times with 10-ml. portions of ether. The ether extracts were combined, dried with magnesium sulfate, and concentrated to a volume of 4 ml. by distillation. Analysis by g.l.p. chromatography indicated that the composition of the mixture of cyclic ethers was unchanged.

2-Vinyl-1,3-dioxolane (**8**, 5 g., 0.05 mole) was treated in the same manner with 1.6 g. (0.04 mole) of sodium hydroxide in 40 ml. of dimethyl sulfoxide at 120°. The recovered **8** weighed 4.2 g. (84%), and examination of its infrared spectrum and g.l.p. chromatograms indicated that it was free of impurities.

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cis- and *trans*-3-Alkyl-2-methyloxiranes and 3-Alkyl-1,2-dimethylaziridines[1a-c]

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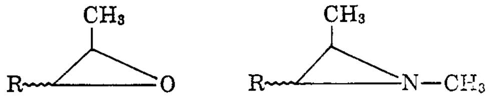
Syntheses are reported of a series of *cis*- and *trans*-3-alkyl-2-methyloxiranes (**1a–h**) and the corresponding *cis*- and *trans*-3-alkyl-1,2-dimethylaziridines (**2a–h**). The stereospecificity of conversion of sulfate esters of amino alcohols to aziridines is discussed briefly. The *cis*-oxiranes were found to have higher boiling points, refractive indices, and densities than their *trans* isomers, but the *cis*-aziridines were found to have the lower of these physical properties. The structural assignments to the 3-*n*-propyl-2-methyloxiranes are corrected, and the applicability of current versions of the von Auwers–Skita rule to aziridines, oxiranes, and other heterocyclic compounds is discussed.

A recent statement[2] of the von Auwers–Skita rule relating physical properties to isomer structure is "with cyclic stereoisomers in which the substituents are bound to configurationally identical ring systems, the isomer with the higher density and the higher refractive index is that which has the higher heat content."[3] Usually, the (higher) boiling point and (lower) molar refraction can be related in a similar manner. Interestingly, there appears to be no previous examination of the applicability of this or similar rules[2,4] to small-ring heterocyclic systems.

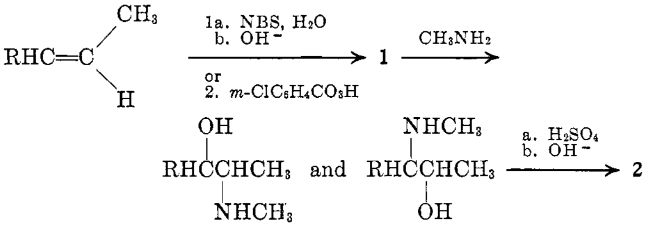
As a preliminary to the study of certain aspects of the relationship of structure to reactivity of aziridines and aziridinium compounds, we prepared several pairs of *cis*- and *trans*-3-alkyl-1,2-dimethylaziridines (**2a–h**). These syntheses required preparation of the corresponding *cis*- and *trans*-3-alkyl-2-methyloxiranes (**1a–h**), which served as intermediates in the preparations of the aziridines. This work therefore made available a sufficient number of compounds for evaluation of the applicability of current versions of the von Auwers–Skita rule to small-ring heterocyclic systems. We report here the syntheses of the aziridines **2a–h** and the oxiranes **1a–h** together with their relevant physical properties.



1a, R = *cis*-CH_3
b, R = *trans*-CH_3
c, R = *cis*-C_2H_5
d, R = *trans*-C_2H_5

2e, R = *cis*-*i*-C_3H_7
f, R = *trans*-*i*-C_3H_7
g, R = *cis*-*t*-C_4H_9
h, R = *trans*-*t*-C_4H_9

The procedures used for syntheses of **1a–h** and **2a–h** are outlined in the accompanying reaction sequence.



Although details have been given for the preparation of *trans*-3-isopropyl-1,2-dimethylaziridine (**2f**) by the first procedure,[5] some discussion of the preparation of the aziridines is desirable because structural variation required marked changes in conditions in some cases and caused notable differences in results in others.

