break-seal flask was separated from the residue by bulb-to-bulb distillation on the vacuum line. Glpc analysis of the distillate showed *tert*-butyl alcohol (1.23 mmol) to be present. The residue was washed three times wth 25-ml portions of carbon tetrachloride. The washings were combined with the methanol solution and then distilled to remove the methanol and carbon tetrachloride which left as residue the methyl benzoate. This was collected on a preparative glpc as described before. About 10 mg of the pure methyl benzoate was combusted, and the 46/44 ratio for carbon dioxide was measured by mass spectrometry (B, Table III). Final acidfication of the residue (0.57 mmol) and extraction with ether gave benzoic acid on evaporation.

Acknowledgment. It is a great pleasure to acknowledge many helpful discussions with Professor W. A. Pryor who also supplied us with many of his results prior to their publication. We are also grateful to the National Science Foundation and also to the E. I. du Pont Co. for financial support.

α-Halo Sulfones. XV. Thermal Rearrangement of the Ketals of 2-Chloro-3-thietanone 1,1-Dioxide[1]

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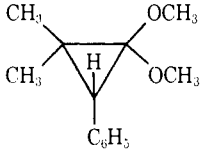
Contribution from the Department of Chemistry, The Ohio State University, Columbus, Ohio 43210. *Received July 29, 1970*

Abstract: The thermolysis of 2-chloro-3,3-diethoxythietane 1,1-dioxide (**24**) at 230–250° affords a 95% yield of ethyl acetate, together with sulfur dioxide and ethyl chloride. Analogously, 2-chloro-3-thietanone 1,1-dioxide ethylene ketal (**13b**) gives rise to 2-chloroethyl acetate (86.5%) and sulfur dioxide. Two isomers of 2-chloro-3-thietanone 1,1-dioxide 1′,2′-propylene ketal (possibly **18** and **20**) have also been prepared; both substances are seen to rearrange to identical mixtures of 2-chloropropyl acetate (**26**) and 3-chloro-2-propyl acetate (**27**). When the thermal decomposition of **13b** is performed in ethanol or *n*-propyl alcohol, the passage to 2-chloroethyl acetate is interrupted and the corresponding esters of (chloromethanesulfonyl)acetic acid (**31**) are produced. The thermal behavior of such α-chloro ketals cannot be reconciled with a concerted $[_\sigma 2_a + {}_\sigma 2_s + {}_\sigma 2_a]$ six-electron rearrangement. Rather, the formation of the various esters is interpreted in terms of the initial generation of a dipolar intermediate which suffers sequential intramolecular chlorine and hydrogen shifts to expel sulfur dioxide and elemental carbon.

Although endowed with considerable strain energy, cyclopropanone ketals are quite stable at elevated temperatures. For example, ketal **1** can be recovered quantitatively after being heated at 250° for 1 hr.[3] In marked contrast, ketals of 2-chlorocyclopropanone are sufficiently labile that partial pyrolysis often



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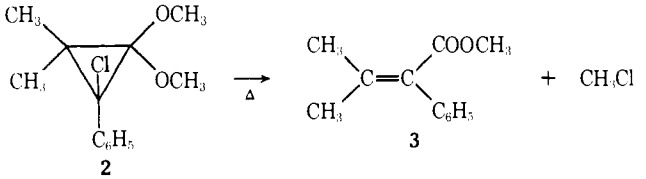
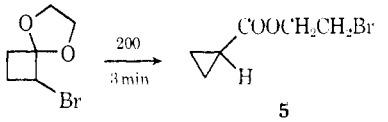


2 3

accompanies attempted distillation. In the case of **2**, heating at 195° for 2 hr results in quantitative conversion to methyl α-phenyl-β-methylcrotonate (**3**) and methyl chloride.[3] This propensity for thermal rearrangement is shared by several ketals of 2-bromocyclobutanone, *e.g.*, **4**, which have recently been shown to undergo concomitant ring contraction with the formation of cyclopropylcarboxylates such as **5**.[4]

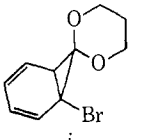
Preliminary attempts to extend this ring contraction process to analogous cyclopentyl and cyclohexyl bromo



4 5

ketals have apparently not given rise to similar phenomena.[4–6] The combination of ring strain and an α-halogenoketal function would therefore appear to be the necessary prerequisite for these unprecedented transformations.

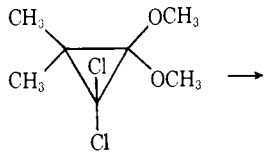
The thermochemical behavior of molecules such as **2** and **4** is of considerable interest in that such isomerizations may be concerted and, as a result, follow well-defined stereochemical specificity. Baldwin and Gano[7] have recently pointed out that the available $[_\sigma 2_a + {}_\sigma 2_s + {}_\sigma 2_a]$ pathway unequivocally demands retention at the carbon atom which represents the migration



i

(1) Part XIV is L. A. Paquette and J. C. Philips, *J. Amer. Chem. Soc.*, **91**, 3973 (1969).
(2) NDEA Fellow, 1967–1970.
(3) S. M. McElvain and P. L. Weyna, *J. Amer. Chem. Soc.*, **81**, 2579 (1959).
(4) J. Salaun and J.-M. Conia, *Tetrahedron Lett.*, 4545 (1968).
(5) Acyclic ketals bearing an α-halogen atom also seem to afford a diversity of unspecified thermal degradation products.[4]
(6) The conversion of 2-bromotropone to 3-bromopropyl benzoate upon attempted ketalization with trimethylene glycol has been interpreted in terms of rearrangement *via* norcaradiene valence tautomer i.[7]
(7) J. E. Baldwin and J. E. Gano, *Tetrahedron Lett.*, 1101 (1969).

