# Kinetics of the Gas Phase Reactions of (+)-trans-2,3-Divinyloxirane

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The racemization of (+)-2,3-divinyloxirane is facile at 150°, log  $(k_1/s^{-1}) = (11.3 \pm 0.5) - (30.1 \pm 0.4)/\theta$  where  $\theta = 2.303RT$  in kcal mol<sup>-1</sup>. A slower but competitive rearrangement yields racemic 2-vinyl-2,3-dihydrofuran. The mechanisms of these reactions are discussed in terms of electrocyclic processes.

La racémisation du (+) divinyl-2,3 oxiranne est facile à  $150^{\circ}$ ,  $\log (k_1/s^{-1}) = (11.3 \pm 0.5) - (30.1 \pm 0.4)/\theta$  où  $\theta = 2.303RT$  exprimé en kcal/mol. Un réarrangement beaucoup plus lent mais compétitif conduit au vinyl-2 dihydro-2,3 furanne racémique. Les mécanismes de ces réactions sont discutés en termes de processus électrocycliques. [Traduit par le journal]

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### Introduction

Thermally induced isomerizations of strained cyclic systems offer an excellent means of studying bond cleavage processes, thus cyclopropanes have been extensively studied (1). Oxiranes provide a similar vehicle with which to study both carbon-carbon and carbon-oxygen cleavage. Although such studies have been plagued by surface catalysis, recently there have been reported several studies which have minimized this drawback (2). The racemization of oxiranes offers a unique probe in examining the reaction in greater detail since it provides the most sensitive method of detecting the reversible electrocyclic process of carbonyl ylide formation (eq. 1) (3). We have previously examined, in



solution, the racemization and the *cis-trans* isomerization of 2,3-diaryloxiranes (3). The oxirane 1a racemizes, at 207°, 220 times more rapidly than it undergoes *trans* to *cis* isomerization. This observation was explained in terms of the carbonyl ylide intermediate for the racemization process. However it is not clear as to how the geometrical isomerization occurred. One possibility involves the intervention of a zwit-



terion species, e.g. 3, produced by a carbonoxygen heterolytic cleavage of 1a. Analogous intermediates have been implicated by Yankee and Cram (4) for the reactions of substituted cyclopropanes in solution.

In order to minimize the complication of zwitterion formation, we have chosen an oxirane system that is readily isomerized in the gas phase. Both *cis*- and *trans*-2,3-divinyloxirane (1b and 2b) have been synthesized and their conversions to vinyldihydrofuran (4) and 4,5-dihydrooxepin (5) have been observed (5, 6).



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# Results

### (a) Synthesis and Stereochemistry

Chiral 1b was prepared in two ways. When samples prepared by the partial asymmetric destruction of 1b using di-3-pinanylborane (7) were studied, a significant infinity rotation was observed. Subsequently we prepared and resolved, via the brucine salt of the phthalate half-ester, samples of threo-4-chloro-1,5-hexadien-3-ol. The infinity rotations observed in the racemization studies of the oxirane prepared in this latter manner were essentially equal to zero. The absolute configuration and optical purity of 1b has been correlated with 4 and with (+)-3hexanol (8) (Scheme 1). The rotational data for each of the compounds used are listed in Table 1.

# (b) Kinetics of the Conversion of 1b to 4 and 5

Vogel and Gunther (5) have referred, in a footnote, to an earlier study carried out in Cologne and report  $\Delta H^{\pm} = 36.0$  kcal mol<sup>-1</sup> and  $\Delta S^{\pm} = -0.4$  e.u. The product proportions (4 and 5) were said to be "practically independent of temperature", and thus it was concluded that 4 and 5 likely arise from a common intermediate. It was necessary for our purposes to define more exactly the kinetics and any temperature dependence of the product ratio. Table 2 gives the rate data and the product proportions observed from samples of 1b at 700 Torr. The samples were analyzed by gas chromatographic (g.c.) techniques using 1,2-dimethoxyethane as an internal standard and a Hewlett Packard