Commercial alkene with N-bromosuccinimide and water was transformed to its bromohydrin or bromohydrins, and this product was converted with aqueous base to the corresponding oxirane (**1**). As for preparations of *cis*- and *trans*-3-isopropyl-2-methyloxirane (**1e** and **1f**), the two-step procedure gave over-all yields of **1a–d** of better than 70%; however, yields of *cis*- and *trans*-3-*t*-butyl-2-methyloxirane (**1g** and **1h**, respectively) were less than 30%.[6] Fortunately, the use of *m*-chloroperbenzoic acid made possible preparation of **1g** and **1h** from the corresponding alkene in yields of better than 65%. Conversions of the alkenes to the oxiranes by both methods were highly stereo-

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[1] (a) Structure–Activity Relationships of Ethylenimines. V. (b) Previous paper in the series: A. T. Bottini and R. L. VanEtten, *J. Org. Chem.*, **30**, 575 (1965). (c) This research was supported by Grant CA-05528 from the National Cancer Institute of the Public Health Service. (d) Public Health Service Predoctoral Fellow, 1963–1964.

[2] H. Van Bekkum, A. Van Veen, P. E. Verkade, and B. M. Wepster, *Rec. trav. chim.*, **80**, 1310 (1961). Earlier statements of the von Auwers-Skita rule are discussed in this reference.

[3] (a) The significance of relating the von Auwers–Skita rule to enthalpy rather than free energy had been discussed earlier.[3b] (b) N. L. Allinger, *J. Am. Chem. Soc.*, **79**, 3443 (1957).

[4] (a) Although olefins appear to follow the dipole rule (van Arkel rule), according to which the isomer of higher dipole moment has the higher physical constants regardless of enthalpy (see ref. 3b and references cited therein), it is not yet clear when saturated cyclic stereoisomers can be expected to follow the dipole rule.[2,4b] Conceivably, saturated cyclic stereoisomers with appreciably different dipole moments may follow the dipole rule rather than the quoted version or similar versions of the von Auwers–Skita rule.[4c] (b) N. L. Allinger and R. J. Curby, Jr., *J. Org. Chem.*, **26**, 933 (1961). (c) *Cf.* E. L. Eliel, "Stereochemistry of Carbon Compounds," McGraw-Hill Book Co., Inc., New York, N. Y., 1962, pp. 216, 217.

[5] A. T. Bottini, R. L. VanEtten, and A. J. Davidson, *J. Am. Chem. Soc.*, **87**, 755 (1965).

[6] A rationale for the poorer yields of **1g** and **1h** is that conversion of a *t*-butylethylene to a bromohydrin is more likely to be accompanied by carbonium ion rearrangement than is similar conversion of a primary or secondary alkylethylene. *Cf.* the study of the addition of hydrogen chloride to *t*-butylethylene reported by G. G. Ecke, N. C. Cooke, and F. C. Whitmore [*ibid.*, **72**, 1511 (1950)].

specific, *cis-* and *trans*-alkenes giving *cis-* and *trans*-oxiranes, respectively.[7]

Treatment of the oxiranes with aqueous methylamine gave the corresponding methylamino alcohols in yields of better than 60%. As expected for an S_N2 reaction,[8] conditions required for these conversions were markedly dependent on the degree of steric hindrance to attack at the epoxide-ring carbons. Thus, *threo-* and *erythro*-3-methylamino-2-butanol were obtained by allowing aqueous methylamine solutions of **1a** and **1b**, respectively, to stand at room temperature for 3 days, but reactions of similar mixtures of **1g** or **1h** with aqueous methylamine required temperatures of over 100° for 2–3 days.

