Tetrahedron Vol. 49, No. 37, pp. 8407-8414, 1993
Printed in Great Britain

0040-4020/93 $6.00+.00

Stereoelectronic Effect in Equilibration and Methoxy Exchange of Cyclic Methoxysulfonium Salts

István Jalsovszky,* Ferenc Ruff and Árpád Kucsman

Department of Organic Chemistry, Eötvös University, H-1518 Budapest 112, P.O. Box 17., Hungary

(*Received in UK* 6 *July* 1993)

Abstract. The conversion of alkylthiolanes and alkylthianes by *tert*-butyl hypochlorite in methanol yields an equilibrium mixture of *cis*- and *trans*-methoxysulfonium chlorides. The corresponding methoxysulfonium tetrafluoroborates prepared from sulfoxides by O-alkylation show equilibration and methoxy exchange in methanol containing chloride ions. The rate constants have been determined by ^{1}H NMR measurements, and an S_N(Ad+E) mechanism is proposed for these reactions. Both the greater thermodynamic stability of the *cis* isomers and the greater reactivity of the *trans* analogues are explained by stereoelectronic effect of σ(C-H) - σ*(S-X) type with X = OMe or Cl.

INTRODUCTION

Chiral sulfides (RR*S) can be converted to diastereoisomeric sulfoxides (RR*S*O) or sulfilimines (RR*S*NTs) in multistep reactions using chlorinating agents (e.g. *t*-BuOCl or TsNClNa) and suitable O- or N-nucleophiles.[1-3] For reactions carried out in solvents containing alcohol the diastereoselectivity is usually attributed to the intermediacy of $(RR^*S^*OQ)^+$ alkoxysulfonium ions[4,5] or that of RR*S*(OQ)Cl alkoxychlorosulfuranes.[1] On the other hand, the stereochemical instability of these intermediates has also been observed. In the presence of chloride ions they can undergo an equilibration between the stereoisomers and/or alkoxy interchange.[1,6] The diastereoselective oxidation of sulfides is a synthetic method widely used, while the separate Ad and E steps of these S_N-S-type reactions on sulfur are of theoretical interest.[1-8] That is what prompted us to study the stereoselective formation and reactivity of alkoxysulfonium salts in detail. As cyclic model compounds the derivatives of thiolane (**1a**), 2-methylthiolane (**1b**), thiane (**1c**), 2-methylthiane (**1d**) and 4-*tert*-butylthiane (**1e**) were chosen. The reactions investigated are shown in Fig. 1.

RESULTS AND DISCUSSION

Synthesis – Authentic samples of 1-methoxythiolanium fluoroborate (**3a**) and its 2-methyl homologues (*cis*- and *trans*-**3b**), as well as those of 1-methoxythianium fluoroborate (**3c**) and its 2-methyl (*cis*- and *trans*-**3d**) and 4-*tert*-butyl derivatives (*cis*- and *trans*-**3e**) were prepared from the corresponding sulfoxides by $(Me_3O)^+BF_4^-$. The O-alkylation proceeded with retention of configuration at sulfur.[9] The methoxysulfonium salts obtained were characterized by their ^{1}H NMR spectra (Table 1).

