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(21) The readers might be interested in our previous argument [*Nature (London)*, **242**, 605 (1973); *J. Am. Chem. Soc.*, **95**, 4031 (1973)] that polymers cannot be regarded as catalysts if one follows the definition of Ostwald.
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(29) In the presence of KCl, C_{16}BzPVP was found to be a weak catalyst for the alkaline hydrolysis of PNPA, though striking acceleration effect was observed for more hydrophobic esters, *p*-nitrophenyl laurate, for example.[27]

Solvolyses of 2-*endo*- and 2-*exo*-Chloro-7-thiabicyclo[2.2.1]heptanes[1]

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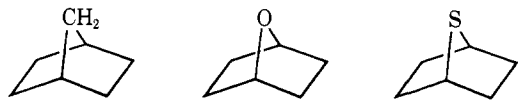
Abstract: 2-*endo*-Chloro-7-thiabicyclo[2.2.1]heptane (**5**) was prepared from the corresponding alcohols (2-exo and 2-endo alcohols) exclusively by common chlorination procedures. However, 2-*exo*-chloro-7-thiabicyclo[2.2.1]heptane (**7**) was only available by the selective reduction of 2-*exo*-chloro-7-thiabicyclo[2.2.1]heptane 7,7-dioxide with $LiAlH_4$. The kinetics of solvolyses of these two epimeric chlorides have been measured. Acetolysis of the endo chloride was observed to follow the second-order kinetics, $v = k$[R–Cl][AcONa]. The mechanism involving rate-determining attack of nucleophile (AcO^-) to the sulfonium intermediate (**11**) was first observed in the acetolyses of **5**, which related to the stereospecific product formation (100% endo) and the profound acceleration by a factor of at least 4.7×10^9 compared with the exo chloro counterpart (**7**). Hydrolysis of **7**, which followed the first-order kinetics, gave skeletally rearranged 3-*exo*-hydroxy-2-thiabicyclo[2.2.1]heptane.

A large amount of kinetic and mechanistic investigations has been performed on the solvolyses of various norbornyl derivatives (**1**).[3a-c] The rate-retarding effects of an oxygen bridge substituted in the place of the methylene bridge of norbornane were observed by Martin and Bartlett[3d] (**2**), in-



1 2 3

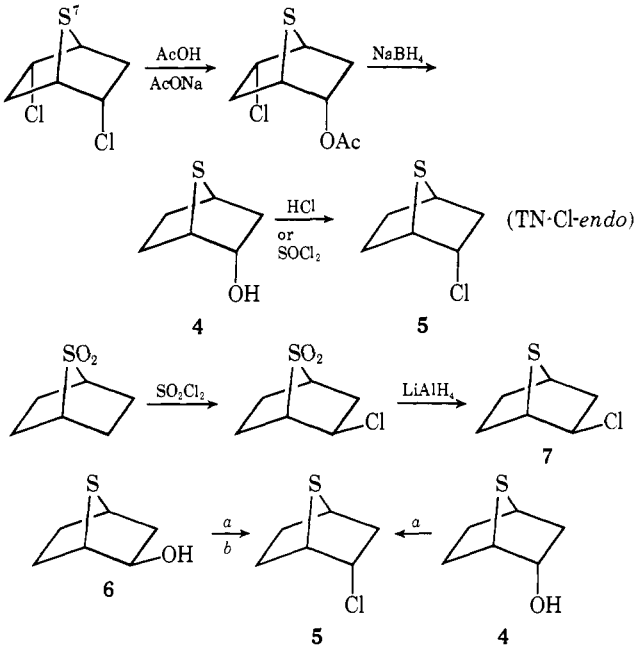
dicating that the inductive effect of oxygen atom overcame the participation by 2p lone pair electrons on oxygen[4] and the incipient carbonium ion was rather destabilized. The neighboring sulfur atom has long been known as a very effective participating group, more effective than oxygen in β or remote participation.[5] In order to gain further insights into the sulfur participation in solvolysis, 2-exo- and 2-endo chlorides of 7-thiabicyclo[2.2.1]heptane (**3**) of known geometry[6] were prepared and solvolyses of them were performed to investigate the electronic and steric effects on the neighboring sulfur participation.

Results

2-*endo*-Chloro-7-thianorbornane (**5**) was prepared from 2,5-bis-*endo*-dichloro-7-thianorbornane[7] via the series of reactions as shown in Scheme I, involving the interesting stereospecific and practically quantitative endo chlorination of the corresponding endo alcohol (**4**) (overall yield of **4** from the dichloride was 73%). Partial reduction of 2,5-bis-*endo*-dichloro-7-thianorbornane with $NaBH_4$ also gave endo chloride **5** together with the recovered dichloride and thianorborane, which was identical with the chloride synthesized via Scheme I in every respect (GLC, ir, NMR).