The amino alcohols were converted to sulfate esters by treatment with an equal molar amount of 6 *N* sulfuric acid, and the sulfate esters were converted to aziridines by treatment with 7 *N* sodium hydroxide. As the former reaction occurs without the making or breaking of a bond to carbon[8,9] and the latter reaction occurs with inversion, *cis-* and *trans*-aziridines are obtained from *cis-* and *trans*-oxiranes, respectively.

We made an important observation concerning the configurational stability of sulfate esters of β-amino alcohols. In the usual procedure employed for preparing the aziridines, water was removed from the sulfate ester by heating under vacuum to 120–160°. This procedure gave crystalline sulfate esters only of amino alcohols prepared from **1e**–**1h** and methylamine. We observed that, when the amino alcohol obtained from sterically pure **1a** was heated to 190°, treatment of the sulfate ester with base yielded a mixture of **2a** and **2b**. As milder drying of the sulfate ester allowed preparation of essentially pure **2a**, we conclude that too vigorous heating of the sulfate ester converted it to a mixture of *threo* and *erythro* sulfate esters, thereby destroying the stereospecificity of the procedure.

Different methods of treatment of sulfate esters may well be responsible for apparently contradictory observations relating to the stereochemistry of formation of sulfate esters of β-amino alcohols.[10]

The oxiranes and aziridines prepared were obtained with purities of >98.5% as indicated by gas–liquid partition chromatography (g.l.p.c.) and infrared and n.m.r. spectroscopy. We would like to note that, although the methyl resonance of *cis*-2,3-dimethyloxirane (**1a**) occurs at higher field than the methyl resonance of *trans*-2,3-dimethyloxirane (**1b**),[11] the C-2-methyl resonance of *cis*-3-*t*-butyl-2-methyloxirane (**1g**) occurs at lower field than the C-2-methyl resonance of its *trans* isomer **1h**.[12] Apparently, the close approach of the *t*-butyl and methyl groups in **1g** causes sufficient deshielding to more than counterbalance the shielding effects of the anisotropy of the *t*-butyl group.[14]

The boiling points, refractive indices, and densities of **1a**–**h** and **2a**–**h** are summarized in Table I. Examination of Table I shows that the *cis*-oxirane has the higher boiling point, refractive index, and density, but that the *trans*-aziridine has the higher of these physical properties.

TABLE I

PHYSICAL PROPERTIES OF *cis-* AND *trans*-3-ALKYL-2-METHYLOXIRANES (**1a**–**h**) AND *cis-* AND *trans*-3-ALKYL-1,2-DIMETHYLAZIRIDINES (**2a**–**h**)

Alkyl group	B.p.,[a] °C.		n^{25}D		d^{25}_4	
	cis	*trans*	*cis*	*trans*	*cis*	*trans*
			Oxiranes			
CH_3[b]	59.7	53.5	1.3802	1.3705	0.8226	0.8010
C_2H_5[c]	85.4	80.2	1.3915	1.3867	0.8195	0.8031
i-C_3H_7	102–103	96–97[d]	1.3957	1.3890	0.8035	0.7910
t-C_4H_9[e]	117.5–119.5	110–111	1.4080	1.3994	0.8340	0.8026
			Aziridines			
CH_3	61.5–62.0	72.5–73.0[f]	1.3930	1.4010[f]	0.7393	0.7584
C_2H_5[g]	87–88	98–98.5	1.4000	1.4069	0.7475	0.7628
i-C_3H_7	102–103[d]	112–113[g]	1.4016[d]	1.4071[d]	0.7448	0.7614
t-C_4H_9[h]	117–118	124–125	1.4110	1.4113	0.7602	0.7676