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Compound	Concentration (g/100 ml)	$\alpha_{obs}$ (temperature, °)	Optical purity (%)	Configuration	Maximum rotation
<b>1</b> <i>b</i>	4.41	-0.374 (22)	81.3	R	- 10.42
1 <i>b</i> *	4.41	-3.852(22)	81.3	R	-107.4
6	7.04	+0.956(20)	44.5	S	+30.5
7	Neat	-2.593 (20)	44.5	R	- 5.83 <sup>b</sup>
7	5.26	-0.175 (20)	44.5	R	-7.46
8	Neat	-0.057(22)	8.57	R	-0.665
9	9.95	-0.111(22)	8.57	R	-13.01
10	12.2	-0.099(22)	8.57	R	-9.46
11	2.00	+0.089(25)	12.9	S	+34.5
12*	2.12	+0.105(25)	5.69	S	+87.0
13	1.92	+0.106(25)	12.9	R	+43.0
4	2.38	+0.096(25)	12.9	S	+31.3
4*	2.38	+0.269 (25)	12.9	S	+ 87.6

TABLE 1. Optical purity and absolute configuration of compounds in Scheme 1<sup>a</sup>

<sup>a</sup>Rotations in 2-propanol; l = 1.00 dm;  $\lambda = 589 \text{ nm}$ , asterisk indicates  $\lambda = 365 \text{ nm}$ . <sup>b</sup>[ $\alpha$ ]<sub>D</sub> -7.13 using density of 0.819 g/ml<sup>-1</sup>, see ref. 8.

actions of 1 <i>b</i>				
Temperature $(\pm 0.04^{\circ})$	$\frac{10^{6}(k_{2}+k_{3})}{(s^{-1})}$	% 4	% 5	

TABLE 2. Rate constants and product composition for the re-

$\frac{\Gamma \text{emperature}}{(\pm 0.04^{\circ})}$	$\frac{10^{6}(k_{2}+k_{3})}{(s^{-1})}$	% 4	% 5
160.08 179.97 190.30 200.05 220.02	$5.48 \pm 0.09 \\ 34.2 \pm 0.3 \\ 88.0 \pm 0.8 \\ 194 \pm 2 \\$	$73.4 \pm 0.1^{a}$ $71.1 \pm 0.2$ $70.4 \pm 0.2$ $69.8 \pm 0.2$ $68.4 \pm 0.2$	$26.6 \pm 0.1 \\ 28.9 \pm 0.2 \\ 29.6 \pm 0.2 \\ 30.2 \pm 0.2 \\ 31.6 \pm 0.2$

"The error quoted is the standard deviation of five analyses.

TABLE 3. Activation parameters for the reactions at  $150^{\circ}$  of 1band (+)-(S)-1b as in Scheme 2

	log A	$E_{a}$ (kcal mol <sup>-1</sup> )	$\Delta H^{\pm}$ (kcal mol <sup>-1</sup> )	$\Delta S^{\ddagger}$ (cal deg <sup>-1</sup> mol <sup>-1</sup> )
<i>k</i> 1	11.34	$30.8\pm0.5$	$29.9 \pm 0.5$	-9±1
k₂	12.74	$36.0 \pm 0.4$	$35.1 \pm 0.4$	$-3 \pm 1$
k3	13.17	$37.7\pm0.4$	$36.8\pm0.4$	1±1

3370A electronic integrator. A typical rate study is given in the Experimental section. Partitioning the data into separate rate constants gives the activation parameters indicated in Table 3. The rate constants correspond to those indicated in Scheme 2.

### (c) Racemization of 1b

Samples of 1b were degassed in Pyrex breakseals and the amount was adjusted to give 1 atm at 150°. The samples were heated for the appropriate length of time in a well thermostated oil bath. After quenching the reaction in an ice-water

bath the break-seals were attached to the vacuum line, opened, and the contents transferred to a tared 1-ml volumetric flask. The contents of the flask were allowed to come to room temperature and the flask was removed from the vacuum line and weighed. In each case the vapor transfer was quantitative. 2-Propanol was then added to a volume of 1 ml and the weight of the solution measured accurately. The concentration of 1b in 2-propanol was calculated on a percentage weight basis to avoid volumetric errors. The rotations of the solutions, at 25°, were then measured at four wavelengths and the appropriate

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cell corrections were made. A typical run is given in the Experimental section. Using data obtained at 365 nm, rate constants could be duplicated to within  $\pm 1\%$ . The rate data for the racemization is listed in Table 4. The observed rate of loss of optical activity is given by  $k_{\alpha}$  and the value for  $k_1$  was obtained from the relationship  $2k_1 = k_{\alpha} - (k_2 + k_3)$ . The values of  $k_2$ and  $k_3$  were obtained by extrapolation from the rates at higher temperatures. The activation parameters for the rate  $k_1$  are listed in Table 3 along with those for the other processes measured.