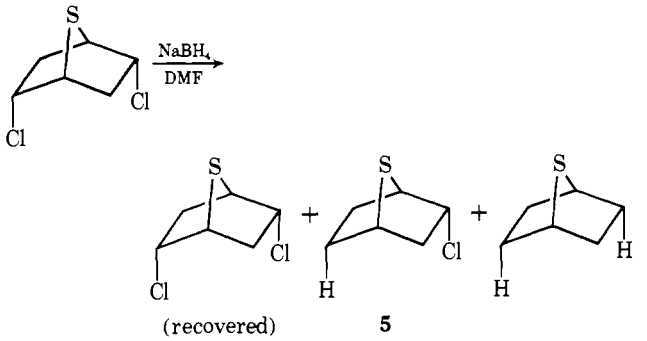
2-*exo*-Chloro-7-thianorbornane (**7**) was, on the other hand, prepared from 7-thianorbornane dioxide via cationic chlorination with SO_2Cl_2[8,9] and the successful partial reduction with lithium aluminum hydride (see Scheme I). Endo alcohol **4** was successfully oxidized to 7-thianorborna-

Scheme I



[a] $SOCl_2$ in dioxane or pyridine. [b] Poor yield.

Scheme II



none-2 in almost quantitative yield. Reduction of 7-thianorbornanone-2 with $NaBH_4$ gave selectively 2-*exo*-hydroxy-7-thianorbornane (**6**) (81%), along with a minor amount of 2-endo alcohol (**4**) (19%), in a marked contrast to that of norbornanone-2, which gave 85% of the 2-*endo*-hydroxynorbornane and 15% of the exo-hydroxy counterpart.[10]

This interesting stereochemistry, which was also observed for the thiasteroid,[11] is interpreted by assuming that steric requirement of the sulfur bridge is larger than that of endo hydrogens at C_5 and C_6. The stereochemistry was determined on the basis of the NMR coupling pattern as well as hydrogen bonding observed by ir. For the exo alcohol only intramolecular hydrogen bonding absorption was observed (narrow band, ν_{OH} = 3531 cm^{-1} in CCl_4 and 3534 cm^{-1} in *n*-hexane) even in very dilute solution (to 4 × 10^{-3} *M*), whereas for the endo alcohol, intermolecular hydrogen bonding absorption (broad band centered at 3477 cm^{-1} in CCl_4), together with monomeric ν_{OH} at 3620 cm^{-1} in CCl_4 or 3625 cm^{-1} in *n*-hexane, was observed only in relatively concentrated solution (8.7 × 10^{-2} *M*) and in dilute solution (1.5 × 10^{-2} *M*) only monomeric ν_{OH} (at 3620 cm^{-1}) was observable.

Both 2-*endo*- (**8**) and 2-*exo*-acetoxy-7-thianorbornane (**9**) were prepared from the corresponding alcohols by the treatment with acetic anhydride in pyridine in practically quantitative yields (Scheme III).

As is generally observed for the NMR spectra of norbornane derivatives, the absorption of the 2-exo proton attached to a carbon bearing an oxygen function or halogen

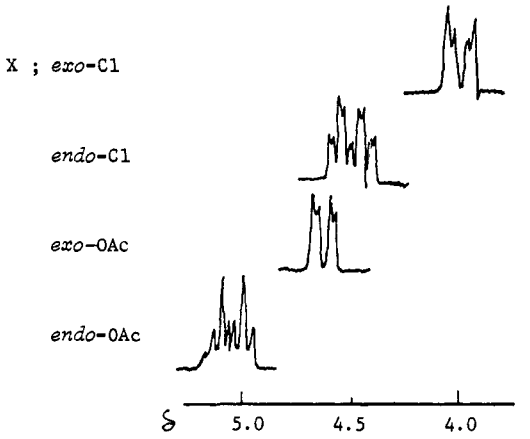
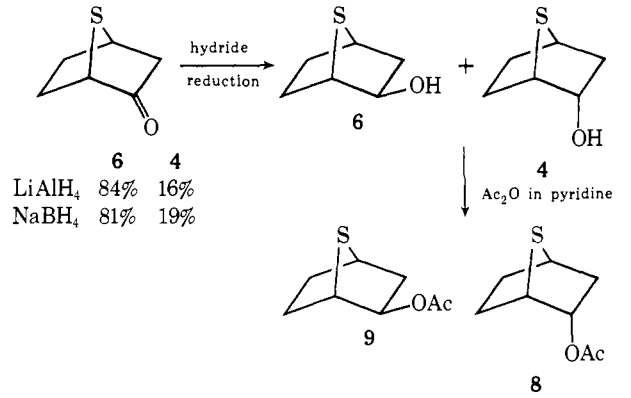


Figure 1. NMR spectra of TN-X (-C_2HX-).

Scheme III



atom appeared as a doublet of triplets at 0.3-0.4 ppm lower field than the corresponding endo proton which appeared as a somewhat broad doublet (see Figure 1).

The acetolysis rate of endo chloride **5**, investigated in the presence of sodium acetate, showed the pseudo-first-order rate constant to be proportional to the base concentration (see Table I). Thus, the acetolysis was concluded to be a second-order reaction (see Discussion).