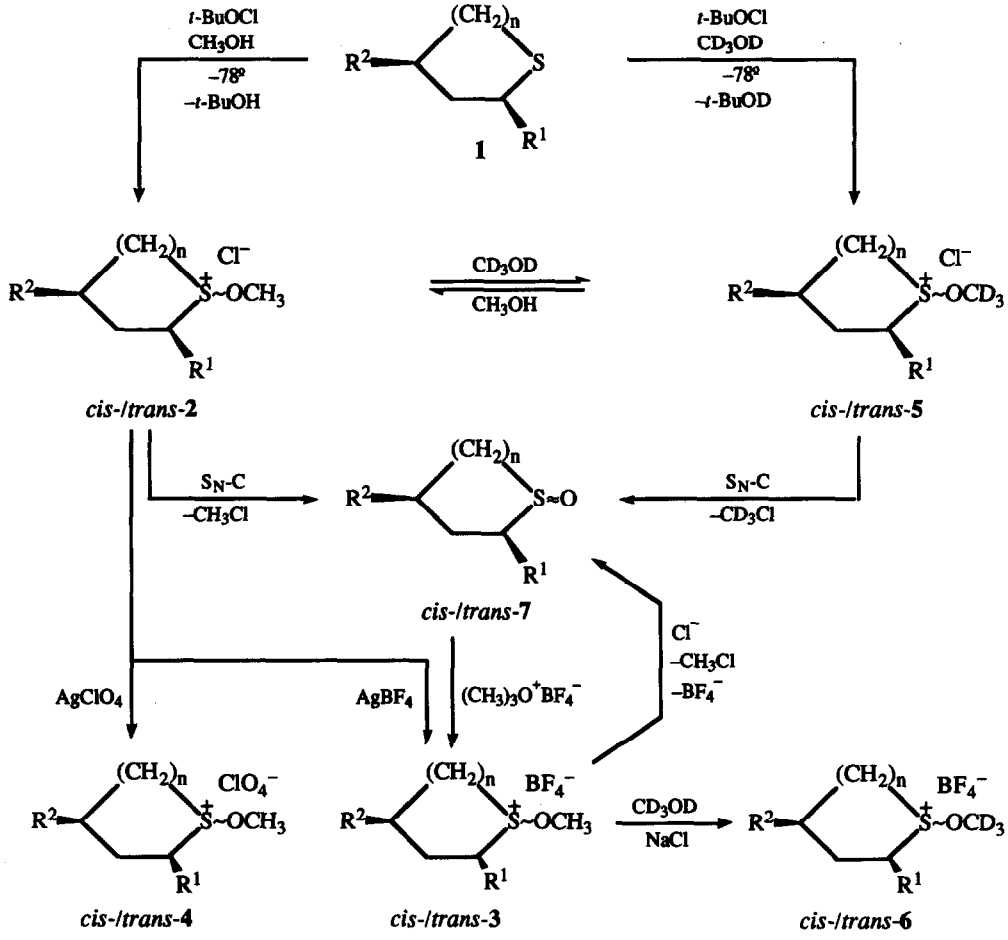

Fig. 1. Synthesis and reactions of cyclic methoxysulfonium salts (**a:** n = 1, R^1,R^2 = H; **b:** n = 1, R^1 = Me, R^2 = H; **c:** n = 2, R^1,R^2 = H; **d:** n = 2, R^1 = Me, R^2 = H; **e:** n = 2, R^1 = H, R^2 = *t*-Bu).

Conversion of sulfides with tert-butyl hypochlorite in methanol. In methanol or deuteromethanol, 2-methylthiolane (**1b**) and 2-methylthiane (**1d**) were treated with *t*-BuOCl at –78° to give methoxy- and deuteromethoxysulfonium chlorides (*cis–trans* mixtures of **2b**, **2d**, **5b** and **5d**, Table 1). These compounds could be obtained in solution, but they were too unstable to be isolated, reacting with chloride ions at the methoxy-carbon at room temperature, to yield methyl chloride and the corresponding sulfoxides (*cis/trans*-**7b** and *cis/trans*-**7d**; cf. Ref. 10). However, methoxysulfonium chlorides could be transferred to stable and readily isolable fluoroborates (**3b** and **3d**) or perchlorate (**4b**). These salts characterized by ^{1}H NMR (Table 1) proved to be mixtures of diastereoisomers: the *cis:trans* ratio was 70:30 for **3b** and **4b**, while 80:20 for **2d**, **3d** and **5d**.

The chemical shifts observed for the 2-methyl group in the ^{1}H NMR spectra of sulfonium chlorides (**2b**, **2d**, **5b** and **5d**), fluoroborates (**3b** and **3d**) and perchlorate (**4b**) are practically independent of the inorganic anion, giving support for the ionic alkoxysulfonium salt structure of all these compounds. In addition, no neutral alkoxychlorosulfurane intermediate (as proposed in Ref 1 for the reaction of thiane with *t*-BuOCl) was detectable by ^{1}H NMR method for the conversion **1b** → **5b** and **1d** → **5d** in deuteromethanol.

Table 1. ^{1}H NMR Chemical Shifts (δ) of Methyl Groups in Cyclic Sulfonium Salts[a]