## (d) Stereochemistry of the Formation of 4

The formation of 4 may occur via a sigmatropic  $\sigma^2 a + \pi^2 s$  process (9) in which case (-)-(R)-1b would produce (-)-(R)-4 by inversion of the migrating center. Upon inspection of molecular models it would seem that  $a\sigma^2 s + \pi^2 a$ process is not a probable pathway. It is possible that 4 is produced from 1b via a carbonyl ylide, in which case the 4 produced directly from chiral 1b would be racemic. Chuche and collaborators (10) have invoked carbonyl ylides to explain the stereochemistry of the dihydrofurans produced from vinyloxiranes. Control samples of 4 did not racemize at temperatures less than 250°. A sample of (-)-(R)-1b of 81.3% optical purity was heated to 200.01  $\pm$  0.02° for 10.5 h and the vinyldihydrofuran (4) was separated and purified by preparative gas chromatography. The 2vinyl-2,3-dihydrofuran produced was greater than 99.6% racemic. Taking into account the competitive racemization of 1b the 4 produced would have displayed a  $[\alpha]^{25}_{365} - 4.70^{\circ.1}$  The value observed,  $+0.285^{\circ}$ , is indicative of a small excess of retention over inversion. The size of the measured rotation,  $+0.068^{\circ}$ , at 365 nm, could be due to trace impurities even though care was taken to prevent such possibilities.

### Experimental

The i.r. spectra were obtained on a Perkin-Elmer 421 Spectrophotometer and the n.m.r. spectra were obtained using a Varian A-60. All rotations were measured in a thermostated cell on a Perkin-Elmer Model 141 Polarimeter. Preparative gas chromatography (g.c.) was carried out using a Nester Faust Model 850 Prepkromatic.

### Resolution of trans-2,3-Divinyloxirane (1b) by Di-3-pinanylborane

A mixture of racemic 1b (5.10 g, 20 mmol) and diglyme (5 ml) was placed in a 50-ml three-necked flask equipped with a condenser, magnetic stirrer, and a rubber septum. The mixture was cooled to  $-20^{\circ}$  and kept under an atmosphere of nitrogen. Di-3-pinanylborane (20 mmol) in diglyme was introduced, using a syringe, in a dropwise manner through the rubber septum. The reaction mixture was maintained at  $-20^{\circ}$  for 1 h and then allowed to warm to 0°. Water (5 ml) was added and the mixture distilled at 10 Torr. The distillate consisted of unreacted 1b, some  $(+)-\alpha$ -pinene, water, and diglyme. After drying over anhydrous sodium sulfate the unreacted 1b was isolated by preparative g.c. (10 ft, 15%  $\beta$ , $\beta'$ -oxydipropionitrile on firebrick,  $60^{\circ}$ ). The presence of about 1% of 5 was indicated as the only impurity by analytical g.c. The recovered 1b (2.0 g) was optically active  $[\alpha]^{24}_{365} - 8.74^{\circ}$ (5.33 g/100 ml, 2-propanol), calculated optical purity of 8.14%.

# Preparation of (+)-(S)-1,5-Hexadien-3-ol (6) from (-)-(R)-1b

The epoxide (-)-(R)-1b (300 mg, 3.1 mmol, optical purity 8.14%) in dry ether (2 ml) was added dropwise to a solution of lithium aluminum hydride (0.114 g, 3.1 mmol) in dry ether (6 ml). After the addition, the mixture was stirred at room temperature for 3 h. The excess hydride was then destroyed by the addition of moist ether at 0°. The aluminate complex was decomposed by the addition of 3 *M* sodium hydroxide and the solution extracted three times with ether. After drying over anhydrous sodium sulfate the ether layer was concentrated by fractional distillation and the product (+)-(S)-6 was isolated by preparative g.c. (15% carbowax on chromosorb B, 70°),  $[\alpha]^{25}_{365}$  +9.15° (2.12 g/100 ml, 2-propanol). The n.m.r. and i.r. spectra of the product were identical with an authentic sample (11).