Since the acetolysis of exo chloride **7** was too slow to be measured, the rate of its hydrolysis in aqueous dioxane was investigated to find that first-order kinetics were satisfied. In Table II are listed the first-order rate constants at different temperatures. The product of the hydrolysis was found

Scheme IV. Solvolysis of **5** and **7**

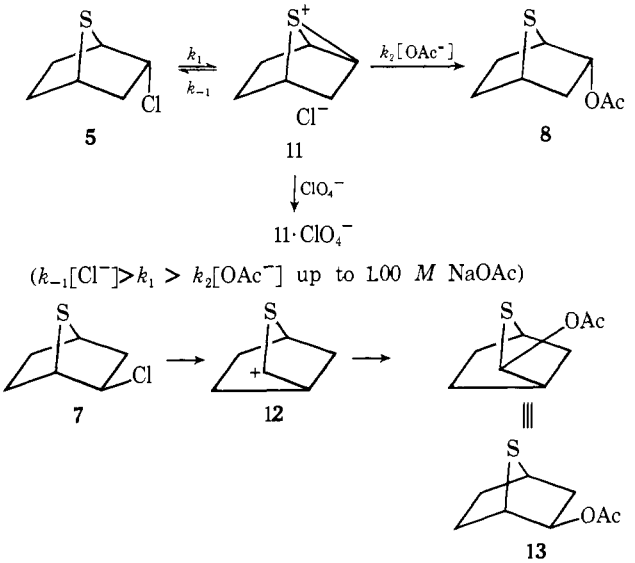


Table I. Acetolysis of 2-*endo*-Chloro-7-thianorbornane[a] (5)

Temp, °C	[NaOAc], *M*	[NaOAc]/[5]	Reaction, %	k_1(app), sec^{-1}	k_2(app), M^{-1} sec^{-1}
45.3	1.00	20	88.3	1.10×10^{-3}	$1.10 \pm 0.03 \times 10^{-3}$
44.9	0.50	10	91.5	4.4×10^{-4}	$0.95 \pm 0.03 \times 10^{-3}$
45.0	0.25	5	63	3.8×10^{-4}	$1.42 \pm 0.15 \times 10^{-3}$
45.6	0.10	2	77.4	1.4×10^{-4} [d]	$1.38 \pm 0.04 \times 10^{-3}$
45.1	0.05	1	88.4	8.5×10^{-5} [d]	$1.75 \pm 0.03 \times 10^{-3}$ [c]
45.2	0.025	0.5	93.4	5.1×10^{-5} [d]	$2.32 \pm 0.05 \times 10^{-3}$
44.8	0.065[b]	0	68.4	2.9×10^{-6} [d]	
65.0	0.065[b]	0	71.8	2.9×10^{-5} [d]	
65.0	0.05	1	71.9	5.3×10^{-4} [d]	$1.08 \pm 0.02 \times 10^{-2}$ [c]

[a] [5] = 0.05 *M*. [b] Molarity of urea. [c] $\Delta H^{\ddagger} = 18.8$ kcal/mol, $\Delta S^{\ddagger} = -21.0$ eu at 45°. [d] First-order treatment did not give a straight line but rather a curve as shown in Figure 2.

Table II. Hydrolysis of 2-*exo*-Chloro-7-thianorbornane (7) in Aqueous Dioxane[a]

Vol % of dioxane	Temp, °C	k_1, sec^{-1}	$\Delta H^{\ddagger}$, kcal/mol	$\Delta S^{\ddagger}$, eu	k_1[b] (25°)
50	110.0 ± 0.2	5.28×10^{-6}	25.5	−12.3	
	130.0 ± 0.2	2.69×10^{-5}			
	150.0 ± 0.2	1.38×10^{-4}			
	(25.0)				2.60×10^{-10}
70	130.0 ± 0.2	2.06×10^{-6}	28.6	−9.6	
	150.0 ± 0.2	1.08×10^{-5}			
	170.0 ± 0.2	5.68×10^{-5}			
	(25.0)				4.90×10^{-12}

[a] [7] = 0.002 *M*. [b] A value extrapolated to 25° with the Arrhenius equation.

Table III. Endo/Exo Reactivity Ratio in Solvolytic Reactions

Substrate	Solvent	Temp, °C	k_1, sec^{-1}	k_{endo}/k_{exo}
2-*endo*-Chloro-7-thia-norbornane (5)	AcOH	45.0	1.1×10^{-3}	
		25.0	1.8×10^{-4} [a]	
2-*exo*-Chloro-7-thia-norbornane (7)	50% dioxane	130.0	2.69×10^{-5}	4.7×10^{9} (25°)
		25.0	2.60×10^{-10} [a]	
	AcOH	25.0	3.80×10^{-14} [b]	
2-*endo*-Chloronorbor-nane[c]	80% EtOH	85.0	6×10^{-7}	1.5×10^{-2} (85°)
2-*exo*-Chloronorbor-nane[c]	80% EtOH	85.0	3.9×10^{-5}	
2-*endo*-Chloro-7-oxa-norbornane[d]	50% dioxane	146.0	3.49×10^{-7}	
		25.0	1.2×10^{-13} [a]	3.1×10^{-3} (25°)
2-*exo*-Chloro-7-oxa-norbornane[d]	50% dioxane	140.0	5.66×10^{-5}	
		25.0	3.8×10^{-11} [a]	

[a] A value extrapolated to 25°. [b] A value in acetic acid calculated by Grunwald–Winstein equation ($m = 1.28$ for 7). [c] J. D. Roberts, W. Bennett, and R. Armstrong, *J. Am. Chem. Soc.*, 72, 3329 (1950). [d] J. C. Martin and P. D. Bartlett, *J. Am. Chem. Soc.*, 79, 2533 (1957).

to be 3-*exo*-acetoxy-2-thianorbornane (**13**), where the characteristic NMR absorption of the proton α to acetoxyl appeared at δ 5.03 (TMS, in $CDCl_3$) as a doublet ($J_{3endo\text{-}4}$ was 0.1–0.3 Hz) (see Scheme IV). For comparison of the relative reactivities of **5** and **7** on the same standard, the rate constants were extrapolated to 25° by the Arrhenius equation, and the rate of **7** extrapolated to acetic acid solvent was calculated by the Grunwald-Winstein equation,[12] $\log k/k_0 = mY$ ($m = 1.28$ for **7**).