terminus for the halogen. Conversely, an ionic mechanism would, of course, be expected to proceed with inversion of configuration at this center. Although these meaningful stereochemical consequences remain to be experimentally evaluated, McElvain and Weyna[8] have obtained convincing evidence that the pyrolysis of dichlorocyclopropanone ketals (**6**) to chloroacrylic esters (**8**) proceeds *via* ionic intermediates of type **7**.



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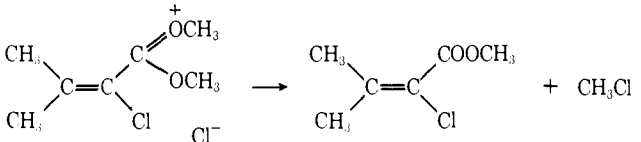
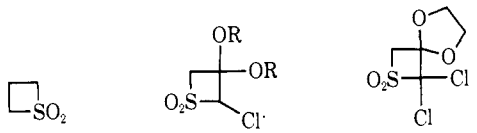


7 **8**

The considerable ring strain inherent in the thietane 1,1-dioxide ring system (**9**)[8] suggested that chloro ketal derivatives **10** would make unusually well-suited models for use in probing the structural and geometrical requirements of this particular intramolecular six-electron rearrangement. The present paper reports



9 **10** **11**

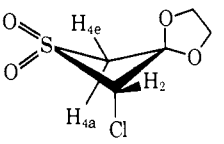
the synthesis and pyrolytic decomposition of a number of 2-chloro-3-thietanone 1,1-dioxide ketals and of the related 2,2-dichloro analog **11**.

Results

Synthesis. In 1963, Truce and Norell noted that sulfenes undergo ready (2 + 2) cycloaddition to ketene diethyl acetal with formation of 3,3-diethoxythietane 1,1-dioxides.[9] In a related reaction, exposure of 2-methylene-1,3-dioxolane (**12**) to methanesulfonyl chloride and triethylamine in tetrahydrofuran solution at room temperature was found to lead directly to **13a** in 40%

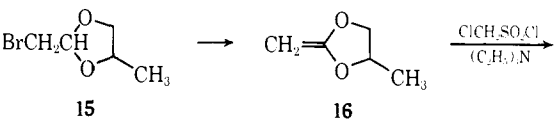
12 **13a**, R = H; **b**, R = Cl

yield. The nmr spectrum of **13a** ($CDCl_3$) features two four-proton singlets at δ 4.35 and 4.00. Chloro ketal **13b** was prepared analogously by treating **12** with chloromethanesulfonyl chloride under identical conditions. The dissymmetry resulting from introduction of the 2-chloro substituent is revealed by the nmr spectrum which displays in $CDCl_3$ the protons of the dioxolane ring as a multiplet centered at δ 4.13. In addition, a long-range spin–spin interaction (J = 2.5 Hz) between H_2 (δ 5.68) and H_{4e} (δ 4.48) is clearly apparent; this rather large coupling constant is presumably the result of a *W*-plan arrangement of the intervening σ bonds.[10] This geometry can uniquely be realized when the chlorine substituent is axially positioned on the puckered[11] thietane dioxide ring as in **14**. Finally, the H_{4a} absorption appears as a doublet (J = 14.0 Hz) centered at δ 4.38.

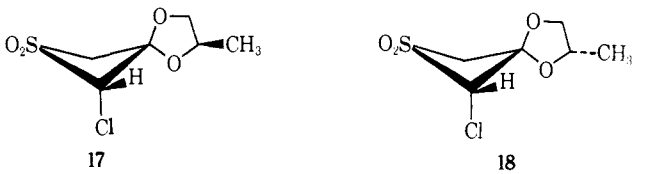


14

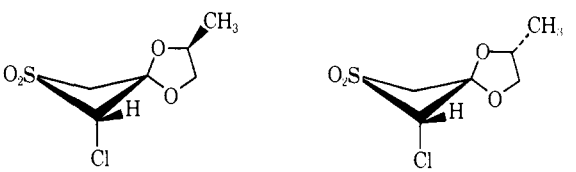
Insofar as ketene acetal **16** is concerned, interest in its application to the current problem stems from the possibility that four axial chloro cycloadducts (**17**–**20**) could result upon treatment with chlorosulfene. Specifically, in passing from isomer pair **17**,**18** to the set described by **19** and **20**, the spatial relationship between the chlorine substituent and the potential migration terminus on the dioxolane ring is abruptly reversed. One can therefore envisage that valence reorganization of any given isomer, if concerned, should not produce crossover products which would be likely in nonconcerted transpositions. Experimentally, addition of chloromethanesulfonyl chloride and triethylamine to **16** afforded two crystalline adducts, subsequent to careful chromatography on silica gel. The nmr spectrum of the more rapidly eluted isomer shows a doublet (1 H, J = 2.5 Hz) at δ 5.64 indicative of an equatorially disposed H_2 proton, a multiplet (4 H) centered at 4.20 resulting from the additional α-sulfonyl protons and the dioxolane methylene group, a one-proton multiplet at 3.52, and a methyl doublet