### Diimide Reduction of (+)-(S)-6 to (-)-(R)-3-Hexanol (7)

A sample of (+)-(S)-6 (2.7 g, 27 mmol),  $[\alpha]^{25}_{365}$ +49.73° (10.2 g/100 ml, 2-propanol) obtained by resolution of the brucine salt of 1,5-hexadien-3-yl hydrogen phthalate, was placed in a 500-ml flask along with sodium azodicarboxylate (17.8 g, 137 mmol) in methanol (220 ml). The suspension was stirred and acetic acid (13.2 g, 220 mmol) in methanol (137 ml) was added dropwise. After stirring for an additional 30 min water was added

<sup>&</sup>lt;sup>1</sup>From optically pure 1b we would expect to find 4 of  $k_2/0.698k_{\alpha}$  enantiomeric purity. At 200° this ratio is 0.0659. The factor 0.698 comes from the percentage of 4 in the final mixture of 4 and 5.

Temperature $\pm 0.04^{\circ}$	$\frac{10^5 k_{\alpha}}{(s^{-1})}$	$10^{5}(k_{2}+k_{3})$ (s <sup>-1</sup> )	$\frac{10^5 k_1}{(s^{-1})}$
150.04	$5.79 \pm 0.10$ $5.77 \pm 0.17$	0.19	$2.90 \pm 0.05$ $2.79 \pm 0.09$
160.09	$14.2 \pm 0.2$	0.52	$6.84 \pm 0.10$
170.02	$30.1 \pm 0.3$	1.35	$14.4 \pm 0.2$

until the yellow color disappeared. The mixture was extracted several times with pentane and the combined extracts were dried over anhydrous sodium sulfate. The drying agent was then removed and the solution distilled through a Vigreux column. Yield, 2.1 g (80%); b.p. 129°/700 Torr;  $[\alpha]^{22}_{D} - 2.593^{\circ}$  (neat, l = 1 dm, density 0.819 g ml<sup>-1</sup>);  $[\alpha]^{22}_{D} - 3.314^{\circ}$  (5.26 g/100 ml, 2-propanol). Kenyon and Poplett (8) give  $[\alpha]^{22}_{D} - 7.13^{\circ}$  for optically pure (-)-(R)-3-hexanol. The n.m.r. and i.r. spectra were identical with those of an authentic sample of 3-hexanol.

### Resolution of 5-Hexen-3-ol (8)

The alcohol, **8**, was prepared by the procedure of Gaudemar (13) using activated zinc, allyl bromide, and propionaldehyde in tetrahydrofuran (THF). The alcohol was partially resolved through its phthalate half-ester following the procedure of Levine and Haller (12). See Table 1 for the rotational data.

# Preparation of (-)-(R)-1,4-Hexanediol (9) from (-)-(R)-8

A solution of diborane in THF (23 ml, 15 mmol) at 0° was added dropwise to (-)-(R)-8 (3.0 g, 25 mmol) in dry THF (75 ml). The mixture was stirred 30 min before the excess diborane was decomposed with moist THF at 0°. Sodium hydroxide (45 ml, 3 *M*) was added followed by hydrogen peroxide (15 ml, 30%) while the temperature was maintained at 30–50°. After 1 h solid potassium carbonate (40 g) was added and the THF layer separated. The aqueous layer was extracted twice with THF and the THF portions combined and dried over anhydrous magnesium sulfate. The drying agent was removed by filtration and fractional distillation gave the product 9 (3.2 g, 90%), b.p. 128–131°/16 Torr (lit. (14) 134–135°/19 Torr). Analysis by g.c. indicated the presence of 3% of 2,4-hexanediol as the only impurity. The rotational data is given in Table 1.

### Preparation of (-)-(R)-2-Ethyltetrahydrofuran (10) from (-)-(R)-9

The procedure used was essentially that of Coates and Melvin (15). p-Toluenesulfonyl chloride (5.2 g, 27 mmol) was added slowly to a solution of (-)-(S)-9 (3.6 g, 25 mmol) in dry pyridine (36 ml) maintained at 0°. The reaction mixture was allowed to warm to room temperature and stirring continued for 30 min. Cold water was then added and the reaction mixture was extracted six times with pentane. The pentane extracts were combined and washed with 2 N hydrochloric acid then dried over anhydrous magnesium sulfate. Careful fractionation through a spinning band column gave (-)-10 (0.97 g, 30%) of greater than 99% purity by g.c., b.p.  $106^\circ/700$  Torr (lit. (16)  $108^\circ/758$  Torr).