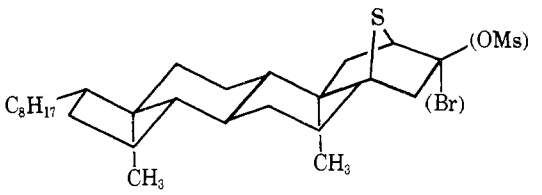
In Table III are listed the exo/endo reactivity ratios of **5** to **7** with those of norbornyl chlorides[13] and 7-oxanorbornyl chlorides.[2]

Discussion

Kinetics and Mechanisms. Although neighboring sulfur participation in solvolysis is well known, the observations supporting the idea were limited to the rate enhancement and/or the stereospecific product formation.[14,15]

Tanida and his coworkers[16] have studied the hydrolyses of 3-exo mesylate and 3-endo bromide of thiasteroid (**10**) where large acceleration (k_{endo}/k_{exo}; 1.2×10^8 after corrections were made for the leaving group as well as solvent) and exclusive formation of the endo product were only reported.

In a marked contrast, the present acetolysis of 2-*endo*-chloro-7-thianorbornane (**5**) was found to involve a novel



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type of the β-sulfur participation, where the observed rate-determining step was not the SN1 ionization, but the acetate ion attack on the sulfonium ion (**11**) thus formed (i.e., the SN1 ionization process was too fast to be a rate determining by virtue of the very effective sulfur participation). Thus, as shown in Table I, the first-order rate constants increased as the concentration of sodium acetate increased, but the second-order rate constants were practically constant, although a small but appreciable salt effect was observed. If the initial acetate concentration was low, a marked decrease in a pseudo-first-order rate constant was observed during the reaction where the second-order rate equation gave satisfactory results (see Figure 2). The observed value of the entropy of activation (−21.0 eu, in accord with the bimolecular mechanism[17]) and exclusive retention of the configuration (via double inversion) of the product (the endo acetate from the endo chloride) also support the mechanism. Acetolyses of some related β-chloro

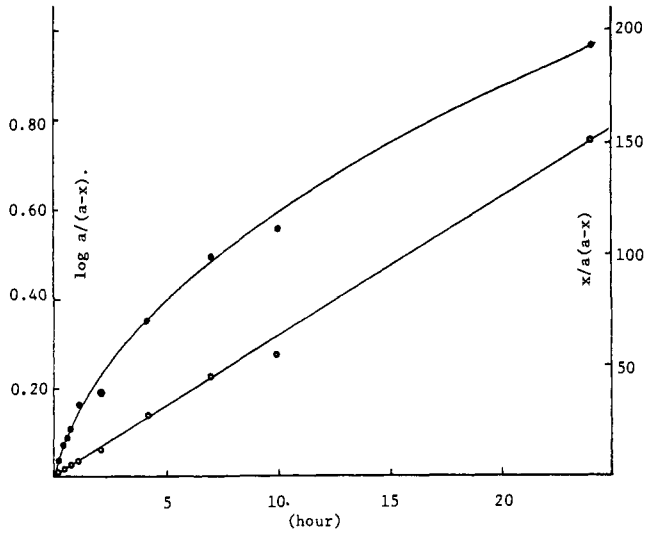
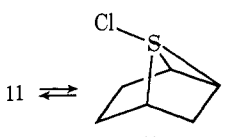


Figure 2. Solvolysis of **5** (0.05 *M*) in acetic acid containing 0.05 *M* of NaOAc at 45.0°: (●) first-order plot; (○) second order plot.

sulfides (β-chloroethyl methyl sulfide, and 3-chloropropene sulfide[18]) were investigated for comparison and simple SN1 kinetics were observed, in accord with the hydrolyses[19] of β-chloro sulfides but in a contrast to the acetolysis of **5**. The rearranged product (of Wagner-Meerwein type) (**13**) was formed exclusively from **7**,[20a] indicating that the sulfur participation was not important for the exo isomer (see Scheme IV). Endo chloride **5** showed an extremely enhanced solvolysis rate while exo chloride **7** showed a remarkably decelerated rate (vide infra) and the first-order rate ratio, k_{exo}/k_{endo} amounted to 4.7×10^9 or more, also indicating the presence of the strong sulfur participation in **5** and its absence in **7**. All of these facts, the marked difference in the rate equation, the marked difference in products, and the marked difference in rate (very large acceleration and large deceleration), demonstrate that the sulfur participation is very sensitive to steric environment and that sulfur participation is extremely effective in the endo chloride, the vacant orbital of which developing in the exo direction can overlap efficiently with lone pair electrons on sulfur.

