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THIOSULFONIUM IONS. METHYLTHIOLATION OF 3-METHYLTHIO-1-BUTENE AND CIS- AND TRANS-1-METHYLTHIO-2-BUTENE

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Summary. Whereas sulfenyl reagents commonly add to carbon double bonds, addition to sulfur of 3-methylthio-1-butene precedes attack at carbon to give allylic thiosulfonium ions that form reversibly and which rearrange rapidly to trans-2-butenyl analogs. Likewise, rearrangement of cis- to trans-1-methylthio-2-butene occurs by way of thiosulfonium ions.

Reactions of alkanesulfenyl reagents RSX with allylic sulfides $RSCH_2CH{=}CH_2$ is unusually complex because two nucleophilic sites (sulfur and carbon) compete for the attacking electrophile and, when attack occurs at sulfur, thiosulfonium ions $RS\overset{+}{S}(R)CH_2CH{=}CH_2$ are formed that readily rearrange.[1] To probe the stereochemistry and regiochemistry of these reactions we investigated the behavior of butenyl methyl sulfides **2** with methanesulfenyl reagents **1**. As described herein, an unexpected amount of sulfide rearrangement was observed to precede the addition step. Thiosulfonium ions, formed reversibly, are implicated as the source of this rearrangement. In the case of 3-methylthio-1-butene **2a**, methylthiolation appears to occur exclusively at sulfur and leads to complete allylic rearrangement. Details follow.

Sulfide Rearrangement. Each sulfide, **2a**,**2c** or **2t**, (98-100% pure, 1.5 molar equivalents) was allowed to react with **1a** ($CH_3\overset{+}{S}(CH_3)_2\overset{-}{B}F_4$) in CD_3NO_2 or CH_2Cl_2 at 0°C, and with 1b (CH_3SCl) in $CHCl_3$ below -60°C.[1c] Excess sulfide was recovered and analyzed by NMR, MS and GC to determine its composition. The results are given in Table I. Clearly the starting sulfide has rearranged to some extent in all cases. However, the equilibrium composition appears to be reached only in the reactions of **2a** and **2t** with **1a**. (The ratios of recovered sulfides **2t**:**2c**:**2a** are close to the ratio 81:13:6 reported in an independent study of the equilibration of butenyl methyl sulfides by photoinduced rearrangement in methanethiol.[2]) Not surprisingly, the trans isomer **2t** is the most stable of the three. The sulfide rearrangements observed in the present study are rationalized by Scheme I which requires that the initial methylthiolation step involve a reversible attack at sulfur followed by pericyclic interconversion of the thiosulfonium ions **3a**, **3c** and **3t**, so formed. Certain features of the interconversion can be gleaned from Table I and Scheme I. First, **3a** is necessarily an intermediate in the conversion of the cis to the trans isomer. Less rearrangement occurs starting with the cis sulfide **2**c than with **2**a implying that thiosulfonium ion **3**a rearranges more rapidly than **3**c, and produces the trans isomer **3**t in preference to **3**c ($k_1 >> k_3,k_4$). Preference for trans stereochemistry in the developing double bond has been noted in many allylic rearrangements and in related S_N2, reactions,[3] and is consistent with the pericyclic nature of the rearrangement proposed in Scheme I.

Although **1**b induced less rearrangement than **1**a, sulfide rearrangement with **1**b was unexpected because thiosulfonium ions from propenyl sulfides and alkanesulfenyl chlorides were shown earlier to form irreversibly.[1] Reversibility of initial thiolation of butenyl sulfides is further substantiated by experiments with CD_3SCl. Recovered sulfides showed varying amounts of deuterium incorporation resulting from methylthio exchange by the sequence **2**a ⇄ **3**a ⇄ **3**t (or **3**c) ⇄ **2**t (or **2**c) (Table I). The amount from **2**c and **2**t is small (6-8%) and is comparable to the amount of rearrangement. In contrast, deuterium incorporation starting with **2**a is extensive (37%) - as is rearrangement (57%). Qualitatively, these results support the conclusion that **3**a rearranges more rapidly than either **3**c or **3**t ($k_1 >> k_2,k_3,k_4$). In fact, the amount of reaction of the cis or the trans sulfide passing through a rearranged thiosulfonium ion **3**a is minimal (6-8%) whereas essentially all of the reaction of **2**a follows a rearrangement pathway through **3**t.