15 **16**



17 **18**



19 **20**

(8) For leading references, consult L. A. Paquette and M. Rosen, *J. Amer. Chem. Soc.*, **89**, 4102 (1967); L. A. Paquette and M. Rosen, *J. Org. Chem.*, **33**, 3027 (1968).

(9) W. E. Truce and J. R. Norell, *J. Amer. Chem. Soc.*, **85**, 3231 (1963).

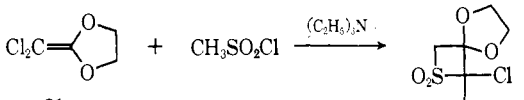
(10) For selected examples of this phenomenon, see J. Meinwald and A. Lewis, *ibid.*, **83**, 2769 (1964); J. Meinwald and Y. C. Meinwald, *ibid.*, **85**, 2514 (1963); K. B. Wiberg, B. R. Lowry, and B. J. Nist, *ibid.*, **84**, 1594 (1962); E. I. Snyder and B. Franzus, *ibid.*, **86**, 1166 (1964).

(11) For the evidence in support of a puckered conformation for the thietane dioxide ring system, see: D. O. Harris, H. W. Harrington, A. C. Luntz, and W. D. Gwinn, *J. Chem. Phys.*, **44**, 3467 (1966); W. D. Kelley, T. R. Lusebrink, and C. H. Sederholm, *ibid.*, **44**, 782 (1966); S. Allenmark, *Ark. Kemi*, **26**, 73 (1966); S. I. Chan, J. Zinn, J. Fernandez, and W. D. Gwinn, *J. Chem. Phys.*, **33**, 1643 (1960).

(J = 6.0 Hz) at 1.38. The less rapidly eluted isomer exhibits a very similar spectrum with corresponding absorptions at δ 5.75, 4.37, 3.50, and 1.42.

When a composite of the spectra of the two products was made and compared with that of the crude cycloaddition mixture, particularly in the high-field region, it was clear that only minor amounts of additional compounds were produced. If, as anticipated, the rate-determining transition state for ring formation is more product-like than reactant-like and hence sensitive to steric and polar factors,[12] thietane dioxides **18** and **20** would best be accommodated by assuming that cycloaddition preferentially takes place from the less-hindered surface of **16**. This conclusion is in agreement with the marginal regioselectivity[13] of the reaction. X-Ray confirmation of these assignments was not pursued in this instance because the pyrolysis product mixtures derived from these chloro ketals (see below) gave evidence that this was not a particularly significant issue.

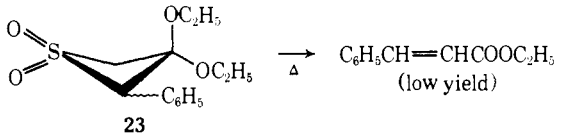
Lastly, dichloro ketal **11** was prepared in low yield by treating 2-dichloromethylene-1,3-dioxolane (**21**) with sulfene generated from methanesulfonyl chloride and



21 **11**

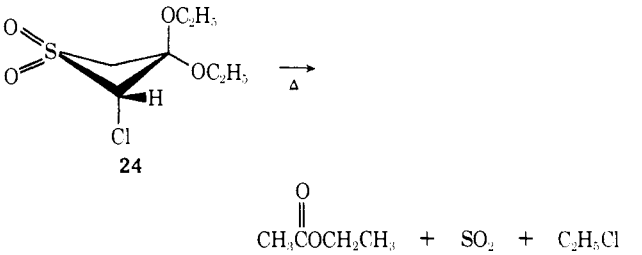
triethylamine. The nmr spectrum of **11** is characterized by two singlets located at δ 4.38 and 4.15.

Pyrolysis Studies. In contrast to episulfones which undergo ready fragmentation to olefins and sulfur dioxide,[14] thietane 1,1-dioxides exhibit appreciable thermal stability. Thus, the 3,3-diethoxy derivative (**22**) is known to be stable to 300° in the gas phase; at 500°, however, much tar formation is seen and small amounts of ethanol, acetic acid, and sulfur dioxide can be detected.[15] Ketal **13a** was found to behave similarly. Although stable to 225–250° in the liquid phase, this sulfone resinified almost completely in the vicinity of 300° with the formation of a low yield of acetic acid. Truce and Norell have noted that the presence of a 2-phenyl substituent in **22** causes the ring system to be less stable. These workers observed that pyrolysis of **23** occurs during attempted distillation (pot temperature 200°) with much tar formation; low yields of ethanol, sulfur dioxide, and ethyl cinnamate were seen.