Sulfonium salts	Substituents				Solvent[c]	δ(ppm)	
	1–X	Y	2-R^1	4-R^2		2-CH_3[d]	1-OCH_3
Thiolanium salts[b] $(R^1R^2C_4H_6SX)^{\oplus}Y^{\ominus}$							
2b[e]	OCH_3	Cl	CH_3	H	C	1.65	4.13
3a	OCH_3	BF_4	H	H	B	—	4.04
cis-**3b**	OCH_3	BF_4	CH_3	H	A	1.66	4.14
					B	1.64	4.11
trans-**3b**	OCH_3	BF_4	CH_3	H	A	1.61	4.12
					B	1.57	4.08
cis-**4b**	OCH_3	ClO_4	CH_3	H	A	1.68	4.18
trans-**4b**	OCH_3	ClO_4	CH_3	H	A	1.66	4.18
5b[e]	OCD_3	Cl	CH_3	H	B	1.65	—
cis-**6b**	OCD_3	BF_4	CH_3	H	B	1.62	—
trans-**6b**	OCD_3	BF_4	CH_3	H	B	1.56	—
Thianium salts[b] $(R^1R^2C_5H_8SX)^{\oplus}Y^{\ominus}$							
cis-**2d**	OCH_3	Cl	CH_3	H	C	1.54	4.27
trans-**2d**	OCH_3	Cl	CH_3	H	C	1.61	4.27
3c	OCH_3	BF_4	H	H	B	—	4.15
cis-**3d**	OCH_3	BF_4	CH_3	H	A	1.54	4.20
					B	1.55	4.20
trans-**3d**	OCH_3	BF_4	CH_3	H	A	1.65	4.25
					B	1.61	4.21
cis-**3e**	OCH_3	BF_4	H	t-C_4H_9	B	—	4.15
					D	—	3.89
trans-**3e**	OCH_3	BF_4	H	t-C_4H_9	B	—	4.15
					D	—	3.95
cis-**5d**	OCD_3	Cl	CH_3	H	B	1.55	—
trans-**5d**	OCD_3	Cl	CH_3	H	B	1.62	—
cis-**6d**	OCD_3	BF_4	CH_3	H	B	1.56	—
trans-**6d**	OCD_3	BF_4	CH_3	H	B	1.62	—

(a) Recorded at 37°C using TMS internal standard. (b) See Fig. 1. (c) A: $CDCl_3$; B: CD_3OD; C: CD_3OD-CH_3OH (6:1, v/v); D: CD_3NO_2-C_6D_6 (1:2 v/v). (d) Doublets. For the precursor sulfoxides *cis*-**7b**, *trans*-**7b**, *cis*-**7d** and *trans*-**7d** δ = 1.42, 1.25, 1.30 and 1.41 ppm were observed in $CDCl_3$, while 1.41, 1.30, 1.28 and 1.40 ppm in CD_3OD, respectively. (e) The signals of the *cis* and *trans* isomers are fused, see text.

^{1}H NMR spectra indicated that the reactions of **1b** and **1d** with *t*-BuOCl in deuteromethanol yielded **5b** and **5d**, respectively. To the mixture containing **5b** or **5d** was added methanol at –40°C. For the thiolane derivative a $CD_3O \rightarrow CH_3O$ exchange was observed (**5b** → **2b**), while the thiane derivative **5d** remained unaltered. On heating to 37°C **5b** underwent a rapid deuteromethoxy – methoxy exchange associated with a fast interconversion of the *cis–trans* isomers. Consequently only one doublet assigned to 2-methyl group was found in the ^{1}H NMR spectrum of both **2b** and **5b** at 37°C (Table 1). For **5d** the $CD_3O \rightarrow CH_3O$ exchange and equilibration was rather slow even at 37°C, so the 2-methyl signals of the *cis* and *trans* isomers appeared separately. The methoxy-exchange reactions occurring for **5b** and **5d** provide further support for the ionic nature of these species.

Table 2. *Cis*:*Trans* Product Distributions and Rate Constants k_{eq} and k_{ex} for the Chloride-Ion Catalyzed Equilibration and Methoxy-Exchange Reactions of Methoxythiolanium and Methoxythianium Tetrafluoroborates[a]

Sulfonium salt	*cis*:*trans* starting	*cis*:*trans* equilibrium	$10^3.k_{eq}$ (s^{-1})	$10^3.k_{ex}$ (s^{-1})
3a	—	—	—	110
cis-**3b**	100:0	72:28	5.5	11
trans-**3b**	0:100	72:28	16	43
cis-**3b**[b]	98:2	70:30	2.5	2.8
trans-**3b**[b]	10:90	70:30	5.7	14
3c[c]	—	—	—	1.2
cis-**3d**	90:10	80:20	—	0.055
trans-**3d**	0:100	80:20	—	1.9
cis-**3e**	100:0	80:20[d]	—	0.37
trans-**3e**	0:100	80:20[d]	—	5.0

(a) See Fig. 1. Solvent: deuteromethanol. The concentrations of the saturated NaCl solutions were 0.153 M (at 21°C) and 0.152 M (at 37°C). Sulfonium salt concentrations were calculated from ^{1}H NMR spectra recorded at 37°C, see Table 1 and text. The measurements were accurate to within ±5%. (b) ^{1}H NMR spectra were recorded at 21°C. (c) The 1-axial:1-equatorial = x:(1-x) = 82:18 ratio of conformers was calculated from equation $k_{ex}(\mathbf{3c}) = x.k_{ex}(cis\text{-}\mathbf{3e}) + (1\text{-}x)\,k_{ex}(trans\text{-}\mathbf{3e})$; cf. Ref. 16. (d) Since the ^{1}H NMR signals of *cis*-**3e** and *trans*-**3e** are fused in CD_3OD the mixture was isolated in form of fluoroborate and its spectrum with separated methoxy signals was recorded in CD_3NO_2-C_6D_6 (1:2 v/v) solvent (see Table 1).