Equilibration between Endo Chloride 5 and Sulfonium Ion II. An equilibrium constant, *K*, in acetic acid (see Scheme IV) was much smaller than unity on the basis of our observation that no appreciable NMR absorption attributable to **11** appeared for **5** dissolved in CD_3CO_2D. However, the presence of a rapid equilibrium became evident by elimination of the salt formed from the system. Thus, addition of lithium perchlorate into the acetic acid solution of **5** at room temperature immediately gave an as yet unidentified white amorphous precipitate with intense absorption at 100 cm^{-1} characteristic of perchlorate, which was most probably the corresponding sulfonium perchlorate.

Initial addition of chloride ion into a solvolysis run did not show a remarkable retardation, demonstrating that chloride ion had to be bound very tightly in some kinetically important intermediate. One plausible structure of the tightly bound chloride is covalently bound chlorosulfurane **11a**,[20b] slowly equilibrated with **11**. Formation of some



11a

chlorosulfuranes are reported in the literature.[20c,d]

Effect of β-Sulfur Atom on the Solvolysis Rate of Chloro Sulfides. It is interesting to note that *exo*-β-chloro sulfide

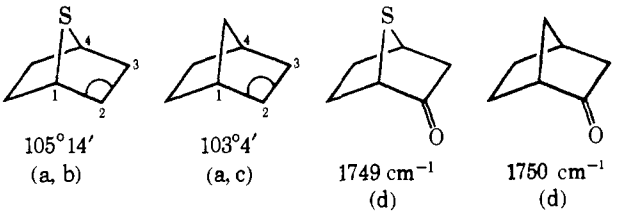


Figure 3. (a) $C_1C_2C_3$ angle determined by gas electron diffraction. (b) T. Fukuyama, K. Kuchitsu, Y. Tamaru, Z. Yoshida, and I. Tabushi, *J. Am. Chem. Soc.*, **93**, 2799 (1971). (c) Y. Morino, K. Kuchitsu, and A. Yokozeki, *Bull. Chem. Soc. Jpn.*, **40**, 1552 (1967). (d) Values of carbonyl stretching vibration maxima observed for the 2.5% solutions in CCl_4.

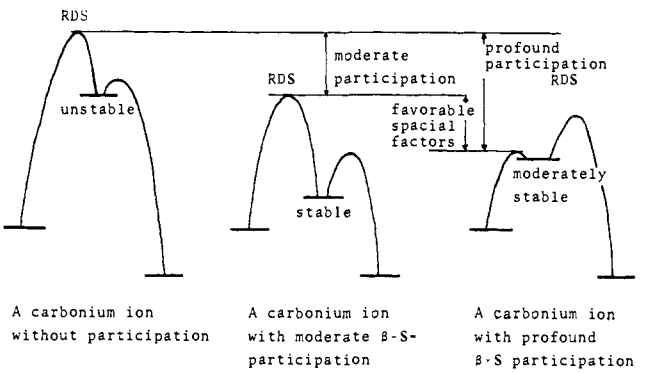


Figure 4. A plausible schematic energy profile. Energy coordinate is taken arbitrarily since the second barrier corresponds to the second-order kinetics. RDS is the rate-determining step.

(**7**) was 2000 times less reactive than 2-*exo*-chloronorbornane in spite of the fact that both chlorides have practically the same angle ($C_1C_2C_3$) as determined by electron diffraction[5,21] or by $\nu_{C=O}$[22] (see Figure 3). This deceleration by introduction of a sulfur atom into the β position seems to be due to electron withdrawal by the sulfur atom, but some other unknown effect must also be operative since the rate of **7** was only seven times faster than that of 2-*exo*-chloro-7-oxanorbornane, although the electron withdrawal by oxygen should be considerably larger than that by sulfur. A rationale for these unusual reactivities may be given by consideration of the enhanced stability of a carbonium ion α to oxygen (2p–2p overlap) (**14**)[23] compared with that α to sulfur (2p–3p overlap) (**12**), both of which should be intermediates leading to the final products.

12 **14**

On correction for the solvent with the Grunwald-Winstein equation, the endo/exo rate ratio of **5** to **7** at 25° was estimated to be 4.7×10^9 or more,[24] the largest value ever reported for the effect of the sulfur participation (see Table III).

The unique kinetic behavior of **5** seems to be partly due to the profound acceleration, caused by a very appropriately located sulfur atom with respect to a developing carbonium ion (i.e., the spacial conditions are almost ideal for participation) and partly to the moderate stability of the sulfonium ion (much more stable than simple carbonium ions but probably less stable than usual sulfonium ions). The idea may be depicted in a schematic energy diagram as shown in Figure 4.

Experimental Section

Melting points (in sealed capillaries) were uncorrected. The elemental analyses were performed either at the Microanalysis Cen-

ter of Kyoto University or at the Faculty of Pharmaceutical Science of Kyushu University. Infrared spectra were measured with a Hitachi Model EPI-G3 grating spectrophotometer and NMR spectra were recorded with a Varian T60 and/or HA100 spectrometers. Mass spectra were measured with a Hitachi Model RMU 6C spectrometer.