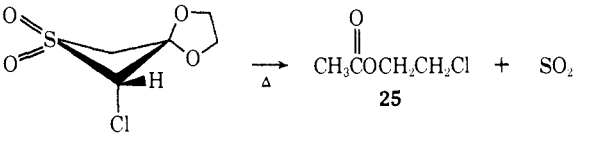
23

By comparison, heating of **24** in the liquid phase at 230–250° for 20 min resulted in smooth conversion to sulfur dioxide, ethyl chloride, and ethyl acetate (95% yield). In addition, a carbonaceous residue remained in the pyrolysis chamber.



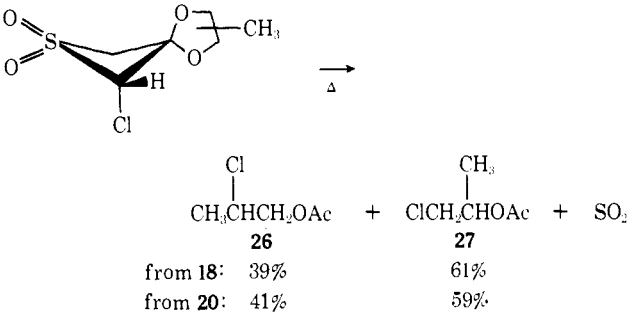
24

Particular interest was attached to the thermal behavior of **13b** which gave rise to 2-chloroethyl acetate (**25**) in 86.5% yield. As in the case of **24**, the production of sulfur dioxide and carbonaceous by-product was again in evidence. Ester **25** was identified from its spectral properties and by comparison with an authentic sample.



13b **25**

When the pure isomeric chloro ketals tentatively identified as **18** and **20** were thermally decomposed in the predescribed fashion, each substance afforded a mixture of two isomeric chloro esters (**26** and **27**) in high yield. Significantly, the product mixtures from the two sources were identical within experimental error. Evidence for the structural assignments of **26** and **27** was provided by their spectra and by unequivocal synthesis.



	26	**27**
from **18**:	39%	61%
from **20**:	41%	59%

Thermal degradation of dichloro ketal **11** was not exceptional. Under parallel conditions, **11** gave rise exclusively to 2-chloroethyl acetate.

Discussion

Mechanistic rationalization of the thermal decomposition of 2-chloro-3-thietanone 1,1-dioxide ketals in terms of a concerted six-electron [$_{\sigma}2_a + {}_{\sigma}2_s + {}_{\sigma}2_a$] process (*cf.* **28**) would require the intervention of episulfone **29**. On the basis of established precedent,[14] **29** would be expected to afford sulfur dioxide and acrylate ester **30** as degradation products. The inoperative nature of this scheme is attested to by at least three observations: (a) no acrylates are seen in these reactions (ethyl acrylate, the product predicted for **24** on this basis, was noted to be stable to the thermal conditions employed);[16] (b) the high yield of saturated

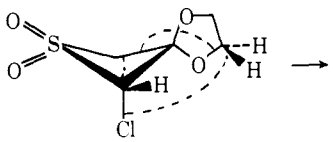
(12) *Cf.* J. E. Leffler and E. Grunwald, "Rates and Equilibria of Organic Reactions," Wiley, New York, N. Y., p 162 ff.

(13) A. Hassner, *J. Org. Chem.*, 33, 2684 (1968).

(14) For reviews, consult: (a) L. A. Paquette, *Accounts Chem. Res.*, 1, 209 (1968); (b) L. A. Paquette, "Mechanisms of Molecular Migrations," Vol. I," B. S. Thyagarajan, Ed., Interscience, Englewood Cliffs, N. J., 1968, pp 121-156.

(15) W. E. Truce and J. R. Norell, *J. Amer. Chem. Soc.*, 85, 3236 (1963).

(16) Our efforts to prepare episulfone i for independent evaluation of



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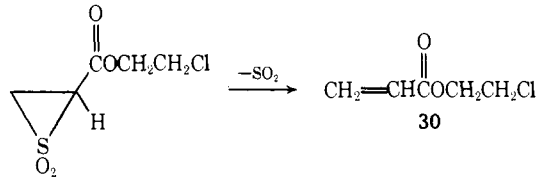
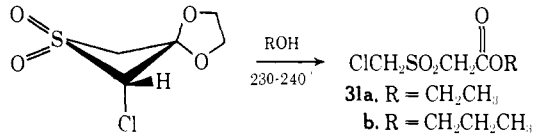


29 30

acetates would seem to preclude the operation of an alternative competing mechanism such as depicted in formula **28**; and (c) most importantly, the nonstereoselective behavior of chloro ketals **18** and **20** cannot be accommodated by a concerted mechanism.

What there is to say at present about the mechanism of the title reaction is based on the stoichiometry of the tranformation and the nature of the products which are formed upon addition of alcohols to the pyrolysis mixture. Thus, once attention is called to the fact that elemental carbon must be included among the products in order to balance the observed reactions,[16a] it is clear that the thermal degradation is not simply a molecular rearrangement entailing the ejection of sulfur dioxide. As noted earlier, a carbonaceous residue was invariably deposited in the pyrolysis chamber. Although the precise nature of this material has not been sought, the amount produced in any given run agreed satisfactorily with the weight of carbon anticipated on the basis of stoichiometric considerations.