Alkoxy exchange and equilibration catalyzed by chloride ions. Pure samples of diastereoisomeric methoxysulfonium fluoroborates, *cis*-**3b**, *trans*-**3b**, *cis*-**3d** and *trans*-**3d** were dissolved in deuteromethanol and an excess of solid NaCl was given to saturate the solutions. (Note that the solubility of NaCl is poor, cf. Table 2.) The methoxy – deuteromethoxy exchange **3b** → **6b** and **3d** → **6d** together with the equilibration of the *cis*-**3b** and *trans*-**3b** stereoisomers were followed up by ^{1}H NMR method (cf. Table 1). Since the solvent was used in a great excess and the concentration of NaCl was also constant, both reactions were first order. The rate constants k_{ex} and k_{eq} calculated for the alkoxy exchange and equilibration together with the equilibrium product distributions are given in Table 2.

In the case of thiane derivatives the rate of the relatively slow equilibration could not be measured, as a parallel reaction involving the nucleophilic attack of chloride ion at the methoxy-carbon also occurs with a commensurable rate (**3** → **7**).

For the steric effect of 2-methyl group the methoxy-exchange reactions of **3a**, **3c**, *cis*-**3e** and *trans*-**3e** having no substituent in α position were also studied. The comparison of k_{ex} values with those obtained for 2-methyl derivatives gave information about the steric effect of an inert group adjacent to the reaction centre.

Data collected in Table 2 point to the following facts. (i) At the given concentrations of reactants methoxy exchange is faster than equilibration in cyclic methoxysulfonium salts. (ii) Methoxythiolanium derivatives with five-membered rings transform faster than the analogous methoxythianium derivatives with six-membered rings. (iii) For alkyl-substituted derivatives the thermodynamic control favours the formation of *cis*-1-methoxy-2-methylthiolanium or -thianium salts which are predominant in the equilibrium mixtures. (iv) Both the equilibration of pure methoxysulfonium diastereoisomers and the conversion of the precursor sulfides by *t*-BuOCl in CH_3OH or CD_3OD lead to the same diastereoisomeric product distribution referring to thermodynamic control (cf. Ref. 5). (v) The less stable *trans* isomers transform faster than the more stable *cis* isomers. (vi) The methoxy exchange is only hindered to a larger extent in the *cis* isomers.