[a] At 750 ± 15 mm. [b] Ref. 7c. [c] H. J. Lucas, M. J. Schlatter, and R. C. Jones, *J. Am. Chem. Soc.*, **63**, 22 (1941). [d] Ref. 5. [e] *Anal.* Calcd. for $C_7H_{14}O$: C, 73.63; H, 12.36. For **1g**, found: C, 73.49; H, 12.48. For **1h**, found: C, 73.41; H, 12.13. [f] G. K. Helmkamp, R. D. Clark, and J. R. Koskinen [*J. Org. Chem.*, **30**, 666 (1965)] reported b.p. 71.0–71.2° (735 mm.), n^{20}D 1.4045. [g] *Anal.* Calcd. for $C_6H_{13}N$: C, 72.66; H, 13.21; N, 14.13. For **2c**, found: C, 72.65; H, 13.57; N, 13.73. For **2d**, found: C, 72.34; H, 13.20; N, 14.29. [h] *Anal.* Calcd. for $C_8H_{17}N$: C, 75.52; H, 13.47. For **2g**, found: C, 75.97; H, 13.61. For **2h**, found: C, 75.45; H, 13.30.

Because of the greater degree of nonbonded interactions in a *cis*-2,3-dialkyloxirane as compared with its *trans* isomer, it seems reasonable to conclude that the *cis*-oxirane has the higher heat content. Accordingly, current versions of the von Auwers–Skita rule[2] appear to be applicable to 2,3-dialkyloxiranes.

After we had prepared and characterized compounds **1a**–**h** and **2a**–**h**, a report appeared in which the *cis* structure was assigned to the more volatile 3-*n*-propyl-2-methyloxirane.[15] In order to check this structural assignment, which is contrary to the assignment based on extension of current versions of the von Auwers–Skita rule to oxiranes, a mixture of 90% *cis*-2-hexene and 10% *trans*-2-hexene[17] was converted to an 88:12% mixture of 3-*n*-propyl-2-methyloxiranes in which the

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(7) (a) Previous work has shown that addition of hypobromous acid (from N-bromosuccinimide and water) occurs in a *trans* manner,[7b] formation of an epoxide on alkali treatment of a β-halo alcohol occurs with inversion of configuration,[7c] and epoxidation of an alkene with a peracid is a *cis*-addition.[7d] (b) R. A. Raphael, *J. Chem. Soc.*, 401 (1952). (c) S. Winstein and H. J. Lucas, *J. Am. Chem. Soc.*, **61**, 1576 (1939). (d) P. D. Bartlett, *Rec. Chem. Progr.*, **11**, 47 (1950).

(8) F. H. Dickey, W. Fickett, and H. J. Lucas, *J. Am. Chem. Soc.*, **74**, 944 (1952), and references cited therein.

(9) R. Ghirardelli and H. J. Lucas, *ibid.*, **79**, 734 (1957).

(10) *Cf.* S. J. Brois and G. P. Beardsley, Abstracts of the 148th National Meeting of the American Chemical Society, Chicago, Ill., Sept. 1964, p. 66S; T. Taguchi and M. Kojima, *Chem. Pharm. Bull.* (Tokyo), **7**, 103 (1959).

(11) M. H. Gianni, E. L. Stogryn, and C. M. Orlando, Jr. [*J. Phys. Chem.*, **67**, 1385 (1963)] reported methyl resonances at τ 9.02 p.p.m. (δ 0.98 p.p.m.) and τ 8.85 p.p.m. (δ 1.15 p.p.m.) for **1a** and **1b**, respectively.

(12) In spectra taken of 10% solutions in chloroform, the C-2-methyl resonances of **1g** and **1h** occur at δ 1.41 and 1.26 p.p.m., respectively; the C-2-methyl resonances of both the *cis-* and the *trans*-isopropyl analogs **1e** and **1f** occur at δ 1.24 p.p.m. As anticipated,[13] coupling of the ring hydrogens of the *cis*-oxiranes **1e** and **1g** ($J \approx 4.4$ c.p.s.) was observed to be greater than the ring-hydrogen coupling ($J \approx 2.3$ c.p.s.) of the *trans*-oxiranes **1f** and **1h**.

(13) The n.m.r. spectra of a number of oxiranes have been analyzed in detail by C. A. Riley and J. D. Swalen [*J. Chem. Phys.*, **32**, 1378 (1960); **34**, 980 (1961); **35**, 1522 (1961)].