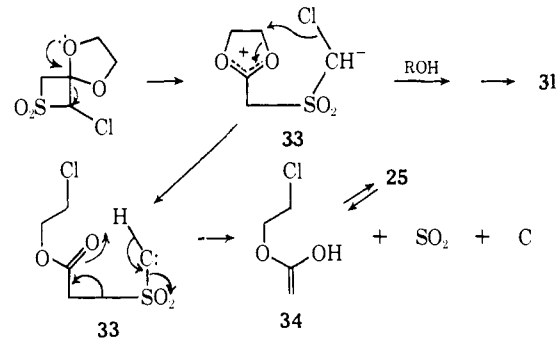
Furthermore, when the pyrolysis of **13b** was conducted in ethanol or *n*-propyl alcohol as solvent (sealed tubes), the passage to 2-chloroethyl acetate (**25**) could be effectively interrupted. The products of this alternate reaction sequence were the corresponding esters of (chloromethanesulfonyl)acetic acid (**31a** and **31b**). Authentic **31a** was synthesized by reaction of ethyl 2-



31a, R = CH_2CH_3
b, R = $CH_2CH_2CH_3$

mercaptoacetate with dichloromethane in the presence of triethylamine at 100°, followed by oxidation with *m*-chloroperbenzoic acid. In confirmation of the structural assignment, **31a** exhibits in its nmr spectrum ($CDCl_3$) two-proton singlets at δ 4.77 and 4.24 in addition to the ethoxyl peaks at 4.29 (q, J = 7.0 Hz) and 1.33 (t, J = 7.0 Hz). The reservation that the ethyl and propyl residues in **31** were introduced *via* an ester interchange process was ruled out by the observation that heating of **31a** in *n*-propyl alcohol under the thermolysis conditions resulted only in minimal conversion to **31b**.

The effect of added alcohol therefore appears to be quenching of an initially produced ring-opened intermediate such as **32**. The plausibility of this first mechanistic operation is founded in the well-recognized



33 34

stabilities of 1,3-dioxolenium cations[17] and α-sulfonyl carbanions.[18]

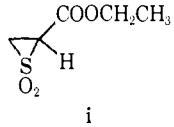
Further passage of intermediate **32** to sulfur dioxide and 2-chloroethyl acetate (**25**) is less clearly understood. However, in view of the fact that chlorine migration to an α-oxonium carbon is observed, it is grossly reasonable to propose that the C–Cl bond is ruptured in **32**. Although the energetics of this rearrangement to **33** are not amenable to evaluation at this time either in theoretical terms or by analogy with pertinent experimental observation, the redistribution of electrons to produce this α-sulfonyl carbene does not appear energetically unrewarding. In completing the hypothetical passage to **25**, the entirely reasonable six-centered transfer of hydrogen from carbon to oxygen is seen to result in the production of elemental carbon, liberation of sulfur dioxide, and formation of **34**. In this analysis, the final rearrangement would be encouraged by the thermodynamic advantage of the generation of neutral products.

From these data, it is clear that introduction of a sulfonyl group into the ring of an α-halocyclobutanone ketal results in marked divergence of reaction pathways upon thermolysis. The reasons for this are probably manifold; certainly, a likely major factor is the ease with which sulfur dioxide is expelled from many sulfones at elevated temperatures. One of the remaining more general questions relates to whether the behavior of molecules such as **4** is under the direct control of orbital symmetry restrictions or not.

Experimental Section

3-Thietanone 1,1-Dioxide Ethylene Ketal (13a). To 197 g (1.0 mol) of bromoacetaldehyde diethyl acetal and 80 g (1.29 mol) of ethylene glycol was added 1 ml of concentrated sulfuric acid. The solution was heated in an oil bath (*ca.* 120°) and the ethanol was removed by distillation through a 15-cm Vigreux column during

its thermal degradation have invariably been thwarted. The schemes which have been examined most exhaustively center about the cyclo-



i

addition of carbethoxysulfene to diazomethane and of sulfene to ethyl diazoacetate.

(16a) NOTE ADDED IN PROOF. At the time of submission of this paper, we were aware of no other reports of discrete carbon atom formation in a *bona fide* organic reaction. Subsequently, however, P. B. Shevlin and A. P. Wolf [*Tetrahedron Lett.*, 3987 (1970)] have demonstrated the formation of carbon atoms in the decomposition of quadricyclanilidene.

(17) H. Hart and D. A. Tomalia, *Tetrahedron Lett.*, 1347 (1967), and references therein.

(18) For an extensive discussion of this point, see D. J. Cram, "Fundamentals of Carbanion Chemistry," Academic Press, New York, N. Y., 1965.

5 hr. After cooling, the solution was diluted with 100 ml of ether and washed with water (three 100-ml portions) and saturated sodium bicarbonate solution (50 ml). The ether solution was dried, evaporated, and distilled to give 137.5 g (83%) of bromoacetaldehyde ethylene ketal, bp 65–67° (12 mm) (lit.[19] bp 68–70° at 13 mm).

