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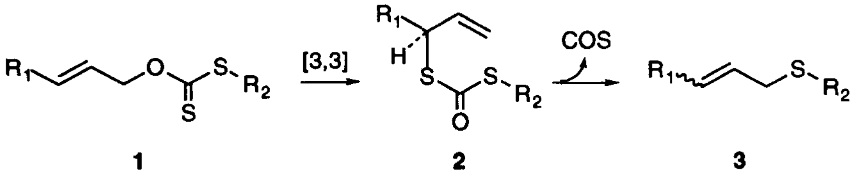
Retro-Ene Type Fragmentation of Allylic Dithiolcarbonates

Masashi Eto, Mitsuhiro Nishimoto, Shoji Kubota, Toshikazu Matsuoka
and Kazunobu Harano*

Faculty of Pharmaceutical Sciences, Kumamoto University, 5-1 Oe-hon-machi, Kumamoto 862, Japan.
E-mail' harano@gpo.kumamoto-u.ac.jp

Abstract: The formation of 2-alkenyl alkyl sulfides from *S*-(2-alkenyl) *S*-alkyl dithiocarbonates with extrusion of COS was found to be effectively catalyzed by Lewis acids. The *ab initio* calculations strongly suggested that the reaction falls into category of "retro-alkylthio-ene" reaction.

Heating of *S*-(2-alkenyl) *S*-alkyl dithiocarbonates [dithiolcarbonates (**2**)] derived from [3,3]-sigmatropic rearrangement [1,2] of *O*-(2-alkenyl) *S*-alkyl dithiocarbonates [allylic xanthates (**1**)] gave the 2-alkenyl alkyl sulfides (**3**),[3] which are useful synthons for carbon skeleton construction. The reaction was found to be catalyzed by phenolic compounds and proceed through an S_Ni'-type mechanism in which alkylthio group attacks the γ-carbon atom of the allylic system, with simultaneous shift of the double bond and elimination of COS.[4]



This paper describes the pericyclic reaction of allylic dithiolcarbonates (**2**) in the presence of catalysts and the reaction mechanism.

In the presence of catalysts which are expected to coordinate to the carbonyl group, the pseudo-first-order rate constants were measured for the extrusion of *S*-(1-phenylallyl) *S*-methyl dithiocarbonate (**2a**) derived from [3,3]-sigmatropic rearrangement of **1a** (R_1=Ph, R_2=Me) (Table 1). The presence of 0.3 eq of *p*-nitrophenol without solvents showed moderate catalytic activity whereas the *o*-nitrophenol did not show sufficient activity, suggesting that the reaction is promoted by the hydrogen bond between the carbonyl function and the hydroxyl group of the phenols.[4a] In the case of a 1:1 inclusion compound (ß-CyD-**2a**), the rate enhancement is compared to *p*-nitrophenol, presumably arisen from the effective hydrogen-bond capability of ß-CyD.[5] The catalytic activity of Lewis acids is outstanding. In the presence of aluminum catalysts, the reaction smoothly proceeded to give the sulfide (*E*-**3a**) in quantitative yield even at room temperature. Analysis of the kinetic data indicates that the $AlCl_3$ or $MeAlCl_2$-catalyzed reaction is *ca.* 10^5 times faster than the uncatalyzed reaction.[6] To know the applicability of the catalytic reaction, we applied the present method to several α- or γ-substituted substrate (**2a-g**). The results are listed in Table 2. In **2a-c**, *E*-(3-phenylallyl) [alkyl or 2-alkenyl] sulfides (**3a-c**) were produced. Substrate **2f** has two allylic reaction sites. However, the terminal vinyl carbon C_b is exclusively attacked. The sulfides from **2d,e** were isolated as mixtures of *E,Z*-isomers. The γ-substituted substrate (**2g**) could not be converted to the corresponding sulfides in the reaction condition used.

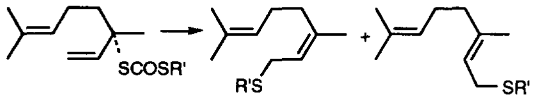
Table 1. First-Order Rate Constants (k) for the Extrusion Reactions of **2a**

catalyst	temp (°C)	$k \times 10^5$ (sec^{-1})
no catalyst	120	1.18a)
phenol (0.3 eq)	120	2.90a)
o-nitrophenol (0.3 eq)	120	4.00a)
p-nitrophenol (0.3 eq)	120	12.3a)
ß-CyD	120	20b)
Me_2AlCl (0.2 eq)	20	17c)
$EtAlCl_2$ (0.1 eq)	20	73c)
$MeAlCl_2$ (0.1 eq)	20	128c)
$AlCl_3$ (0.1 eq)	20	160c)

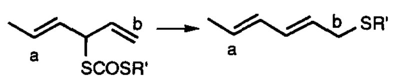
a) Measured by weighing the decrease of **2a** due to loss of COS. b) Calculated from the half life of the 1:1 inclusion complex. c) Measured by GLC.