2-*endo*-Acetoxy-5-*endo*-chloro-7-thianorbornane. 2,5-Bis-*endo*-dichloro-7-thianorbornane (20 g, 0.109 mol), prepared by the method of Corey and Block,[7] was treated with 360 ml of anhydrous acetic acid containing 35 g (0.427 mol) of anhydrous sodium acetate at 70°. The reaction was monitored by GLPC (SiDC 550, H_2, 170°). After 70 min, the reaction mixture, consisting of 45% of the starting dichloride, 45% of 2-*endo*-acetoxy-5-*endo*-chloro-7-thianorbornane, and 10% of 2,5-bis-*endo*-diacetoxy-7-thianorbornane (on the basis of relative area intensity, in the order of elution by GLC), was cooled externally with ice. After the treatment with saturated sodium bicarbonate and drying over magnesium sulfate, the solvent was distilled off. The residue (viscous liquid) was adsorbed on silica gel. Elution with petroleum ether and then petroleum ether–benzene (1:1) afforded 8.5 g of the dichloride, 8.77 g of the monoacetoxy monochloride, and 2.1 g of the diacetate. In the absence of sodium acetate, no appreciable substitution of chloride by acetoxyl was observed.

2-*endo*-Acetoxy-5-*endo*-chloro-7-thianorbornane: δ_{CCl_4} (TMS) 5.10 (doublet of triplets, J = 9 and 4.5 Hz, 1 H), 4.48 (doublet of triplets, J = 9 and 4.5 Hz, 1 H), 3.67 (multiplet, 2 H), 2.6–2.1 (multiplet, 4 H), and 2.06 (singlet, 3 H); ν_{max} (neat) 1748 (s), 1380 (m), 1240 (s), 1020 (m), and 675 cm^{-1} (m); *m/e* 206 (M^+, 3%), 150 (30), 127 (72), 99 (45), and 43 (100). 2,5-Bis-*endo*-diacetoxy-7-thianorbornane: bp 120–122° (1.0 mm); mp 66.5–67° (crystallization from *n*-hexane); δ_{CCl_4} (TMS) 5.10 (doublet of triplets J = 9 and 4.5 Hz, 2 H), 3.67 (triplet, J = 4.5 Hz, 2 H), 2.1–1.7 (multiplet, 4 H), and 2.05 (singlet, 6 H); ν_{max} (KBr) 1740 (s), 1440 (m), 1380 (m), 1240 (s), and 1030 cm^{-1} (s).

2-*endo*-Hydroxy-7-thiabicyclo[2.2.1]heptane (4). In a 2-l. round-bottom flask fitted with an efficient mechanical stirrer, a thermometer, and a reflux condenser was dissolved 45 g (1.18 mol) of sodium borohydride in 100 ml of dimethylformamide and 16 ml of dilute sodium hydroxide (pH 11). Into the mixture 7.6 g (33 mmol) of 2-*endo*-acetoxy-5-*endo*-chloro-7-thianorbornane dissolved in 40 ml of DMF was added dropwise for 1 hr with vigorous stirring with a mechanical stirrer at 55°. On stirring and heating at 55° overnight, the reduction was practically over and the excess of sodium borohydride was treated with saturated potassium sodium tartrate. After the evolution of hydrogen gas practically ceased, the reaction mixture was washed with 100 ml of water saturated with sodium chloride and dried over magnesium sulfate and then condensed to a waxy solid through a 10-cm Vigreux column under atmospheric pressure. Ir spectrum of the crude product exhibited strong ν_{C-O} and ν_{O-H} absorptions at 1035 and 3040 cm^{-1} together with weak ν_{B-H} and $\nu_{C=O}$ absorptions (of DMF) at 2350 and 1670 cm^{-1}, respectively. Recrystallization from benzene–hexane gave 3.8 g (88.5%) of **4**; mp 179–181°. Repeated recrystallization and sublimation (110° (110 mm)) gave pure **4**: mp 186.5–187.5° (in a sealed tube); δ_{CCl_4} (TMS) 4.30 (doublet of triplets, J = 3 and 11 Hz, 1 H), 3.5 (multiplet, 2 H), 2.73 (singlet, 1 H), 2.5–1.65 (multiplet, 5 H), and 1.14 (doublet of doublets, J = 3 and 12 Hz); ν_{max} (Nujol) 3350 (s), 1120 cm^{-1} (m), 1070 (s), 1035 (s), and 990 cm^{-1} (s); *m/e* 130 (M^+, 91%), 102 ($M^+ - C_2H_4$, 17), 97 (19), 87 (64), 86 ($M^+ - C_2H_4O$, 100), and 85 (90). Anal. Calcd for $C_6H_{10}OS$: C, 55.35; H, 7.74; O, 12.29; S, 24.63. Found: C, 55.31; H, 7.65; O, 12.51; S, 24.50.

2-*endo*-Chloro-7-thiabicyclo[2.2.1]heptane (5). Into a solution of 500 mg (3.84 mmol) of **4**, either in 10 ml of benzene or in 10 ml of diethyl ether, was introduced dry HCl at room temperature (with occasional external cooling with water) for about 2 hr. On treatment with saturated sodium bicarbonate and saturated sodium chloride, the organic layer was dried over magnesium sulfate and the solvent was distilled off through a 10 cm Vigreux column at atmospheric pressure. The residue (510 mg) of a transparent, waxy solid which was practically pure, was further purified by preparative GLC and sublimation (at 60–70° (760 mm)): mp 63.0–63.2° (in a sealed tube); *m/e* 150 ($P^+ + 2$, relative intensity 30), 148 (P^+, 74), 113 ($P^+ - Cl$, 53), and 85 (100); δ_{CDCl_3} (TMS) 4.45 (doublet of triplets, J = 10 and 4 Hz, 1 H), 3.83 (narrow multiplet, 2 H), 2.8–1.6 (multiplet, 5 H), and 1.57 (doublet of doublets, J = 13 and 4 Hz, 1 H); ν_{max} (neat) 3030, 2950, 2865, 1463, 1458, 1307, 1208, 933, 844, and 665 cm^{-1}. Anal. Calcd for C_6H_9SCl: C, 48.48; H, 6.10. Found: C, 48.56; H, 6.00.