To a solution of 14.0 g (0.085 mol) of this ketal in 150 ml of dry tetrahydrofuran was added 3.5 g (0.085 mol) of sodium hydride (57% in oil) and 5 drops of methanol. The reaction mixture was heated at reflux for 24 hr and cooled to 0°. Triethylamine (9.0 g, 0.091 mol) was added, followed by the dropwise introduction of 10.0 g (0.085 mol) of methanesulfonyl chloride in 25 ml of the same solvent. The reactants were stirred for 2 hr at room temperature, filtered, and evaporated to give a yellow oil which partially crystallized on standing in the refrigerator overnight. Trituration of this material with ethyl acetate yielded 5.6 g (40.5%) of **13a**: mp 106–107° (from ethyl acetate); $\nu_{max}^{CHCl_3}$ 1330 and 1094 cm^{-1}.

Anal. Calcd for $C_5H_8O_4S$: C, 36.65; H, 4.87; S, 19.54. Found: C, 36.77; H, 5.04; S, 19.33.

2-Chloro-3-thietanone 1,1-Dioxide Ethylene Ketal (13b). A mixture of 6.0 g (0.14 mol) of sodium hydride (57% in oil), 5 drops of methanol, 24.0 g (0.14 mol) of bromoacetaldehyde ethylene ketal, and 250 ml of dry tetrahydrofuran was refluxed for 24 hr under nitrogen. The mixture was cooled to 0° and 14.5 g (0.147 mol) of triethylamine was added in one portion. With stirring, 21.6 g (0.145 mol) of chloromethanesulfonyl chloride[20] was added dropwise during 20 min. After stirring for 3 hr at room temperature, the precipitated solid was removed by filtration and the filtrate was evaporated. The resulting yellow semisolid was triturated with carbon tetrachloride and filtered to afford 19.5 g (67.5%) of **13b**: mp 117–118.5° (from benzene); $\nu_{max}^{CHCl_3}$ 1348 and 1117 cm^{-1}.

Anal. Calcd for $C_5H_7ClO_4S$: C, 30.24; H, 3.52; Cl, 17.91. Found: C, 30.35; H, 3.49; Cl, 17.91.

Isomers of 2-Chloro-3-thietanone 1,1-Dioxide 1′,2′-Propylene Ketal (18 and 20). Bromoacetaldehyde 1,2-propylene ketal was prepared analogously from the diethyl ketal in 86% yield; bp 67–69° (25 mm) (lit.[21] 95–97° at 42 mm).

From 15.4 g (0.085 mol) of this ketal, 3.5 g (0.085 mol) of 57% sodium hydride dispersion, and 10.0 g (0.085 mol) of chloromethanesulfonyl chloride according to the predescribed procedure, there was obtained a dark yellow oil which was chromatographed on silica gel. Elution with ether–petroleum ether (3:2) gave a combined yield of 8.18 g (27.4%) of two ketals. The earlier and later fractions afforded the pure isomers. The more rapidly eluted substance was obtained as white crystals: mp 93–95° (from ether); $\nu_{max}^{CHCl_3}$ 1340 and 1130 cm^{-1}.

Anal. Calcd for $C_6H_9ClO_4S$: C, 33.89; H, 4.27; S, 15.08. Found: C, 33.91; H, 4.30; S, 15.06.

The less rapidly eluted isomer was recrystallized from chloroform and was obtained as white crystals: mp 85–86°; $\nu_{max}^{CHCl_3}$ 1345 and 1116 cm^{-1}.

Anal. Calcd for $C_6H_9ClO_4S$: C, 33.89; H, 4.27; S, 15.08. Found: C, 33.86; H, 4.38; S, 15.06.

2,2-Dichloro-3-thietanone 1,1-Dioxide Ethylene Ketal (11).[22] To 8.58 g (0.0553 mol) of 2-dichloromethylene-1,3-dioxolane[23] and 5.50 g (0.0553 mol) of triethylamine dissolved in 120 ml of diethyl ether and stirred at room temperature was added 6.33 g (0.0553 mol) of methanesulfonyl chloride in 40 ml of ether under nitrogen over a 30-min period. Solid, white triethylammonium chloride precipitated with no noticeable exothermicity. After stirring for 2.5 hr at room temperature, the solution was filtered free of solids which were washed in turn with fresh ether. Ether was removed from the combined filtrates *in vacuo* to give a mobile yellowish oil, a portion of which was subjected to molecular distillation at 60° and 0.06 mm. This distillate, upon sitting several days, developed a crystalline white solid which was used in turn to seed the remainder of the undistilled oil. A total of 0.5 g (2.6%) of white solid was then obtained which was washed with acetone–ether and recrystallized from chloroform: mp 135–136.5°; $\nu_{max}^{CHCl_3}$ 1355 and 1193 cm^{-1}.

Anal. Calcd for $C_5H_6Cl_2O_4S$: C, 25.77; H, 2.59; S, 13.76. Found: C, 25.58; H, 2.51; S, 13.64.