# Resolution of 2-Acetoxy-5-vinyltetrahydrofuran (11)

A solution of **11** (65.4 g, 420 mmol) (17) in dry THF (50 ml) was added over a period of 1 h to a suspension of di-3-pinanylborane (7) (160 mmol) in ether and diglyme at -15 to  $-20^{\circ}$ . The reaction mixture was stirred for 4 h at 0° and then water (6 ml) was added to destroy the excess borohydride. All of the volatile components were then distilled at 0.1 Torr and 50°. The crude distillate contained diglyme,  $\alpha$ -pinene, ether, and (+)-(S)-**11**. Fractional distillation gave 20.4 g (63%) of 11, b.p. 68–71°/4.5 Torr (17). See Table 1 for rotational data.

While the method of synthesis of 11 (17) does not preclude an isomeric pair, the reactant was primarily of one isomer, as judged by n.m.r., and after the resolution process consisted of a ratio of 20:1. No attempt was made to identify these isomers.

### Preparation of (+)-(S)-3-Vinyl-2,3-dihydrofuran (4) from (+)-(S)-11

A solution of (+)-(S)-11 (20 g, 138 mmol) in ether (160 ml) was passed slowly, in a stream of nitrogen, through a column of glass beads heated to 245°. The condensate from the Dry-Ice – acetone trap was then washed three times with a saturated sodium carbonate solution and dried over anhydrous sodium sulfate. After filtration the solution was concentrated to 10 ml and then subjected to preparative g.c. (column 6 ft,  $\beta$ ,  $\beta$ '-oxydipropionitrile, 60°). Yield 3.6 g (30%) of (+)-4. See Table 1 for rotational data. The n.m.r. and i.r. spectra were identical to those obtained from an authentic sample.

#### Diimide Reduction of (+)-(S)-4 to (+)-(R)-13

The technique used to reduce 4 to 13 was essentially that described above for the reduction of 6 to 7. Some reduction (approximately 10%) to 10 did occur, but the major product isolated by preparative g.c. (6 ft,  $\beta$ , $\beta'$ oxydipropionitrile, 60°) was (+)-(*R*)-13 (68%). The n.m., spectrum  $\delta_{\text{TMS}}$  (CDCl<sub>3</sub>): 0.96 (t, 3H, CH<sub>3</sub>); 1.59 (*q*, 2H, --CH<sub>2</sub>--); 7.5 (m, 2H, ring CH<sub>2</sub>); 4.5 (m, 1H, 3° ring H); 4.86 (*q*, 1H, J = 2.8 Hz, vinyl H); 6.26 (*q*, 1H, J = 2.5 Hz, vinyl H).

# Reduction of (+)-(R)-13 to (-)-(R)-2-Ethylfuran (10)

A solution of sodium borohydride (170 mg, 4.47 mmol) in methanol (4 ml) was added dropwise to a solution of rhodium trichloride trihydrate (342 mg) in methanol (90 ml). Charcoal (2 g) was then added to the solution under an atmosphere of nitrogen. The flask was then immersed in a Dry-Ice – acetone bath and (+)-(R)-13 (1.7 g, 17 mmol) was added. Hydrogen was then passed through the flask for 4 h at  $-78^{\circ}$ , 2 h at  $-30^{\circ}$ , and 2 h at 0°. The reaction mixture was filtered and 200 ml of water was added. The solution was extracted with pentane and the pentane layer, after drying over anhydrous sodium sulfate, was concentrated to 10 ml. Preparative g.c. (6 ft,  $\beta\beta$ '-oxydipropionitrile, 65°) gave 1.23 g (73%) of (-)-10. See Table 1 for rotational data. The n.m.r. and i.r. spectra were identical with those of an authentic sample (16).

# Reduction of (+)-(S)-11 to (+)-(S)-5-Hexene-1,4-diol (12)

A solution of lithium aluminum hydride (20 g, 520 mmol) dissolved in dry ether (250 ml) was placed in a 1-1 three-necked flask fitted with a dropping funnel, reflux condenser, and a gas inlet tube. Upon cooling to  $0^{\circ}$  a solution of (+)-11 (13 g, 87 mmol) was added dropwise over a period of 2 h. The reaction mixture was then allowed to stand overnight at room temperature and ethyl acetate was added to destroy the excess hydride. Water was then added carefully followed by Celite (40 g). The ether solution was filtered and the Celite residue was washed six times with ether. The combined ether portions were concentrated to 100 ml and dried over anhydrous sodium sulfate. The ether was then removed and distillation gave 9.04 g (94%) of (+)-12, b.p. 65-67°/0.01 Torr (lit. (18) 98-100°/1.8 Torr). See Table 1 for rotational data.