Endo Chloride 5 from Partial Reduction of 2,5-Bis-*endo*-dichloro-7-thianorbornane. A solution of 0.5 g of 2,5-bis-*endo*-dichloro- 7-thianorbornane in 2 ml of dimethylformamide was added into the mixture of 1.2 g of $NaBH_4$, 5 ml of dimethylformamide, and 1 ml of aqueous NaOH (pH 11) at 50°. After 7–10 min, the reaction was quenched by addition of *n*-hexane and water (12% of the dichloride reacted in this condition). After extraction with *n*-hexane, the hexane solution was dried with anhydrous $MgSO_4$ and the products were analyzed by GLC, showing 88% dichloride was recovered and 8% of thianorbornane together with of a monochloride was formed. The monochloride was identical with that prepared via Scheme I, on the basis of GLC, ir, and NMR spectra.

Reduction of 2-Oxo-7-thiabicyclo[2.2.1]heptane. (a) With $LiAlH_4$. Into a suspension of 200 mg (5.26 mmol) of $LiAlH_4$ in 50 ml of dry ether was added a solution of 200 mg (1.56 mmol) of 2-oxo-7-thianorbornane, obtained from the chromic acid oxidation of **4**, in 10 ml of dry ether at room temperature. After being stirred for 30 min, the excess $LiAlH_4$ was destroyed in the usual way and combined ether extracts were dried over magnesium sulfate. Evaporation of solvent gave 195 mg of a white solid. The product composition of the reduction was determined by GLC (SiDC 550 and PEG) to be 84% of **6** and 16% of **4**.

(b) With $NaBH_4$. Into a solution of 200 mg (1.56 mmol) of 2-oxo-7-thianorbornane in 5 ml of methanol–THF (1:7) was added 200 mg (5.26 mmol) of $NaBH_4$. After being stirred for 2 hr at room temperature, usual work-up gave 200 mg of a mixture of **4** (19%) and **6** (81%). 2-*exo*-Hydroxy-7-thiabicyclo[2.2.1]heptane (**6**): mp 141.5–143.0° (in a sealed tube, with sublimation); δ_{CDCl_3} (TMS) (100 MHz) 3.80 (doublet of triplets, J = 6 and 1.5 Hz, 1 H, not well resolved), 3.7 (multiplet, 2 H), 2.1–1.4 (multiplet, 6 H), and 1.9 (singlet, 1 H); ν_{max} (Nujol) 3405, 1112, 1080, and 1012 cm^{-1}; *m/e* 130 (P^+, 97.3%), 112 (9.2), 102 (40), 97 (13), 87 (65), 86 (92), and 85 (100). Anal. Calcd for $C_6H_{10}OS$: C, 55.35; H, 7.74; S, 24.63. Found: C, 55.13; H, 7.99; S, 24.33.

2-*exo*-Acetoxy-7-thiabicyclo[2.2.1]heptane (9). A solution of 100 mg (0.77 mmol) of **6** in 0.5 ml of acetic anhydride and 0.5 ml of dry pyridine was allowed to stand for 2 days at room temperature and poured into cold water and extracted repeatedly with ether. Combined ether extracts were treated with dilute hydrochloric acid and dried over magnesium sulfate. Evaporation of ether through a 10-cm Vigreux column gave 120 mg of a colorless oil. Preparative GLC gave pure **9**: δ_{CCl_4} (TMS) 4.78 (doublet of doublets J = 7 and 3 Hz, 1 H), 3.77 (broad singlet, 2 H), 2.3–1.3 (multiplet, 6 H), and 2.02 (singlet, 3 H); *m/e* 172 (P^+, 20%) 129 (45%), and 85 (100%); ν_{max} (neat) 1740, 1380, 1360, 1243, 1070, and 1120 cm^{-1}. Anal. Calcd for $C_8H_{12}SO_2$: C, 55.78; H, 7.02. Found: C, 55.78; H, 7.06.

Chlorination of 4 and 6 with Thionyl Chloride in Dioxane. 4 (20 mg, 0.154 mmol) was treated with 18.3 mg (0.154 mmol) of thionyl chloride dissolved in 1.0 ml of dry dioxane at room temperature for 30 min. After usual work-up, the quantitative formation of **5** was observed by GLC determination using cyclododecane as an internal standard. Using similar conditions, 2-*exo*-hydroxy-7-thianorbornane was recovered, and only prolonged reaction (3–4 hr) at elevated temperature (80°) gave **5** in a low yield (3–5%) with practically quantitative recovery of **6**. Thus, the treatment of a mixture of 20 mg (0.154 mmol) of **4** and **6** (20 and 80%, respectively) with 18.3 mg (0.154 mmol) of thionyl chloride in dry dioxane at room temperature for 30 min gave a mixture of chloride **5** and recovered alcohol **6** (20 and 80%, respectively, i.e., the complete conversion of the endo alcohol and complete recovery of the exo alcohol). These observations seem to reflect the relative case for the carbonium ion formation from endo and exo leaving groups.