General Pyrolysis Procedure. A small sample (20–50 mg) of the ketal was sealed in one leg of a U tube (3-mm inner diameter, total length 6–8 in.) and heated for *ca.* 20 min to 230–250°, during which time the volatile products distilled into the other arm which was cooled in a Dry Ice–acetone bath. The U tube was then weighed and opened at the midpoint, and the collector half weighed after warming to *ca.* 50° in order to expel sulfur dioxide and ethyl chloride (when present). A second weighing at this point, in conjunction with the tare of the receiver, gave the amount of ester produced. Nmr and vpc analyses were usually performed at both stages of the work-up. In those cases where it was desirable to purify the product ester, this was accomplished by preparative scale vpc.

Thermal decomposition of **24**[9] afforded ethyl acetate, ethyl chloride, and sulfur dioxide in a combined yield of 87%. Nmr analysis of the composite clearly established the presence of both components. Removal of the volatile components by warming left uniquely ethyl acetate in 95% yield. The identity of the ester was further proven by infrared comparisons.

Pyrolysis of **13b** gave sulfur dioxide and 2-chloroethyl acetate (**25**) in a combined yield of 89%. The pure ester was subsequently isolated in 86.5% yield: $\delta_{TMS}^{CDCl_3}$ 4.35 (t, J = 6.5 Hz, 2), 3.67 (t, J = 6.5 Hz, 2), and 2.10 (s, 3).[24]

Anal. Calcd for $C_4H_7ClO_2$: C, 39.20; H, 5.99. Found: C, 38.96; H, 5.76.

Thermolysis of the less rapidly eluted isomer of 2-chloro-3-thietanone 1,1-dioxide 1′,2′-propylene ketal in analogous fashion afforded in 97.5% total yield a mixture of 2-chloropropyl acetate (**26**, 39%) and 3-chloro-2-propyl acetate (**27**, 61%). The two esters were separated gas chromatographically for ultimate identification.

An authentic sample of **26** was prepared by the method of Brown and Ash:[25] ν_{max}^{neat} 1748 cm^{-1}; $\delta_{TMS}^{CDCl_3}$ 4.21 (t, J = 2.0 Hz, superimposed on m, 3), 2.10 (s, 3), and 1.51 (d, J = 6.5 Hz, 3).

An authentic sample of **27** was prepared by acetylation of 1-chloro-2-propanol with acetyl chloride in pyridine: ν_{max}^{neat} 1745 cm^{-1}; $\delta_{TMS}^{CDCl_3}$ 5.14 (sextet, 1), 3.59 (d, J = 5.5 Hz, 2), and 1.35 (d, J = 6.5 Hz, 3).

Pyrolysis of the more rapidly eluted isomer of 2-chloro-3-thietanone 1,1-dioxide 1′,2′-propylene ketal similarly led to the formation of **26** (41%) and **27** (59%) in 95.3% overall yield.

Lastly, thermolysis of **11** gave 2-chloroethyl acetate as the only characterizable product.

Thermolysis of 13b in Alcohols. A solution of 1.0 g (5.02 mmol) of **13b** in 10 ml of anhydrous ethanol was heated for 1 hr in a steel autoclave immersed in a silicone oil bath heated to 230–240°. The solvent was removed *in vacuo* and the resultant dark oil was passed rapidly through a column of neutral alumina (elution with ether). There was obtained 346 mg (34%) of the ethyl ester of (chloromethanesulfonyl)acetic acid (**31a**): bp 110° (0.05 mm); $\nu_{max}^{CHCl_3}$ 1740, 1340, and 1115 cm^{-1}.

Anal. Calcd for $C_5H_9ClO_4S$: C, 29.93; H, 4.52; S, 15.98. Found: C, 30.14; H, 4.57; S, 15.78.

The same procedure was followed in the case of *n*-propyl alcohol. Ester **31b** was obtained in 26.5% yield: $\nu_{max}^{CHCl_3}$ 1733, 1348, and 1127 cm^{-1}; $\delta_{TMS}^{CDCl_3}$ 4.73 (s, 2), *ca.* 4.25 (q, J = 7.5 Hz, 2), 4.17 (s, 2), 1.63 (septuplet, J = 7.5 Hz, 2), and 0.95 (t, J = 7.0 Hz, 3).

In a control experiment, ester **31a** was dissolved in *n*-propyl alcohol and heated at 230–240° in the autoclave for 1 hr. The nmr spectrum of the recovered oil showed the product to consist of a mixture of **31a** and **31b** in the approximate ratio of 4:1.

Independent Synthesis of 31a. A solution of 10.0 g (0.082 mol) of ethyl 2-mercaptoacetate and 8.0 g (0.082 mol) of triethylamine in 50 ml of dichloromethane was heated in a glass pressure vessel at 100° for 12 hr. The solvent was evaporated and the semisolid residue was triturated with ether. After filtration to remove the solids, the ether solution was washed with water (two 100-ml portions) and dried over magnesium sulfate. Evaporation of the ether afforded 10.0 g of a colorless oil shown by nmr to consist of the desired α-chloro sulfide (~20%) admixed with a substantial amount of the related disulfide (~80%).