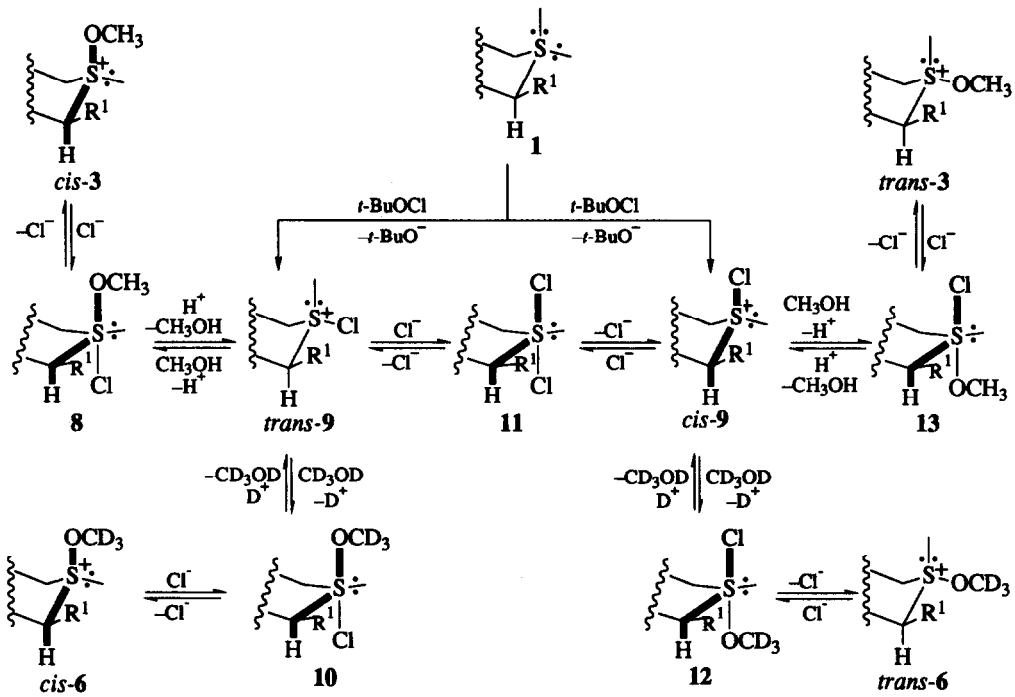

Fig. 2. Mechanism of formation and chloride-ion catalyzed reactions for cyclic methoxysulfonium salts (R^1 = H or CH_3, see Fig. 1; the alkyl group R^1 occupies always the equatorial position, as shown in Refs. 21, 22 and 28).

Mechanism. Experimental results related with the formation and reactivity of cyclic methoxysulfonium salts suggest the mechanism shown in Fig. 2. Under the given conditions the consecutive nucleophilic displacements are supposed to follow a reversible addition-elimination mechanism involving the backside attack of the nucleophile on sulfur with the formation of a sulfurane intermediate (cf. Refs. 11-14). The transformation of methoxysulfonium salts (e.g. *cis*-**3** and *trans*-**3**) catalyzed by the chloride ion starts with a rapid equilibrium formation of (not detectable) methoxychlorosulfurane intermediates (**8** and **13**, respectively). The rate-determining step is the elimination of OCH_3 (poor leaving group). The individual reaction rates are controlled by both the sulfonium salt ⇌ sulfurane equilibrium at the given concentrations and by the departure of the methoxy group. The resulting diastereoisomeric chlorosulfonium intermediates (*cis*-**9** and *trans*-**9**) react with deuteromethanol in a similar way to yield *cis*-**6** and *trans*-**6**.

The equilibration of methoxysulfonium diastereoisomers (*cis*-**3** and *trans*-**3**) may proceed through a common dichlorosulfurane intermediate (**11**) which can be formed by reversible Cl^--addition from both chlorosulfonium diastereoisomers (*cis*-**9** and *trans*-**9**; cf. Ref. 15). At the given concentration of reactants equilibration proved to be slower than methoxy exchange. This means that chlorosulfonium salt intermediates react with deuteromethanol which is present as solvent in a great excess, rather than with chloride ions of small concentration to give **10** and **12**. The ratio $k_{ex}/k_{eq} \sim 2$ also reveals that equilibration is not predominantly controlled by an intramolecular ligand exchange occurring in methoxychlorosulfurane intermediates (**8** ⇌ **13**). The formation of a diastereoisomeric mixture in the reaction of cyclic sulfides (**1**) with *t*- BuOCl in methanol may also be attributed to the interconversion of *cis*-**9** and *trans*-**9** through **11**.

Stability of cis isomers. In contrast with the stereochemistry of cyclohexane, the axial position in thiane derivatives is known to be more favoured for polar S-substituents than the equatorial one. In comparison with 1(e) derivatives the 1(a)-substituted conformers and the 1(a),2(e)- or 1(a),4(e)-disubstituted *cis* isomers of cyclic sulfoxides[4,6,16] and sulfilimines[17] exhibit an increased stability. For this phenomenon no generally accepted explanation has so far been published (cf. Refs. 4, 17, 18). Table 2 shows that the predominance of *cis* isomers is also valid for the equilibrium mixtures containing 1-methoxy-2-methyl- (or 1-methoxy-4-*tert*-butyl-) substituted cyclic sulfonium salts. Since the diastereoisomeric product distribution is the same for both **3d** and **3e** independently of the position of the C-alkyl group, it seems very likely that both *cis* isomers are stabilized by the same factor. Fig. 2 shows that only the structure of the *cis* isomers allows the polar S-O bond and an α-C-H bond to occupy antiperiplanar positions which gives rise to a stabilizing stereoelectronic effect of σ(C-H) – σ*(S-O) type. The same effect may account for the axial preference of the 1-methoxy group in **3c** (see Table 2) and for the different acidity of α-methylene protons observed for the base-catalyzed H-exchange in *cis*- and *trans*-4-phenylthiane-1-oxide dissolved in deuteromethanol. Here the breaking of the axial α-C-H bond antiperiplanar with the axial S-O bond proved to be favoured (cf. Refs. 19, 20).