(14) Other examples of deshielding similar to that observed in **1g** have been reported recently by E. M. Arnett and J. M. Bollinger [*J. Am. Chem. Soc.*, **86**, 4729 (1964)] and by W. Nagata, T. Terasawa, and K. Tori [*ibid.*, **86**, 3746 (1964)].

(15) D. Gagnaire and P. Monzeglio, *Compt. rend.*, **259**, 1128 (1964). The structural assignment appears to be based upon the unfounded "analogy with other known epoxides, the *cis* isomer being the more volatile," as well as interpretation of the infrared spectra of the epoxides. In the reference[16] cited by the authors to support their infrared spectral correlations, the isomeric pairs of oxiranes **1a** and **1b** and **2a** and **2b** are described; for both pairs, the *trans* structure was assigned (correctly) to the more volatile isomer.

(16) H. van Risseghem, *Bull. soc. chim. France*, 1661 (1959).

(17) The analysis of the mixture of 2-hexenes was carried out by Professor G. S. Zweifel of this department.

less volatile isomer was the major component. The yield and stereospecificity of the reaction show convincingly that the major component was *cis*-3-*n*-propyl-2-methyloxirane and that the previous configurational assignments[15] to the 3-*n*-propyl-2-methyloxiranes are incorrect.

When aziridines substituted only in the 2- and 3-positions with alkyl groups are considered, the *cis* isomer can be expected to have the greater enthalpy, and the von Auwers–Skita rule in its present form should be applicable in the same manner as for the 2,3-dialkyloxiranes. Such an application is consistent with the reported physical properties of the 2,3-dimethylaziridines; the *cis* isomer has the higher boiling point, refractive index, and density.[9]

Assessment of the relative heat contents of the 1,2,3-trialkylaziridines is more difficult because, with the exception of *trans*-1,2,3-trimethylaziridine (**2b**), each aziridine is a mixture of energetically different conformers.[5] From consideration of the reported structure of aziridine,[18] it appears that there is a shorter distance between two methyl carbons in **2b** than in the more stable conformer of its *cis* isomer **2a**, *i.e.*, the conformer with the N-methyl *trans* to the methyls at C-2 and C-3. By assuming that the bond angles and bond distances in **2a** and **2b** are the same as the corresponding angles and distances reported for aziridine,[18a] specifically, $r_{\mathrm{C-C}} = 1.480$ Å., $\angle\ \mathrm{C_2N{-}H} = 112°$, $\angle\ \mathrm{H_2C{-}C} = 159°\ 25'$, and $\angle\ \mathrm{HCH} = 116°\ 41'$, and that the exocyclic C–C and C–N bond lengths are 1.54 and 1.47 Å., respectively,[19] we calculated a distance of 2.99 Å. between the C-methyl carbons of **2a** and a distance of 2.60 Å. between the N-methyl- and *cis*-C-methyl carbons of **2b**. As 2.0 Å. is a reasonable estimate[19b] of the van der Waals radius of the methyl group, we see that there is appreciable steric interference present in the two isomers. Because of the 0.4-Å. shorter distance between the interfering methyl groups in the *trans* isomer **2b**, we consider it reasonable to conclude that the *cis* isomer **2a** has a smaller enthalpy than **2b** and that current versions of the von Auwers–Skita rule apply to the 1,2,3-trimethylaziridines.