Acetolysis of 2-*endo*-Chloro-7-thianorbornane (5). A solution of 112 mg (0.75 mmol) of **5** in 15 ml of acetic acid containing 615 mg (7.50 mmol) of anhydrous sodium acetate was allowed to stand at 45° overnight. The reaction mixture was poured into ether and treated with saturated sodium bicarbonate and saturated sodium chloride. After drying over magnesium sulfate, solvent was distilled off to give 121 mg of an oil, which was practically pure on the GLC determination. Structure of the product thus obtained was determined to be 2-*endo*-acetoxy-7-thianorbornane (**8**): δ_{CCl_4} (TMS) 5.03 (doublet of triplets, J = 10.5 and 3 Hz, 1 H), 3.75

(narrow multiplet, 2 H), 2.6–1.5 (multiplet, 5 H), 2.03 (singlet, 3 H), and 1.30 (doublet of doublets, J = 12 and 3 Hz, 1 H); ν_{max} (neat) 3030, 2980, 2950, 1748, 1375, 1240, and 1030 cm^{-1}; *m/e* 172 (22), 129 (59), and 85 (100). Anal. Calcd for $C_8H_{12}SO_2$: C, 55.78; H, 7.02. Found: C, 55.60; H, 6.92.

Hydrolysis of 2-*exo*-Chloro-7-thiabicyclo[2.2.1]heptane (7). The solution of 30 mg (0.2 mmol) of **7** in 1 ml of dioxane and 1 ml of water containing 20 mg (0.24 mmol) of sodium acetate was sealed in an ampoule and placed in an oil bath maintained at 130° for 3 days. After cooling, the reaction mixture was diluted with 3 ml of water and extracted with two portions of methylene chloride. Combined methylene chloride extracts were dried over magnesium sulfate and evaporated through a 10-cm Vigreux column to give 27 mg of a viscous oil. Purification of product by GLC or column chromatography was unsuccessful probably due to its instability. On the bases of NMR and ir spectra, the structure of the product was determined to be 3-*exo*-acetoxy-2-thiabicyclo[2.2.1]heptane (**13**):[25] δ_{CDCl_3} (TMS) (100 MHz) 5.03 (doublet, J = 0.1–0.3 Hz, 1 H), 3.48 (multiplet, 1 H), 2.06 (singlet, 3 H), 2.67 (multiplet, 1 H), 1.9–1.5 (multiplet, 6 H); ν_{max} (neat) 1735 (s), 1450 (m), 1260 (m), and 805 cm^{-1} (m).

Solvent. Anhydrous acetic acid was prepared by refluxing a solution of acetic anhydride in glacial acetic acid for 24 hr and subsequent distillation under N_2. Dioxane was dried by refluxing over sodium metal and the distillate at 100° was stored under nitrogen atmosphere.

Acetolyses of 5. **5** (37.1 mg, 0.25 mmol) was dissolved in an appropriate amount (up to 5.0 ml) of anhydrous acetic acid containing a given amount of sodium acetate, kept at the temperature for the kinetic measurements (±0.1°). From a thermostated volumetric flask, an aliquot of 0.5 ml was withdrawn directly into 10 ml of ether at the desired intervals. After treatment with saturated sodium bicarbonate and subsequent drying over sodium sulfate, the solution was carefully condensed to ca. 1 ml and the residual solution was analyzed by means of GLC on Silicone DC 550. From the relative area intensities of **5** to **8**, with or without *o*-dichlorobenzene as an internal standard, reactions were followed. The following equation, involving calibration factor independently determined, was applied to calculate the molar ratio.

$$\frac{\text{area intensity of } 5}{\text{area intensity of } 8} \times 1.33 = \frac{\text{mol of } 5}{\text{mol of } 8}$$

Titrimetric determination of liberated chloride by means of the Volhard method was also applied to the run of 0.05 *M* NaOAc and found it in an excellent agreement with the GLC determination.

Hydrolyses of 7. Into 5.0–7.0 ml of dioxane was dissolved ca. 3 mg of **7** and ca. 3 mg of diphenylmethane (as an internal standard) and 3.0–5.0 ml of distilled water was added into the mixture. Aliquots, four 2-ml portions, were taken out from the flask into ampoules. The sealed ampoules were placed in the thermostated bath (±0.2°). The rest of the 2 ml of sample was stored in a refrigerator as the sample at time zero. Each ampoule, taken out at the appropriate interval, was quenched in ice–water and treated with 10 ml of ether and distilled water. After drying over sodium sulfate, the solution was carefully condensed to ca. 1 ml and the residual solution was analyzed by means of GLC on Silicone DC 550. From the relative area intensities of **7** to diphenylmethane, percent reacted was determined. The first-order rate constants were obtained by a least-squares treatment of the data.

References and Notes

(1) The major part of the present study was presented to the Symposium of Organic Sulfur Chemistry, Kiryu, Gumma, Japan, February 1971, Abstracts of papers, p 56.

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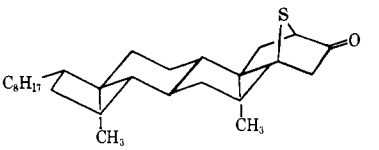

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