<u>Adduct Formation</u>. Six adducts are possible from either sulfide because of rearrangement, and regiochemical and stereochemical options in the addition step. Complex mixtures were indeed obtained which could not be separated. Simplification of the analysis was achieved by conversion of the adducts to erythro and threo isomers of 1,2,3-trimethylthiobutane (**4**er and **4**th) by the reactions shown in Scheme I. Thereby, the number of possible components in the adduct mixtures was reduced from six to two. The erythro-threo composition, summarized in Table I,[4] shows that **1**a reacts with the trans sulfide **2**t to give mainly erythro adduct **4**er while the cis sulfide **2**c gives mainly the threo adduct **4**th.[5] Therefore the adducts are formed largely if not exclusively by <u>anti</u> addition (consistent with the known stereochemistry of sulfenyl addition[6]) and the amount of rearrangement by way of **3**a in the adducts (10-13%) is no greater than in the starting sulfides **2**c and **2**t (12-15%). Of more interest are the erythro-threo ratios from **2**a. They approximate those from **2**t.[5] This result, together with the similar compositions of recovered sulfides from **2**a and **2**t (Table I), means that intermediate **3**t is common to the reactions of both sulfides. Thus, the sequence **2**a ⇄ **3**a ⇄ **3**t must be more rapid than adduct formation. If adducts were formed directly from **2**a or **3**a they would have the structural feature $-CH_2X$ by analogy with the regiochemistry of addition to 3-propenyl sulfide.[1] However, the NMR of adducts from **2**a showed no evidence of $-CH_2X$ groups.[7] The amount of addition to **2**a or **3**a that precedes rearrangement must therefore be negligible.

Mass spectral analysis of erythro-threo mixtures obtained from **2** and CD_3Cl showed the presence of molecular ions m/z 196, 199 and 202 (Table I). Ions m/z 196 and 202 can result only from methylthio exchange in the starting reagents by way of **3**, and their abundance is therefore a measure of rearrangement. Accordingly, methylthio exchange and hence rearrangement is low (3%) for **2**c, modest (14%) for **2**t, and extensive (29%) in **2**a.

Overall, our results establish the facility with which allylic thiosulfonium ions **3**a rearrange to give the butenyl ion **3**t having trans stereochemistry. Methylthiolation of isomeric sulfides **2**a and **2**t pass through the same intermediate **3**t.[8], which is formed reversibly. The cis isomer **3**c is slow to rearrange and leads mainly to threo adduct by anti addition.