Reactivity of trans isomers. S_N2 displacements proceed easier on a cyclohexane ring-carbon if the leaving group is in axial position.[21] 2-Alkyl (or 4-alkyl) substituted cyclic methoxysulfonium salts are of opposite behaviour: in S_N(Ad+E) reactions the *trans* isomer carrying the leaving group in equatorial or pseudoequatorial position exhibits the greater reactivity. A similar phenomenon observed for the reduction of *cis*- and *trans*-4-*tert*-butylthiane-1-oxides (*cis*-**7e** and *trans*-**7e**) with iodide ions was attributed to the greater stability of the *cis* isomer.[16]

This explanation seems to be in accordance with the relative stability of methoxysulfonium diastereoisomers observed by us experimentally. For the changes in free energy $\Delta G^\circ = -0.30$ and -0.82 kcal·mol^{-1} values were found in the equilibrium *trans* ⇌ *cis* isomerisation of the **3b** and **3d** diastereoisomers. On the other hand, the remarkably great difference in the values of free energy of activation, $\Delta G^\ddagger$(cis) – $\Delta G^\ddagger$(trans) = 0.84, 2.2 and 1.5 kcal·mol^{-1}, obtained for the methoxy-exchange reactions of the **3b**, **3d** and **3e** diasteroisomers, respectively, indicates that the increased reactivity of the *trans* isomers is more attributable to the relative stability of intermediates formed in the starting steps of two consecutive S_N(Ad+E) reactions (compare *trans*-**3** → **13** → *cis*-**9** and *cis*-**3** → **8** → *trans*-**9** in Fig. 2) than to the free-energy difference of the reactants. Since only the sulfurane **13** (formed in a fast equilibrium reaction) and the chlorosulfonium ion *cis*-**9** (formed by the slow departing of the methoxy group) are stabilized by a stereoelectronic effect of σ(C-H) – σ*(S-Cl) type, the multistep reaction starting from *trans*-**3** is favoured. The subsequent steps (*cis*-**9** → **12** → *trans*-**6** and *trans*-**9** → **10** → *cis*-**6**) resulting in methoxy-deuteromethoxy exchange are relatively fast, so they do not control the rate of the reaction.

Thiolane derivatives. As in the case of *cis*-**3d** methoxythianium salt, the relative stability of *cis*-**3b** methoxythiolanium salt can be attributed to a favourable σ(C-H) – σ*(S-O) stereoelectronic effect. At the same time the moderate decrease in selectivity found for the formation of thiolanium salt diastereoisomers is probably due to the pseudoaxial orientation of the S-O bond in *cis*-**3b**.Thus the C(2)-H and S-O bonds cannot take up a perfect antiperiplanar position. This view may be supported by the structural data found for *cis*-2-methylthiolane-1-oxide[22] suggesting a torsional angle of 162° for the H-C(2)-S-O moiety. The selective acidity of α-methylene protons dependent on the direction of the C-H bond has also been observed in some cases for thiolane derivatives.[23,24]

As it is known, cyclopentane[25,26] and thiolane derivatives[16,27] exhibit increased reactivity in S_N2 reactions as compared with that of analogous compounds having six-membered rings. This is obviously due to the different stereochemistry and mobility of the five-membered rings. Thus our findings referring to methoxythiolanium derivatives are in agreement with expectations.

The similar conformation of *cis*-**3b** and *cis*-**3d** 2-methyl derivatives about the S-C(2) bond (showing pseudoaxial or axial S-O bond orientation; cf. Refs. 28, 29) may account for the marked decrease in the rate of methoxy exchange observed in both cases. The relative reactivities k_{ex} (2-Me/2-H) controlled by the steric effect of the 2-methyl group are about 0.1 and 0.05 for *cis*-**3b/3a** and *cis*-**3d/3c**, respectively. On the other hand, the k_{ex}(2-Me/2-H) 0.4 and ~1 values obtained for the corresponding *trans* derivatives indicate that the steric effect of the equatorial 2-methyl group is only moderate or negligible if the S-O bond is isoclinal (five-membered ring) or equatorial (six-membered ring).