# Reduction of (+)-(S)-12 to (-)-(R)-1,4-Hexanediol (9)

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The procedure used was the same as that for the reduction of 6 to 7. From 63 mmol of 12 there was obtained 6.97 g (74%) of 9. The i.r. n.m.r., and g.c. retention time were identical with those of the sample obtained by the hydration of 7, except that there was no trace of 2,4-hexanediol as an impurity.

### Preparation of threo-4-Chloro-1,5-hexadiene-3-ol

A 2:1 mixture of 1b and 5 (38 g, 390 mmol) was added simultaneously with dry hydrogen chloride to anhydrous ether (400 ml) containing a small amount of thymol blue maintained at  $-50^{\circ}$ . The red color indicated the presence of excess hydrogen chloride. Upon completion of addition the reaction mixture was washed with cold aqueous sodium bicarbonate, then with a saturated sodium chloride solution. The ether layer was dried over anhydrous sodium sulfate, filtered, and concentrated. Distillation caused darkening and isomerization so the crude alcohol was used directly in preparing the half-ester.

### Preparation of threo-4-Chloro-1,5-hexadien-3-yl Hydrogen Phthalate

The crude *threo*-4-chloro-1,5-hexadien-3-ol (35 g, 260 mmol) was added to dry pyridine (48 ml) and phthalic anhydride (38.6 g, 280 mmol). The mixture was stirred overnight at room temperature and then warmed to 85° for 1 h before ice, ether, and concentrated hydrochloric acid (72.5 ml) were added. The ether layer was separated and the aqueous layer extracted several times with ether. The combined ether layers were dried over anhydrous sodium sulfate and after filtration the solvent was removed. The remaining syrup (63 g) was poured into a

solution of sodium carbonate (22 g) in water (24 ml). The solution was extracted with ether and the extracts discarded. Concentrated hydrochloric acid (60 ml) was added to the aqueous layer and the phthalate extracted with chloroform. After drying the chloroform was removed and there remained 50.2 g (67% based on crude chlorohydrin) of the phthalate ester which after being recrystallized from a benzene – Skelly B mixture gave m.p.  $72-72.5^{\circ}$ .

Anal. Calcd. for C<sub>14</sub>H<sub>13</sub>ClO<sub>4</sub>: C, 59.89; H, 4.63; Cl, 12.65. Found: C, 59.68; H, 4.84; Cl, 12.42.

### Resolution of threo-4-Chloro-1,5-hexadien-3-yl Hydrogen Phthalate and its Conversion to (-)-1b

*threo*-4-Chloro-1,5-hexadien-3-yl hydrogen phthalate (38.7 g, 140 mmol) was added to dry acetone (100 ml) and the solution heated to boiling. Brucine (37.8 g, 82 mmol) was added and the clear solution allowed to cool slowly to 0°. The solid was collected and repeatedly crystallized from acetone until the m.p. raised to 150–151°. The halfester was isolated by extraction with ether from an acidified solution of the salt. After removal of the ether there remained 7.5 g of the phthalate  $[\alpha]^{21}_{D} + 13.20$ , (2.84 g/100 ml, 2-propanol).

The resolved half-ester (7.5 g, 26 mmol) was dissolved in aqueous sodium carbonate and the solution added dropwise to a hot solution of sodium hydroxide (10-fold excess) such that water and the divinyloxirane distilled out. The oxirane layer was separated and dried over 4A molecular sieves. Yield 2 g, 78%. G.c. analysis indicated a purity of greater than 98%. The impurities were identified by mass spectrograph – g.c. to be acetone, ether, and allylmethyl ketone.  $[\alpha]^{21}_{589}$  – 8.48;  $[\alpha]^{21}_{365}$  – 87.35, (4.41 g/100 ml, 2-propanol).

### Racemization Kinetics

In a typical run a sample of (-)-(R)-1b (about 1 mmol) was weighed and degassed on a vacuum line. It was then vapor transferred to a 30 ml break-seal. The tube was sealed off and removed from the vacuum line to a constant temperature bath. At the appropriate time the tube was removed and quenched in an ice-water bath. It was then attached to the vacuum line and after a pressure of 10 microns was achieved the break-seal was opened and the contents vapor transferred to weighed 1-ml volumetric flask cooled in liquid nitrogen. The contents of the volumetric flask were then allowed to come to room temperature and after careful removal of any grease from the joint the flask was weighed. Isopropyl alcohol was added up to a volume of 1 ml and the weight of the solution obtained. Concentrations of 1b in the solution were calculated in percentage weight to avoid any volumetric error. A tube corresponding to zero time and an infinity tube were put through the same manipulations for each run.