Table 2. Yields of Allylic Sulfides (**3**) derived from the Lewis acid Catalyzed Reaction

RSCOSR' R/R'		Catalyst	Temp	Solvent	Yield of **3** R	%
1-Phenylallyl/Me	(**2a**)	$AlCl_3$ (0.1 eq)	RT	$CHCl_3$	3-phenylallyl	100
/Et	(**2b**)	$AlCl_3$ (0.1 eq)	RT	$CHCl_3$		100
/allyl	(**2c**)	$AlCl_3$ (0.25 eq)	RT	$CHCl_3$		55
Linalyl/Me	(**2d**)	$AlCl_3$ (0.1 eq)	RT	$CHCl_3$	geranyl	55
/Bz	(**2e**)	$AlCl_3$ (0.1 eq)	RT	$CHCl_3$		62
1-Vinyl-2-butenyl/Me	(**2f**)	$MeAlCl_2$ (0.3 eq)	0 °C	hexane	sorbyl	63
3-Phenylallyl/Me	(**2g**)	$AlCl_3$ (0.1 eq)	RT	$CHCl_3$		0

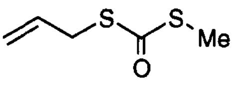


2d,e **3d**: E/Z=71/29. **3e**: E/Z=83/17

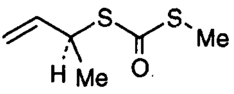


2f

To establish the reaction mechanism, we performed molecular orbital calculations on a model reaction pathway of *S*-allyl *S*-methyl dithiocarbonate (**2A**). The PM3 transition states (TS) were located by TS option,[7] which was characterized by the presence of a single negative Hessian eigenvector (Fig. 1 and 2). The IRC calculations clearly indicate that the breakage of two bonds (S••COS••C) with the departure of COS from **2A** is nearly synchronous. The PM3-calculated reaction barriers in gas phase for uncatalyzed and $AlCl_3$-catalyzed reactions are 33.4 and 29.1 kcal/mol, respectively and ones in CH_2Cl_2 solvent are 28.1 and 20.1 kcal/mol, respectively (COSMO-MOPAC93). These results indicate that the nature of the concerted reaction mechanism is not altered by use of $AlCl_3$. The reaction barrier for an α-substituted substrate [*S*-(1-methylallyl) *S*-methyl dithiocarbonate (**2B**) -> *E*-3-methylallyl methyl sulfide] is *ca.* 3.7 kcal/mol smaller than the one for **2A**.[8]



2A



2B

In order to verify the PM3-calculated mechanism, the *ab initio* calculations were carried out. The TS's were located by using the opt=CalcAll option.[9] The reaction barriers for uncatalyzed condition at the 3-21G* and 6-31G* levels are 54.9 and 58.0 kcal/mol, respectively, which should correspond to an actual barrier of about 35-38 kcal/mol.[10] The MP2/6-31G* energy was 13.7 kcal/mol lower with respect to the RHF calculation.

Table 3. Heats of Formation and Reaction Barriers for Extrusion of COS from Dithiolcarbonate (**2A**)

	PM3[a)]		3-21G*[b)]	MP2/3-21G[b)]	6-31G*[b)]	MP2/6-31G*[b)]
	no catalyst	$AlCl_3$				
SM	-14.38	-153.44	-1058.67140	-1058.37173	-1063.86204	-1064.92979
TS	18.97	-124.31	-1058.58396	-1058.44502	-1063.76958	-1051.85942
Product	11.42	-147.40				
ΔΔHf[a)] (gas)	33.4	29.1	54.9	46.0	58.0	44.3
ΔΔHf[a)] (CH_2Cl_2)	28.1	20.1				

a) kcal/mol. b) Hartree.