The entire mixture was dissolved in ether and oxidized by the dropwise addition of a solution containing 34.8 g (0.164 mol of

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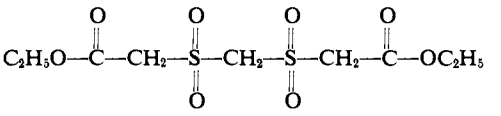
85% purity) of *m*-chloroperbenzoic acid in 250 ml of ether. The reaction mixture was stirred overnight at room temperature, washed with saturated sodium bicarbonate solution (three 100-ml portions), dried, and evaporated to yield a semisolid. This material was chromatographed on silica gel (elution with ether–petroleum ether) to give initially 0.80 g (6.1%) of **31a**, followed by 5.0 g (40%) of **35**: mp 73–74°; $\nu_{max}^{CHCl_3}$ 1735, 1342, and 1120 cm^{-1}; $\delta_{TMS}^{CDCl_3}$ 5.25 (s, 2), 4.38 (s, 4), 4.28 (q, J = 7.0 Hz, 4), and 1.32 (t, J = 7.0 Hz, 3).

Anal. Calcd for $C_9H_{16}O_8S_2$: C, 34.17; H, 5.10; S, 20.27. Found: C, 34.35; H, 5.20; S, 20.19.



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Acknowledgment. We are indebted to the National Science Foundation for their partial support of this research through Grant No. GP-2939.

Aminoacylhydroxamates. A Case of Slow Proton Transfer between Electronegative Atoms in Solution

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Abstract: Aminoacylhydroxamic acids can exist in two forms that migrate with characteristic mobility on the same chromatogram under standard chromatographic conditions in acid aqueous butanol; they are designated fast and slow hydroxamates. Chromatographic mobility is shown to depend on pretreatment of the compound in aqueous solution and is not a chromatographic artifact. The fast and slow forms of hydroxyprolylhydroxamate have been analyzed by various means including ir and nmr spectroscopy. The only chemical difference that can be demonstrated is that in the slow form the basic amino nitrogen is protonated while in the fast form it is not. It is suggested that the nonprotonated amine in acid solution may be stabilized through internal hydrogen bonding; the same may be true of the protonated amine in basic solution.

It is considered almost axiomatic that "proton transfer between electronegative atoms, such as nitrogen, oxygen, sulfur and the halogens, occur so rapidly in solution that they cannot be kinetically examined."[1] The purpose of this paper is to describe a case of slow proton transfer between acidulated water and the amino nitrogen of aminoacylhydroxamates.

The work to be described grew out of an observation of aberrant chromatographic behavior in prolylhydroxamate which was subsequently confirmed for other aminoacylhydroxamic acids.[2] Many of these compounds, it was found, can exist in two forms designated as fast and slow because each form migrates with characteristic mobility under standard chromatographic conditions (15% formic acid in aqueous butanol)[3] (Figure 1). Typical mobilities are given in Table I. Since routine chromatographic analysis on paper is by an "overflow" method, mobilities are reported as R_{PH}, *i.e.*, relative to the mobility of fast prolylhydroxamate (PH).[4] Preparation of aminoacylhydroxamic acid from the corresponding methyl ester under standard conditions (*i.e.*, in slightly basic medium)[5] usually gives only the fast product. After pretreatment with aqueous HCl at pH 2–3, the fast form is converted into the slow form. In the case of PH and HPH treated with mineral acid, this conversion appears quantitative as judged by appearance of the chromatograms. In other cases, for example isoleucyl- and tryptophanylhydroxamic acid, most of the fast hydroxamate is converted to the slow form by mild mineral acid treatment, but some of it still migrates in the fast form. In such cases an equilibrium may be established between forms since prolonged acid treatment does not appear to affect the distribution further and trailing is commonly seen. Lysylhydroxamic acid gives only one (relatively very slow) spot during chromatography after preparation in the usual way; its migratory rate is not affected by mild mineral acid pretreatment. Histidylhydroxamic

Table I. Chromatographic Mobility of Hydroxamic Acids[a]

Hydroxamic acid	Mobility (R_{PH})[b] Fast	Slow
N-Acetylprolyl-	1.57	1.57
Benzoyl-	2.2	2.2
Glycyl-	0.52	0.29
Histidyl-	0.35	0.17
Hydroxyprolyl-	0.70	0.39
Isoleucyl-	1.48	1.00
Leucyl-	1.60	1.30
Lysyl-		0.14
Methionyl-	0.37	0.14
Prolyl-	1.00	0.64
Propionyl-	0.13	0.14
Tryptophanyl-	0.96	0.60
Tyrosyl-	0.88	0.54

[a] Hydroxamic acids applied to Whatman no. 1 paper from neutral solution (fast) or solution made to pH 2–3 with HCl (slow). Descending chromatograms developed in 2-butanol–formic acid–water (75:15:10, v/v) for 18–20 hr and air-dried; spots visualized with $FeCl_3$ spray. [b] Relative to fast prolylhydroxamate.

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(4) Abbreviations used are: PH, prolylhydroxamate; HPH, hydroxyprolylhydroxamate; R_{PH}, mobility of chromatographed spot relative to fast PH; R_f, mobility of chromatographed spot relative to solvent front.

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