SCHEME I

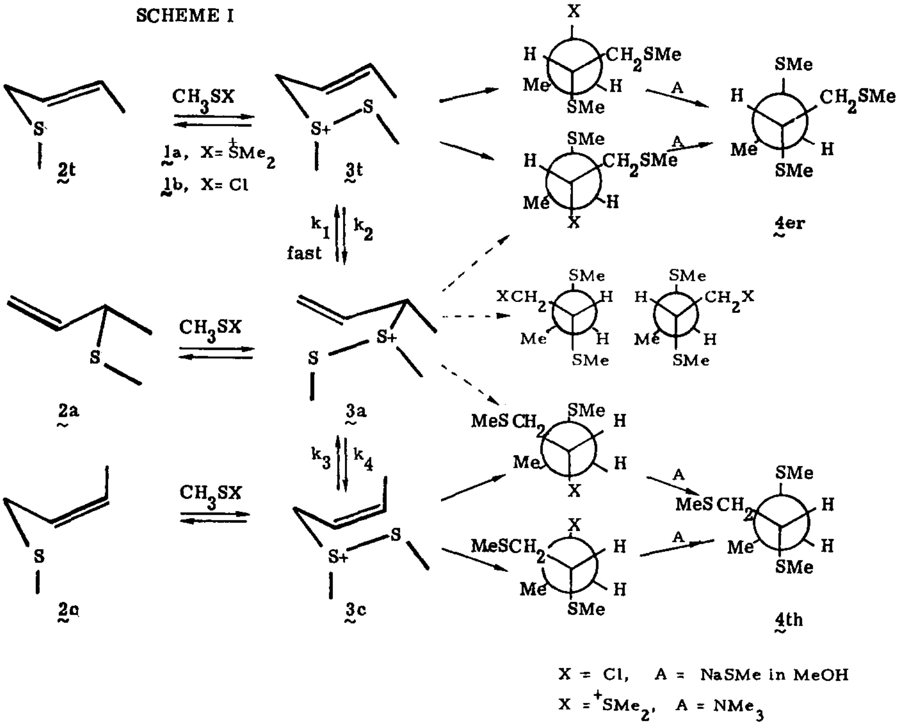

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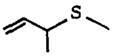
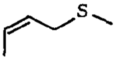
Table I. Composition of Sulfides and Adducts from Excess Butenyl Methyl Sulfides with CH_3SX

Sulfide	CH_3SX	Sulfide Composition (%)			$C_4H_7SCD_3$ (%)	Adducts (%)		$4\text{-}d_0$:	$4\text{-}d_3$:	$4\text{-}d_6$
		2t	**2c**	**2a**		**4**-er	**4**-th	196 :	199 :	202 (m/z)[b]
	$-^a$	98.4	1.6	-						
	**1a**	86	8	6		87	13			
2t	**1b**	90	5	5		60	40			
	1b-d_3	90	6	4	8			6	86	8
	$-^a$	-	-	100						
	**1a**	88	4	8		78	22			
	1b	59	< 1	40		59	41			
2a	**1b**-d_3	57	< 1	43	37			9	72	20
	$-^a$	<1	>99	-						
	**1a**	13	86	2		10	90			
2c	**1b**	5	94	<1		16	84			
	1b-d_3	7	92	< 1	6			0	97	3

a. Before reaction. b. Corrected for isotopic abundance.

References and Notes

(1) a. J.K. Kim, M.L. Kline, M.C. Caserio, J. Am. Chem. Soc., **100**, 6243 (1978); b. J.K. Kim, M.C. Caserio, J. Org. Chem., **44**, 1897 (1979); c. M.L. Kline, N. Beutow, J.K. Kim, M.C. Caserio, ibid., **44**, 1904 (1979).

(2) E.S. Huyser, R.M. Kellog, J. Org. Chem., **30**, 2867 (1965).

(3) P. Bickart, F.W. Carson, J. Jacobus, E.G. Miller, K. Mislow, J. Am. Chem. Soc., **90**, 4869 (1968); J.E. Baldwin, J.E. Patrick, ibid., **93**, 3556 (1971); D.A. Evans, G.C. Andrews, T.T. Fujimoto, D. Wells, Tetrahedron Letters, 1389 (1973); G. Stork, A.F. Kreft, III, J. Am. Chem. Soc., **99**, 3851 (1977); R.M. Magid, O.S. Fuchey, ibid., **101**, 2107 (1979).

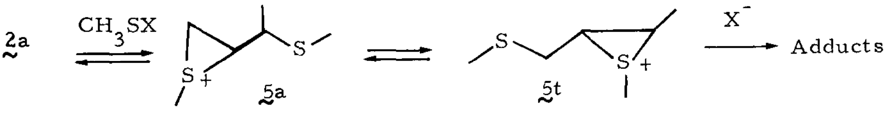
(4) Analysis was based on NMR, GC and MS evidence.

(5) Data from **1b** is less reliable than from **1a** because some rearrangement of initial adducts occurs above 0°. Also, thiolate displacement of chloride can occur by inversion (mainly) and retention, further confusing the origin of the **4**er:**4**th ratio.

(6) a. W.H. Mueller, P.G. Butler, J. Am. Chem. Soc., **88**, 2866 (1966); **90**, 2075 (1968); b. G.H. Schmid, Topics in Sulfur Chemistry, **3**, 101 (1977).

(7) NMR of first-formed adducts showed the X group attached to a secondary carbon only. Also, doublets for the methyl protons of CH_3CHX groups dominated over those for CH_3CHSCH_3 by about 3:1. The regiochemistry of addition therefore favors attack of X at methyl-bearing carbon.

(8) An alternative rearrangement sequence by way of thiiranium ions **5** is possible. That is



This route is considered less likely because thiiranium ions, once formed, react more rapidly at carbon than sulfur with nucleophiles.^{6b} Thiiranium ions **5** probably are formed en route to the adducts, but they are not key intermediates in the sulfide rearrangement.

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