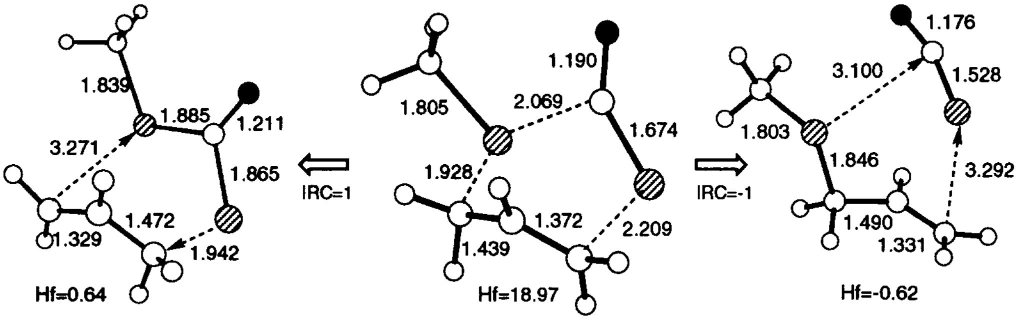
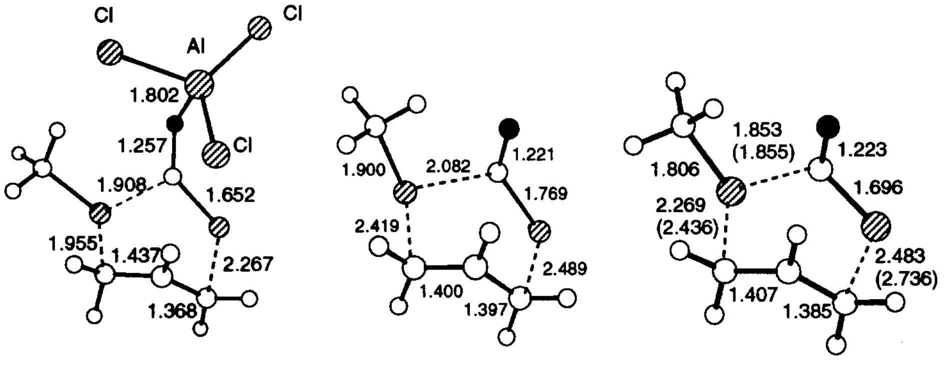


Fig. 1. PM3-calculated Transion-State and Intermediary Geometries along Reaction Pathway.



$AlCl_3$-catalyzed
PM3

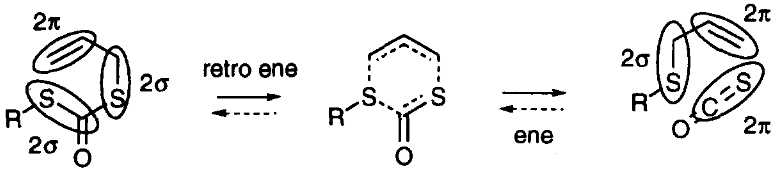
MP2/3-21G

MP2/6-31G*

Fig. 2. Transition-state Geometries. The 6-31G* values are presented in parentheses.

As shown in Fig. 2, the allyl group is loosely united to the MeSCOS moiety as compared with the PM3 TS. The MP2/6-31G* calculation predicts that the two C--S bonds connected to the allyl group are 0.17-0.25Å shorter than the RHF/6-31G* values.

Based on these findings, we have convinced that the fragmentation reaction of allylic dithiolcarbonates falls into category of retro-ene type reaction, which is thermally allowed pericyclic reaction to proceed through a six-membered nonionic cyclic transition state [2π+2σ+2σ].[11]



The observed reaction behaviors[3] are in good agreement with the proposed mechanism and not affected by Lewis acid coordination. The study of the sequential [3,3]-sigmatropic rearrangement-retro ene reaction of olefinic xanthates is currently in progress.

ACKNOWLEDGMENT

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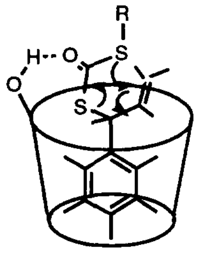
5. Heating of a 1:1 inclusion compound (ß-CyD-**2a**) at 120 °C for 6h, followed by treatment with aq. DMSO and extraction with benzene gave pure *E*-(3-phenylallyl) methyl sulfide (*E*-**3a**) in 81 % yield. The *S*-acetylmethyl derivative smoothly extruded COS to give the corresponding sulfide in 90% yield. The methyl substituent on 2-position of the allylic moiety retarded the reaction rate.



6. Activation energy for **2a** in the presence of $MeAlCl_2$ (0.1 eq) is 13.5 kcal/mol.
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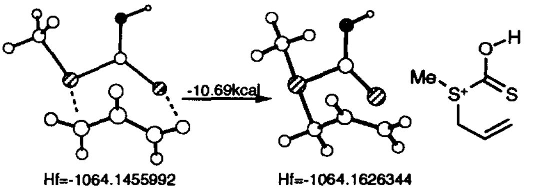

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