EXPERIMENTAL

Preparation of methoxysulfonium tetrafluoroborates from sulfoxides (**7** → **3**, Fig. 1). To the solns of sulfoxides **7a**,[30] *cis-/trans*-**7b**,[2,3] **7c**,[31] *cis-/trans*-**7d**[2,3] and *cis-/trans*-**7e**[4] (5 mmol) in CH_2Cl_2 (5 mL) was added $Me_3O^+BF_4^-$ (6 mmol), and the mixture was stirred at room temp for 2 hr with excluding moisture. For the conversion of *trans*-**7b** more CH_2Cl_2 (40 mL) was added, then the mixture was stirred for additional 10 min (the solubility of *trans*-**3b** is very poor). After filtration the soln was evaporated in vacuo. The residue was washed with pentane-CH_2Cl_2 (9:1) and pentane, dried in vacuo, and stored at –20° in a dry box. Yield 90-98%. The purity of sulfonium salts **3a**, *cis-/trans*-**3b**, **3c**, *cis-/trans*-**3d** and *cis-/trans*-**3e** was checked by ^1H NMR method (Table 1). The deuteromethoxy analogues (**6**) investigated only in soln were not isolated.

Preparation of methoxysulfonium tetrafluoroborates and perchlorates from sulfides (**1** → **2** → **3** and **1** → **2** → **4**, Fig. 1). To the cooled (–78°C) solns of sulfides **1b**[2] and **1d**[2] (4 mmol) in abs MeOH (6 ml) were added *t*-BuOCl and (after 5 min) silver tetrafluoroborate or perchlorate (4 mmol) dissolved in MeOH (2-3 mL). After 1 hr the mixture was allowed to warm to room temp, then centrifuged with exclusion of moisture and filtered by using Celite under a stream of dry argon. The solvent was removed under reduced pressure, and the residue was dissolved in dry $CHCl_3$ (2-3 mL). The sulfonium salt was precipitated by adding pentane (20 mL) to the soln in small portions, then the mother liquor was removed by decantation. The solid or viscous product was washed with pentane-$CHCl_3$ (9:1) and pentane, then dried in vacuo. Yields for *cis-trans* mixtures of **3b**, **3d** and **4d** were 84, 81 and 73%, respectively. Purity and diastereoisomeric product distributions were checked by ^1H NMR spectroscopy (Table 1).

Detection of equilibration and methoxy exchange for methoxysulfonium salts. To the cooled (–78°C) solns of sulfides **1b** and **1d** (0.5 mmol) in CD_3OD (0.6 mL) was added *t*-BuOCl (0.5 mmol). After the reaction had been completed (5 min) yielding deuteromethoxysulfonium salt (**5b** and **5d**), the soln was warmed up to –40° and mixed with MeOH (0.1 mL). Diastereoisomeric product distribution (at 37°C) and methoxy exchange (at –40 and 37°C) were measured by recording the ^1H NMR spectra.

Kinetic measurements. To finely powdered NaCl (20 mg) in an NMR tube was added 0.3 mL of CD_3OD saturated with NaCl, then a soln of methoxysulfonium tetrafluoroborate (**3a-e**, 0.45-0.55 mmol) in CD_3OD (0.2 mL) was injected into the tube. ^1H NMR spectra were recorded either at 21 or 37°C repeatedly at regular times. The concentrations were 0.153 M (at 21°C) and 0.152 M (at 37°C) for NaCl, and 0.9-1.1 M for **3**.

The rate constants for equilibration (k_{eq}) were calculated from equation $\ln([A]_o - [A]_\infty)/([A] - [A]_\infty) = [A]_o k_{eq} t/([A]_o - [A]_\infty)$, where $[A]_o$, $[A]$, and $[A]_\infty$, represent the intensity of the signal of 2-CH_3 group for one of the **3** diastereoisomers at the start, at the time t, and at the time when equilibration has been completed, respectively.

The rate constants for the methoxy exchange (k_{ex}) were calculated from the first order rate equation by measuring the intensity of the signal of O-CH_3 group. Measurements were carried out by using one of the **3** diastereoisomers (in the case of disubstituted derivatives) and by following up the reaction until two half-lifes. Since $k_{ex} > k_{eq}$, the detection of the methoxy exchange was not disturbed by the equilibration of the substrate.

Spectra. ^1H NMR spectra were recorded on Bruker WM-250 FT spectrometer in $CDCl_3$ and CD_3OD solns at 21 and 37°C, using TMS int. stand.

Acknowledgement. The authors thank Dr. I. Kövesdi for his very useful contribution to the NMR measurements, A. Fürjes and A. Dobó for technical assistance, and Dr. G. Dibó, Mr. T. Bobák and Ms. J. Máthé for preparing the manuscript. Financial support from "OTKA" foundation is gratefully acknowledged.