The solution was then transferred to a thermostated polarimeter tube (1-ml volume, 1.001 dm long) and the rotation was measured. Precision of the measurement was  $\pm 0.002^{\circ}$ . All samples were analyzed by g.c. after the rotation was measured. A sample run at 160.09° consists of the following data: 10<sup>5</sup> s,  $[\alpha_t]/[\alpha_0]$ ; 0.180, 0.846; 0.540, 0.479; 0.900, 0.302; 1.14, 0.213; 1.50, 0.126; 1.80, 0.0843; infinity tube 3 days, 0.000. These results give  $k_{\alpha} = (14.2 \pm 0.2) \times 10^{-5} \text{ s}^{-1}$ .

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#### Kinetics of the Rearrangement of 1b to 4 and 5

A sample of 1b (25-30 mg) was placed in a 10 ml ampoule, degassed by three freeze-thaw cycles, sealed, and placed in a constant temperature oil bath. The tubes were removed from the bath at the appropriate time and the reaction was quenched. After opening, each tube was analyzed, in pentuplicate, on a Perkin-Elmer Model 900 Gas Chromatograph equipped with a Hewlett Packard 3370A Integrator. Some runs were conducted using 1,2-dimethoxyethane as a reference and some without a reference. A 150 ft,  $\beta_1\beta'$ -oxydipropionitrile wall-coated column was used at 60° with a flame detector. A sample run at 190.30  $\pm$  0.05° for the rate of disappearance of 1b is: 10<sup>3</sup> s [1b]!/[1b]°; 1.80, 0.863; 6.60, 0.582; 9.00, 0.464; 12.0, 0.369; 14.4, 0.289; 16.8, 0.236; 19.2, 0.185; these results give  $k_2 + k_3 = (8.80 \pm 0.12) \times 10^{-5} \text{ s}^{-1}$ .

#### **Product Studies**

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(a) Sealed ampoules of 1b were heated for approximately two half-lives at temperatures from 160 to 220°. Each sample was then analyzed and the final kinetic results, along with the probable error as calculated from the standard deviation, are shown in Table 3.

(b) A sample of *trans*-2,3-divinyloxirane (1.5 g, 16 mmol)  $[\alpha]^{25}_{365} - 87.35$ , 81.3% optical purity was degassed and sealed into tubes such as to render a pressure of 1 atm at 200°. The tubes were then placed in a thermostated oil bath at 200.0  $\pm$  0.1° for 10.5 h (10 half-lives for  $k_2 + k_3$ ). The vinyldihydrofuran produced was separated from the 4,5-dihydrooxepine by preparative g.c. and its rotation measured  $[\alpha]^{22}_{365} + 0.058^{\circ}$  (neat, 1 cm),  $[\alpha]^{22}_{365} + 0.285^{\circ}$  (23.8 g/100 ml, 2-propanol). Thus, the product 4 was found to be greater than 99.6% racemic.

### Discussion

# (a) The Mechanism of the Racemization Process

The most facile reaction of the oxirane, 1b, is the racemization process. Since this is formally a simultaneous inversion of two chiral centers the reversible conrotatory opening of the oxirane to produce a carbonyl ylide best fits the requirements (see eq. 1) (3, 19). It is of interest to note that a negative entropy of activation ( $\Delta S^{+} - 9$ e.u.) occurs during this bond cleavage reaction. This is consistent with the loss of the rotational degrees of freedom associated with the two vinyl groups.

# (b) The Mechanism of Vinyldihydrofuran Foundation

The oxirane 1b may open to carbonyl ylides of 10 different configurations (see Fig. 1); of these a-f are produced by a conrotatory ring opening. The vinyldihydrofuran, 4, is produced by the formation of the carbon-carbon bond between positions 2 and 3. Since the major part of the vinyldihydrofuran produced is racemic, even for that which has not racemized at the



FIG. 1. Configurations of carbonyl ylide 13.

