54.2 (C1, C5), 56.1 (C6); IR ($CHCl_3$ reference cell) 2981, 1485, 1045 (S–O stretch) cm^{-1}; mass spectrum, *m/e* (relative intensity) 239 (2.0) = M^+, 223 (67.3), 221 (100), 203 (32.3), 117 (29.3), 91 (41.7), 79 (35.6), 77 (43.0).

***anti,syn*-2-Chloro-6-deuterio-9-thiabicyclo[3.3.1]nonane 9-Oxide (8).** To a stirred solution of 1.502 g (0.0066 mol) of *anti,anti*-2,6-dichloro-9-thiabicyclo[3.3.1]nonane 9-oxide (**7**) in 15 mL of anhydrous tetrahydrofuran (THF) under nitrogen was added 30 mL of 1.0 M lithium triethylborodeuteride (Super-Deuteride) in THF. The mixture was refluxed for 7 days and then quenched cautiously with 5 mL of water. An additional 50 mL of water was added and the aqueous layer was extracted with ether (3 × 50 mL). The combined ether extracts were dried (Na_2SO_4) and the solvent was stripped. The resulting yellow oil was dissolved in $CHCl_3$ and stirred over basic alumina to remove traces of boron compounds. The alumina was removed by filtration and the chloroform stripped to yield 0.31 g (58.6%) of **8**: mp 117–118 °C; ^1H NMR 1.4–3.4 (br m, 11 H), 4.75–5.25 (m, 1 H); ^{13}C NMR 19.4, 21.9, 23.9, 27.3, 29.21, 29,18, 31.5, 47.5, 53.1; ^2H NMR 2.02; IR ($CHCl_3$ reference cell) 2985, 1485, 1035 (S–O stretch) cm^{-1}.

***syn*-2-Deuterio-9-thiabicyclo[3.3.1]nonane (9).** To a stirred solution of 0.705 g (0.0036 mol) of *anti,syn*-2-chloro-6-deuterio-9-thiabicyclo[3.3.1]nonane 9-oxide (**8**) in 20 mL of anhydrous diethyl ether was added 0.7074 g (0.0168 mol) of lithium aluminum hydride. The mixture was stirred 24 h at room temperature under nitrogen and quenched by catious addition of saturated Na_2SO_4 solution. The lithium salts were removed by suction filtration and the filtrate was dried over anhydrous Na_2SO_4. Solvent was stripped and the crude residue was purified by sublimation (100 °C, 20–25 mmHg) to yield 0.306 g (58.6%) of **9**, mp 164–166 °C (sealed capillary): ^1H NMR 1.5–2.3 (br m, 11 H), 2.85 (br s, 2 H); ^{13}C NMR 21.5 and 21.6 (C3, C7), 31.7 (C6, D-coupled triplet, *J*: 50 Hz), 32.1 (C2, C4, C8), 33.2 (C1, C5); ^2H NMR 2.14; IR (film) 2980, 1485 cm^{-1}.

***anti,anti*-2,6-Dideuterio-9-thiabicyclo[3.3.1]nonane (5).** Reduction of 2.052 g (0.0097 mol) of **1** in 50 mL of dry diethyl ether with 0.233 g (0.0055 mol) of lithium aluminum deuteride was conducted as described in the general procedure. The yield was 1.395 g (99.6%) of **5**: mp 173 °C (sealed capillary); ^1H NMR 1.6–2.3 (m, 11 H) 2.8 (br s, 2 H); ^{13}C NMR 21.5 (C3, C7), 31.8 (C2, C6; D-coupled triplet; *J* = 45 Hz), 32.0 (C4, C8), 33.1 (C1, C5); ^2H NMR 1.9; IR (film) 2980, 1483 cm^{-1}; mass spectrum, *m/e* (relative intensity) 144 (63.5 = M^+, 143 (3.5), 142 (0.4), 11 5 (32.1), 102 (91.2), 88 (100), 68 (44.1).

Reduction of 0.813 g (0.0027 mol) of **2** in 20 mL of THF with 0.248 g (0.0059 mol) of lithium aluminum deuteride as described in the general procedure yielded 0.358 g (91.6%) of **5**, mp 168–169 °C (sealed capillary). Spectral properties were the same as those reported above.

Reduction of 2.001 g (0.0095 mol) of **1** in 10 mL THF with 38 mL of 1.0 M Super-Deuteride in THF according to the general procedure gave an oil, the principle component of which, according to the ^{13}C NMR spectrum, was 9-thiabicyclo[3.3.1]nonadiene. Reduced material was isolated by crystallilzation from methanol and sublimation, leading to 0.095 g (6.9%) of **5**, mp 164–165 °C (sealed capillary). Spectral properties were the same as those reported above.

Reduction of 4.023 g (0.134 mol) of **2** in 20 mL of THF with 50 mL of 1.0 M Super-Deuteride in THF according to the general procedure gave an oil containing diene. Pure reduction product was obtained by recrystallization for methanol–ether and sublimation: 0.0304 g (17%), mp 164–165 °C (sealed capillary). Spectral properties were the same as those reported above.

***anti,anti*-4,8-Dideuterio-2-thiaadamantane (6).** Reduction of 0.603 g (0.0027 mol) of **3** in diethyl ether with 0.475 g (0.0113 mol) of lithium aluminum deuteride according to the general procedure gave 0.326 g (77.6%) of **6**: mp 287–289 °C (sealed capillary); ^1H NMR 1.8–2.3 (m, 11 H), 2.8 (br s, 2 H); ^{13}C NMR 27.2 (C5, C7), 33.6 (C1, C3), 36.9 (C6), 38.5 (C9, C10), 38.1 (C4, C8; D-coupled triplet, *J* = 45 Hz); ^2H NMR 2.09; IR (film) 2900, 2840, 1300 cm^{-1}; mass spectrum *m/e* (relative intensity) 156 (100) = M^+, 155 (3.7), 154 (0.2), 98 (15.6), 81 (22.6), 80 (75.7), 79 (40.3).

Reduction of 1.000 g (0.0045 mol) of **3** in 16 mL of THF with 18 mL of 1.0 M Super-Deuteride in THF yielded 0.166 g (23.6%) of **6**, mp 284–285 °C (sealed capillary). Spectral properties were the same as those reported above.

Acknowledgment. We are grateful to Dr. Robert Anderegg, Mary Deysher, and Dave Morison of the University of Maine Mass Spectrometry Facility for obtaining the mass spectra. The Hewlett-Packard 5985 GC/MS was purchased with the aid of a grant from the Chemical Instrumentation Division of the National Science Foundation. We thank Raj Subramaniam and Bud Lester for help with the ^2H NMR spectra.