It might be expected that when one of the ring substituents is *t*-butyl there would be a larger contribution to the enthalpy resulting from interaction of the *cis*-ring substituents than from interaction of the N-methyl group and an opposed ring-methyl group. (This of course assumes that the contribution to the enthalpy from the conformer in which the N-methyl group is opposed to the *t*-butyl group can be neglected because of the small population of this conformer.) However, calculations of internuclear distances suggest that, even for the 3-*t*-butyl-1,2-dimethylaziridines, the *trans* isomer (**2h**) is the more strained. In order to minimize the steric interaction between the methyl and *t*-butyl groups at C-2 and C-3, the *t*-butyl group can rotate until two of its methyl groups are equidistant from the ring-methyl group. So arranged, the distance between the ring-methyl carbon and one of the methyl carbons of the *t*-butyl group is 2.83 Å.[20] While two methyl carbons of the *t*-butyl group interact with the ring-methyl group at the same time, because of the exponential nature of the potential functions which describe the energy of steric interactions,[21] it is conceivable that the contribution to the enthalpy is still less than that resulting from interaction of the N-methyl group with the opposed methyl group at C-2, where the distance between methyl carbons is calculated to be 2.60 Å.

From the foregoing discussion, we consider that there is ample reason to believe that versions of the von Auwers–Skita rule relating higher density and refractive index to higher enthalpy apply to 1,2,3-trialkylaziridines as well as 2,3-dialkylaziridines and 2,3-dialkyloxiranes. Admittedly, until the thermodynamic data necessary for calculation of ΔH for **2g** → **2h** are available, this belief is with some reservation.[22] Because of the applicability to such diverse systems as medium-ring carbocycles and small-ring heterocycles, we suggest that current versions of the von Auwers–Skita rule are generally applicable to compounds containing saturated heterocyclic rings.

Experimental

Boiling points are uncorrected. Infrared spectra were obtained with a Beckman IR-4 spectrophotometer. N.m.r. spectra were determined at 56.4 or 60 Mc. with a Varian Associates HR-60 system equipped with electronic integrator and base-line stabilizer. Resonance frequencies in n.m.r. spectra were determined using the side-band technique with a Packard CD-200 audiooscillator. Unless stated otherwise, resonance frequencies were determined relative to internal tetramethylsilane (TMS) and are reported in p.p.m. downfield from the TMS resonance. Gas–liquid partition chromatograms were obtained using either a Loe Model 1 Chromat-O-Flex or a Wilkens Aerograph Model A-700. Microanalyses were performed by Mr. V. H. Tashinian, Berkeley, Calif.

Oxiranes 1a–h.—Using essentially the same procedure described for the conversion of *trans*-4-methyl-2-pentene to *trans*-3-isopropyl-2-methyloxirane (**1f**),[5] alkenes of >94% purity obtained from either Phillips Petroleum Co., Bartlesville, Okla., or Chemical Samples Co., Columbus, Ohio, were converted *via* their bromohydrins to the corresponding oxiranes. Fractional distillation gave oxiranes with purities greater than 98.5% as determined by g.l.p.c. on a 0.25 in. × 10 ft. column packed with didecyl phthalate on Chromosorb W-HMDS and on a 0.25 in. × 15 ft. column packed with silicone XF-1150 on Chromosorb W-HMDS. The physical properties of **1a–d** were in excellent agreement with literature values, and the n.m.r. spectra of the other oxiranes were in complete accord with their assigned structures.

cis-3-*t*-Butyl-2-methyloxirane (**1g**) and its *trans* isomer (**1h**) were prepared in better yield from the corresponding alkene and *m*-chloroperbenzoic acid (Food Machinery Chemical Corp.). The following procedure is typical. A solution of 50 g. (<0.29 mole) of *m*-chloroperbenzoic acid (85% min.) in 450 ml. of methylene chloride–chloroform was added slowly to a solution of 40 g. (0.41 mole) of *trans*-2,2-dimethyl-3-pentene in 50 ml. of methylene chloride. The reaction was exothermic, and the tempera-

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(18) (a) T. E. Turner, V. C. Fiora, and W. M. Kendrick, *J. Chem. Phys.*, **23**, 1966 (1955). (b) See also R. D. Johnson, R. J. Myers, and W. D. Gwinn, *ibid.*, **21**, 1425 (1953). J. Igarashi, *Bull. Chem. Soc. Japan*, **34**, 369 (1961).