REFERENCES

1. Johnson, C.R.; Rigau, J.J. *J. Am. Chem. Soc.* **1969**, *91*, 5398-5399.
2. Jalsovszky, I.; Ruff, F.; Kajtár-Peredy, M.; Kövesdi, I.; Kucsman, Á. *Tetrahedron*, **1986**, *42*, 5649-5656.
3. Jalsovszky, I.; Ruff, F.; Kajtár-Peredy, M.; Kucsman, Á. *Synthesis*, **1990**, 1037-1039.
4. Johnson, C.R.; McCants, D., Jr. *J. Am. Chem. Soc.* **1965**, *87*, 1109-1114.
5. Klein, J.; Stollar, H. *Tetrahedron*, **1974**, *30*, 2541-2548.
6. Rigau, J.J.; Bacon, C.C.; Johnson, C.R. *J. Org. Chem.* **1970**, *35*, 3655-3657.
7. Glass, R.S.; Hojjatie, M.; Stezer, W.N.; Wilson, G.S. *J. Org. Chem.* **1986**, *51*, 1815-1820.
8. Johnson, C.R.; Jones, M.P. *J. Org. Chem.* **1967**, *32*, 2014-2016.
9. Johnson, C.R.; McCants, D., Jr. *J. Am. Chem. Soc.* **1965**, *87*, 5404-5409.
10. Annunziata, R.; Cinquini, M.; Colonna, S. *J. Chem. Soc. Perkin Trans. 1*, **1975**, 404-406.
11. Corriu, R.J.P.; Guerin, C. *J. Organomet. Chem.* **1980**, *198*, 231-320, and refs. therein.
12. Anh, N.T.; Minot, C. *J. Am. Chem. Soc.* **1980**, *102*, 103-107.
13. Deiters, J.A.; Holmes, R.R. *J. Am. Chem. Soc.* **1987**, *109*, 1686-1692.
14. Deiters, J.A.; Holmes, R.R. *J. Am. Chem. Soc.* **1987**, *109*, 1692-1696.
15. Mislow, K.; Simmons, T.; Mellillo, J.T.; Ternay, A.L., Jr. *J. Am. Chem. Soc.* **1964**, *86*, 1452-1453.
16. Curci, R.; DiFuria, F.; Levi, A.; Scorrano, G. *J. Chem. Soc. Perkin Trans. 2*. **1975**, 408-412.
17. Claus, P.K.; Vierhapper, F.W.; Willer, R.L. *J. Org. Chem.* **1979**, *44*, 2863-2871.
18. Zefirov, N.S. *Tetrahedron Letters*, **1975**, 1087-1090.
19. Hutchinson, B.J.; Andersen, K.K.; Katritzky, A.R. *J. Am. Chem. Soc.* **1969**, *91*, 3839-3844.
20. Cieplak, A.S. *J. Am. Chem. Soc.* **1981**, *103*, 4540-4552.
21. Eliel, E.L.; Allinger, N.L.; Angyal, S.J.; Morrison, G.A. *Conformational Analysis;* Washington D.C. 1981; pp. 86-90, and refs. therein.
22. Forgács, Gy.; Schultz, Gy.; Hargittai, I.; Jalsovszky, I.; Kucsman, Á. *J. Chem. Soc. Faraday Trans. 2*. **1989**, *85*, 303-315.
23. Lett, R.; Bory, S.; Moreau, B.; Marguet, A. *Tetrahedron Letters*, **1971**, 3255-3258.
24. Barbarella, G.; Garbesi, A.; Fava, A. *J. Am. Chem. Soc.* **1975**, *97*, 5883-5889.
25. Fierens, P.J.C.; Verschelden, P. *Bull. soc. chim. Belges*, **1952**, *61*, 427-451.
26. Brown, H.C.; Borowski, M. *J. Am. Chem. Soc.* **1952**, *74*, 1894-1902.
27. Tamagaki, S.; Mizumo, M.; Yoshida, H.; Hirota, H.; Oae, S. *Bull. Chem. Soc. Japan*, **1971**, *44*, 2456-2460.
28. Jalsovszky, I.; Kucsman, Á.; Ruff, F.; Koritsánszky, T.; Argay, Gy.; Kálmán, A. *J. Mol. Struct.*. **1987**, *156*, 165-192.
29. Jalsovszky, I.; Kucsman, Á.; Ruff, F.; Koritsánszky, T.; Kálmán, A.; Argay, Gy. *J. Mol. Struct.*. **1987**, *156*, 193-212.
30. Tarbell, D.S.; Weaver, C. *J. Am. Chem. Soc.* **1941**, *63*, 2939-2942.
31. Tamres, M.; Searles, S., Jr. *J. Am. Chem. Soc.* **1959**, *81*, 2100-2104.