epoxide stage, then a planar intermediate such as the carbonyl ylide is a reasonable candidate as an intermediate. The opening of a ring such as 4 is disrotatory and could produce carbonyl ylide 13e, f, h, or k. While e and f are common



to both sets, *i.e.* those arising from 1b and 4, they are also sterically very crowded. The stereochemical studies of Chuche and coworkers (10) indicate that an isomerization about the carbon-oxygen bond of the carbonyl ylide must occur, the *cis*-oxirane being ruled out since it gives rise to the dihydrooxepine exclusively (6). Isomerization at the carbonyl ylide stage is similarly capable of explaining the *trans-cis* isomerization of oxirane (resulting in the formation of 5). Thus a scheme such as



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is capable of fitting all of the stereochemical and kinetic data. Schemes using carbonyl ylide 13cand its isomerization to 13h are equally valid. For the conversion of (+)-1b to 4 the data require that we have at least one planar intermediate and it is most readily reconciled with an isomerization from one of the members of the set 13a-13b to the set 13g-13k.

### (c) The Zwitterion Intermediate 3

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This study was initially undertaken to minimize the role of the zwitterion intermediate 3. In the 2,3-divinyloxirane system if any of the cis isomer is produced then it will be immediately converted to 4,5-dihydrooxepine (5) (6), and thus the rate of trans to cis isomerization in this system cannot exceed the value of  $k_3$ . The ratio  $k_1/k_3$  at 200° for 1b is 22.6 while for 1a the same rate ratio at 200° is 212 (3). If the geometrical isomerization, as manifested by dihydrooxepine formation, is a feasible gas phase process proceeding via the cleavage of the carboncarbon bond then it is not unlikely that the trans-cis isomerization occurs via a carbonyl ylide isomerization. While the carbonyl ylide as written looks like a very polar structure it would appear that solvation is not critical to the formation of such a species. We are now attempting to elucidate whether there are any significant solvent effects upon carbonyl-ylide ring openings.

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1. (a) H. M. FREY. Adv. in physical organic chemistry. Vol. 4. Academic Press, New York. 1966. p. 147; (b) R. G. BERGMAN and W. L. CARTER. J. Am. Chem. Soc. 91, 7411 (1969); (c) M. ARAI and R. J. CRAWFORD. Can. J. Chem. 50, 2158 (1972).

- M. C. FLOWERS and R. M. PARKER. J. Chem. Soc. (B), 1980 (1971).
- 3. H. H. J. MACDONALD and R. J. CRAWFORD. Can. J. Chem. 50, 428 (1972).
- 4. E. W. YANKEE and D. J. CRAM. J. Am. Chem. Soc. 92, 6328, 6329, 6331 (1970).
- 5. E. VOGEL and H. GUNTHER. Ang. Chem. Int. Ed. 6, 395 (1967).
- 6. E. L. STOGRYN, M. H. GIANNI, and A. J. PAS-SANNANTE. J. Org. Chem. 29, 1275 (1964).
- 7. H. C. BROWN and G. ZWEIFEL. J. Am. Chem. Soc. 83, 486 (1961).
- H. C. BROWN, N. R. AYYANGAR, and G. ZWEIFEL. J. Am. Chem. Soc. 86, 397 (1964);
   J. KENYON and R. POPLETT. J. Chem. Soc. 273 (1945).
- 9. R. B. WOODWARD and R. HOFFMANN. The conservation of orbital symmetry. Academic Press, New York. 1969.
- 10. (a) J. C. POMMELET, N. MANISSE, and J. CHUCHE. Tetrahedron, 28, 3929; (b) J. C. PALADINI and J. CHUCHE. Tetrahedron Lett. 4383 (1971).
- 11. L. W. BUTZ, E. W. J. BUTZ, and A. M. GADDIS. J. Org. Chem. 5, 171 (1940).
- 12. P. L. LEVINE and H. L. HALLER. J. Biol. Chem. 83, 185 (1929).
- 13. M. GAUDEMAR. Bull. Soc. Chim. 175, 974 (1962).
- 14. C. GLACET. C. R. 218, 283 (1944).
- R. M. COATES and L. S. MELVIN, JR. J. Org. Chem. 35, 865 (1970).
- 16. R. PAUL. Bull. Soc. Chim. 5, 1053 (1938).
- 17. C. GLACET. Ann. Chim. [12] 2, 293 (1947).
- S. F. BIRCH, R. A. DEAN, and N. J. HUNTER. J. Org. Chem. 23, 1390 (1952).
- H. HAMBERGER and R. HUISGEN. Chem. Commun. 1190 (1971); A. DAHMEN, H. HAM-BERGER, R. HUISGEN, and V. MARKOWSKI. Chem. Commun. 1192 (1971).