(19) (a) *Cf.* the C–C and C–N bond distances summarized in "Tables of Interatomic Distances and Configurations in Molecules and Ions," compiled by H. J. Bowen, *et al.*, The Chemical Society, London, 1958; (b) see also L. Pauling, "The Nature of the Chemical Bond," 3rd Ed., Cornell University Press, Ithaca, N. Y., 1960, Chapters 7 and 8.

(20) The distance of closest approach between these two carbons can be calculated to be 2.36 Å. This indicates that there is a sizeable barrier to rotation of the *t*-butyl in **2g**.

(21) See H. E. Simmons and J. K. Williams, *J. Am. Chem. Soc.*, **86**, 3222 (1964), and references therein.

(22) Although we consider that the relative physical properties of the oxiranes and aziridines are best understood in terms of enthalpy differences, there is the possibility, particularly for **2g** and **2h**, that dipole moment differences[4] may be the overriding factor in determining relative physical properties.

ture was controlled by adjusting the rate of addition to the peracid. After a short time, a white precipitate of benzoic acid appeared. The reaction mixture was stirred overnight and then made basic with a 15% solution of sodium carbonate. The heavy organic layer was separated and distilled to yield 29 g. (>88%) of **1h**). The elemental analyses of **1g**, **1h**, and the new aziridines are given in footnotes to Table I.

1,2,3-Trialkylaziridines.—Treatment of the oxiranes with aqueous solutions of primary amines using appropriate modifications of the conditions described for the reaction of methylamine and **1f** gave amino alcohols in better than 60% yield. Reactions with **1a–d** were carried out at or below room temperature for 3–7 days; reactions with **1g** and **1h** were carried out in a manganese steel bomb at 100–110° for 48 hr. Each amino alcohol was converted to its corresponding aziridine *via* the sulfate ester as described for the preparation of **2f**[5] except that the sulfate ester was not heated above 140°. Yields exceeded 50%. The purity of the aziridines was assayed by g.l.p.c. with the same columns used to assay the oxiranes, and examination of their n.m.r. and infrared spectra showed further that contamination with amino alcohols or unsaturated isomers was insignificant.

Conversion of *threo*-3-Methylamino-2-butanol to 2a and 2b.—The amino alcohol, b.p. 151–155° (42 g., 0.41 mole), prepared from *cis*-2,3-dimethyloxirane (**1a**) and methylamine was treated with 2 equiv. of sulfuric acid. The mixture was heated gradually at water pump pressure to 190° and held at that temperature for 12 hr. The brown glass that resulted, which failed to crystallize at room temperature, was treated with excess 7 *N* sodium hydroxide. The reaction mixture was steam distilled until the head temperature reached 100°. The distillate was saturated with sodium hydroxide, and the ammoniacal organic phase was separated and dried with sodium hydroxide. Distillation gave two major fractions. The first fraction, b.p. 61–62°, weighed 16 g. (44%) and was 97.5% **2a**; the second fraction, b.p. 72–73°, weighed 7 g. (19%) and was 95% **2b**. The major contaminant in each fraction was the other isomer. When the sulfate ester prepared from the same amino alcohol was heated to <140° prior to treatment with base, the product contained less than 1.5% **2b**.

The stereospecificity of the conversion of the amino alcohol from **1c** and methylamine to **2c** was also destroyed by heating the sulfate ester to >170° for 8 hr.

Kinetics and Mechanism of Acid-Catalyzed Enol Ester Hydrolysis

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The acid-catalyzed hydrolysis rates of several enol esters have been measured in 50 wt. % aqueous dioxane. Relative rate at 65°, activation enthalpy (kilocalories per mole), and activation entropy (entropy units) are as follows: vinyl acetate, 1.00, 15.5, 0.7; vinyl propionate, 0.77, 13.2, −6.7; vinyl butyrate, 0.46, 14.8, −3.0; vinyl pivalate, 0.06, 22.7, 16.4; and isopropenyl acetate, 0.78, 16.8, 4.0. The mechanistic implications of the data are discussed.

In spite of the vast accumulation of data on free-radical reactions of enol esters, no studies have appeared on the mechanism of acid-catalyzed enol ester hydrolysis. Only recently has kinetic information been published on the basic hydrolysis of a few select enol esters and the results indicated no unusual features.[1]

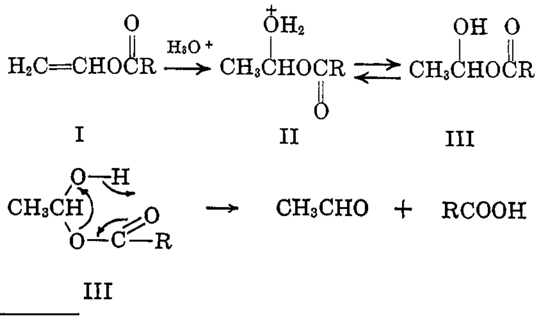
Our initial interest was focused on the mechanism of acid-catalyzed hydrolysis of cyclopropyl esters, since the possibility exists for a rate-determined ring opening of the cyclopropyl group followed by expulsion of acetaldehyde and an acyl carbonium ion.[2,4] Because many reactions of vinyl and cyclopropyl groups are similar[5,6] it was reasonable to suppose that enol esters might exhibit unique or unusual behavior during acid hydrolysis. Evidence will be presented which clearly eliminates either rapid reversible or rate-determined protonation of the olefin in the mechanistic sequence.

Results

The rate constants for acid-catalyzed hydrolysis of several vinyl esters were determined by acid titration of aliquots from sealed ampoules (see Experimental) and are tabulated in Table I. The rate law is pseudo first order and exhibited no sign of reversibility. The data for vinyl acetate at 65° clearly indicate that the reaction is first order in hydronium ion. The relative rates at 65° are tabulated in Table II and a summary of the activation parameters appears in Table III.

Discussion

The finding that the sulfuric acid catalyzed hydrolysis of vinyl acetate in aqueous dioxane containing O^{18}-enriched water produced no isotopic enrichment in the product acid clearly indicates that the hydrolysis mechanism involves exclusive vinyl–oxygen cleavage.[7] Although protonation of the ether oxygen atom with subsequent cleavage to a vinyl carbonium ion is a formal possibility, the well-known inertness of vinyl and phenyl halides toward solvolysis[8] would preclude this path in favor of an initial hydration of the double bond followed by a sequence of steps outlined below without any specific implications about the details of the conversion of I to II, *vide infra.* The kinetic in-



$$\underset{\text{I}}{H_2C{=}CHO\overset{O}{\overset{\|}{C}}R} \xrightarrow{H_3O^+} \underset{\text{II}}{CH_3\overset{\overset{+}{O}H_2}{\overset{|}{C}}HO\underset{\underset{O}{\|}}{C}R} \rightleftarrows \underset{\text{III}}{CH_3\overset{OH}{\overset{|}{C}}HO\overset{O}{\overset{\|}{C}}R}$$

$$\text{III} \longrightarrow CH_3CHO + RCOOH$$

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[1] C. H. DePuy and L. R. Mahoney, *J. Am. Chem. Soc.*, **86**, 2653 (1964).

[2] The first step of such a mechanism has an analogy in the ring-opening reactions of cyclopropanols in the presence of acids.[3]

[3] C. H. DePuy and F. W. Breitbeil, *J. Am. Chem. Soc.*, **85**, 2176 (1963).

[4] The mechanism of acid-catalyzed cyclopropyl ester hydrolysis will be the subject of a separate paper.

[5] C. A. Coulson and W. F. Moffitt, *Phil. Mag.*, **40**, 1 (1949).

[6] A. O. Walsh, *Trans. Faraday Soc.*, **45**, 179 (1949).

[7] L. A. Kipriaviova and A. F. Rekasheva, *Dokl. Akad. Nauk SSSR*, **144**, 386 (1962).

[8] L. P. Hammett, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1940, p. 153.